Graduation Studio Report

Metropolitan Ecology of Places Series

A future-proof water system for Campbelltown and the Greater Sydney area

Evaluating the potentials and implications of decentral wastewater treatment in suburban developments

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A future-proof water system for Campbelltown and the Greater Sydney area
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Urbanism

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Acknowledgement to aboriginal and torres strait islanders as Australia's first people, the Traditional Owners and Custodians of the lands and waters.

Abstract

This project explores the potential of a specific type of natural-based decentralised wastewater treatment solution in a fast-growing area: Campbelltown local government area (LGA), Sydney, with a focus on experimental design based on different densification scenarios and centralisation level of treatment scheme. The analysis and design are carried on for three scales: Greater Sydney area, Campbelltown LGA, and two samples sites in the city centre of Campbelltown LGA. for Greater Sydney area, the design is revealed as a long-term and all-rounded proposal; for the main city centre of Campbelltown LGA, the design focuses on the redevelopment and functional division of its main water bone Bowbowing Creek to serve as a treatment media. In order to experiment the schemes in detail, Leumeah centre and Campbelltown centre are designed with 6 scenarios (2 densification scenarios x 3 levels of treatment centrlisation) for each site.

The results are evaluated with the same criteria, which reveals the feasibility, pros and cons of each scenario while confirming the possibility of implementing decentralised wastewater treatment in this area although it does not bring out the same performance for all the scenarios. Further research can be carried out to simulate the long-term performance of the schemes and to test the performance with different technical components of DEWATS for the locations.

Keywords: *decentralised wastewater treatment, water re-use, constructed wetlands, climate adaptation, densification, Sydney*

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Abbreviation

ABR	anaerobic baffle reactor
BOD	biological oxygen demand
COD	chemical oxygen demand
CW	constructed wetland
DEWATS	decentralised waste water treatment system
FC	fecal coliforms
HF	horizontal flow
LGA	local government area (Australian administrative classification)
MPN	most probable number
SA1	statistical area 1 (Australian administrative classification)
TC	total coliforms
TSS	total suspended solids
VF	vertical flow

1. Introduction

1.1 Motivation

In the eyes of great majority, Sydney is a warm and comfortable place, which is surrounded by sea with endless water. Before I decided to study there for undergraduate, I also had the same imagination as above, but during my living there, I noticed that the rainfall was quite rare, especially in the summer, there can be bushfire of different scales every year in the western Sydney district. I was impressed of the big difference in the environment between western and eastern Sydney, people enjoy the seemingly calm in the eastern part and cannot imagine that the other side of the city is facing with the risk of drought and extreme heat, which might finally come to the eastern side as well.

Exposed to potential stormwater shortage, the local experts and government are dedicated to seek out solutions that can reduce the existing dependence on stormwater water supply. Having witnessed the threatens a lot, I desire to contribute to that with a focus on water recycling and re-use, and involving that into urban design.

Parts of Australia suffer drought and low rainfall as La Niña and climate change create weather extremes

While the east coast has flooded, other areas see below average rainfall as climate crisis means 'the wet getting wetter and the dry getting drier'

- **Sign up for the Rural Network email newsletter**
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Fig 1.1 News about water shortage in Sydney (May, 2022)

Sydney's dams may be almost full – but don't relax, because drought will come again

Published: January 6, 2022 4.17am CET

Brendan Esposito/AAP

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Dams serving capital cities such as Canberra, Hobart and Sydney are near full after two years of widespread rainfall. But these wet conditions won't last.

Under climate change, droughts in Australia will become more frequent and severe. Our drinking water supplies, and water crucial for irrigation and the environment, will dwindle again.

Sydney, Australia's most populous city, is among those that must prepare for the next drought. The NSW government is developing the Greater Sydney Water Strategy, to guide water management in coming decades.

Among the plan's more contentious proposals are increased use of Sydney's existing desalination plant and expanding the use of recycled water (highly treated sewage), including for drinking water. So let's examine whether such measures are enough to secure Sydney's water future.

Fig 1.2 News about water shortage in Sydney (Wright, 2022)

2. Problem statement

2.1 Limit amount of freshwater in general

Different forms of water on earth

Water is one of the most common renewable resource on earth, people are so familiar with it that the way it comes to life is always ignored.

According to U.S. Geological Survey's (USGS) Water Science School (2019), water covers around 71% of the Earth's surface, 96.5% of which is held by the oceans. Additionally, water exists not only in liquid, but also in gas and solid forms (Fig 2.1). Water's special molecular structure makes it flexible and long-lasting on earth and becomes important for all lifes.

The scarcity of freshwater

Although the total amount of water resource is large, the amount of fresh water that can be directly used by life forms is small: 97% of it is seawater that contains too much salt; 2% of the water is ice formed on the Arctic and Antarctic, glaciers and snow-capped mountains (Fig 2.2). Therefore, the accessibility of freshwater is always an important focus for most area in the world.

While developing and tropical countries are more badly affected by water scarcity, it is a common problem worldwide, even in countries where water resources are adequate (Fig 2.3). This may be due to a number of factors: mismanagement of distribution systems and infrastructures, contamination, climate change......It is clear that fresh water is more hard-earned than how we imagine, it can become nonrenewable resources for everyone in the future unless its production, reproduction and distribution are well- managed and realised.

The hydrological cycle (Fig 2.4)

Evaporation & Transpiration
The hydrological cycle is driven by the sun by shining and heating the water from ocean and other forms of hydrological carriers. Thus, certain amount of water becomes vapour by evaporation. There is also small amount of water come to the air from the plants in transpiration.

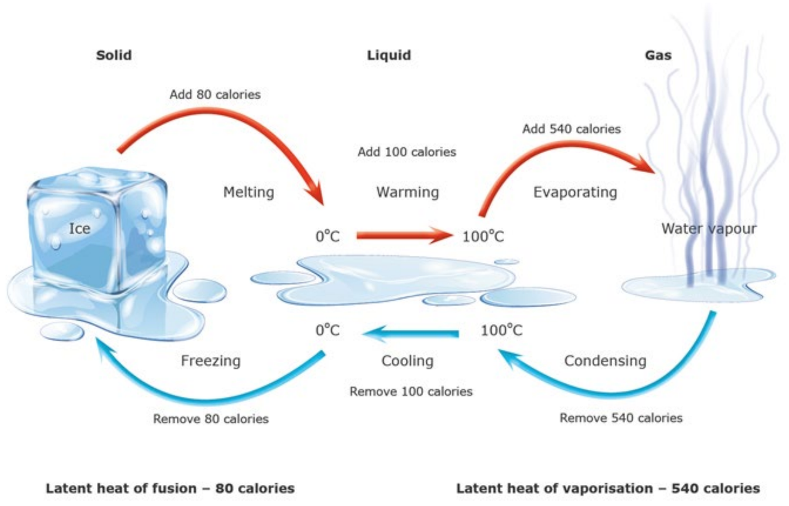


Fig 2.1 States of water (Science Learning Hub, 2014)

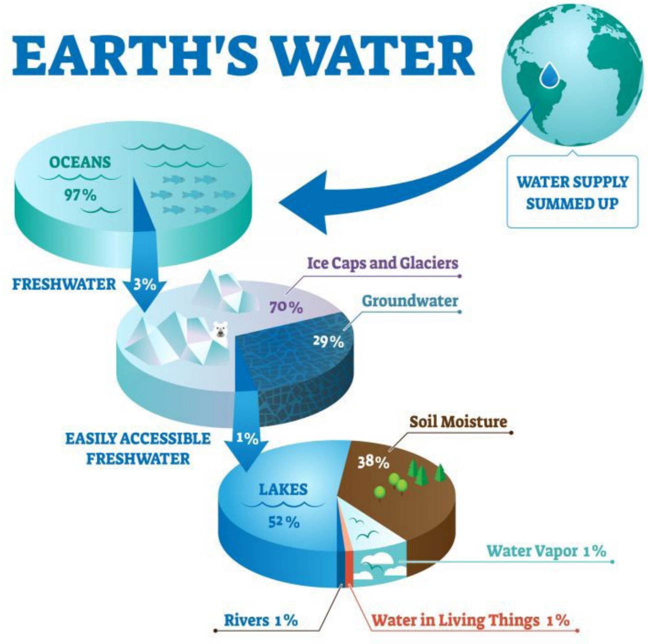


Fig 2.2 Water's existence on earth (Australian environmental education, n.d.)

Condensation
The vapour is then condensed to water droplets upon meeting the cold air, the accumulation of droplets forms the cloud.

Precipitation
After the cloud is full of droplets, the rainfall begins when the temperature is met. The precipation can also happen in other forms such as snow and mist, depending on different temperature.

Surface & Ground water
When the rain coms to the surface of the ground, large amount of water flows to lower terrain that forms streams or rivers defined as surface water. The rivers with the best capacity become catchments that serve human activity. Meanwhile, certain amount of rain water permeate into the ground. Ground water can be easily absorbed by the roots of some plants, but people have to dig deep wells to achieve those water. Both surface and ground water find a way back to the ocean or evaporate in land to form a new round of hydrological cycle. The repetitive cycle is an invisible and endless force that sustain all lives on earth.

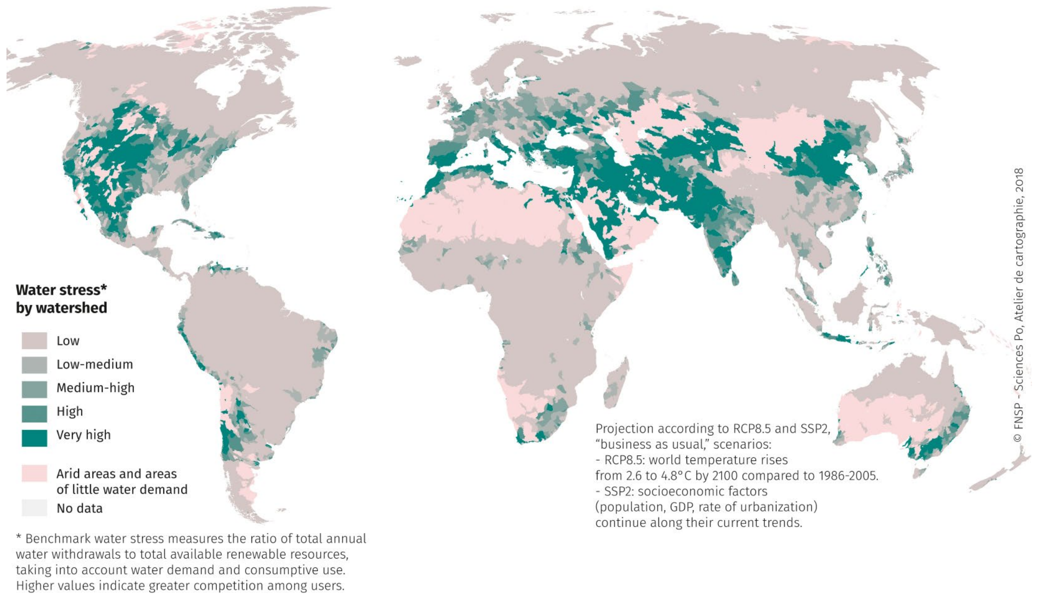


Fig 2.3 World projected water stress in 2040 (Science Po, Atelier de cartographie, 2018)

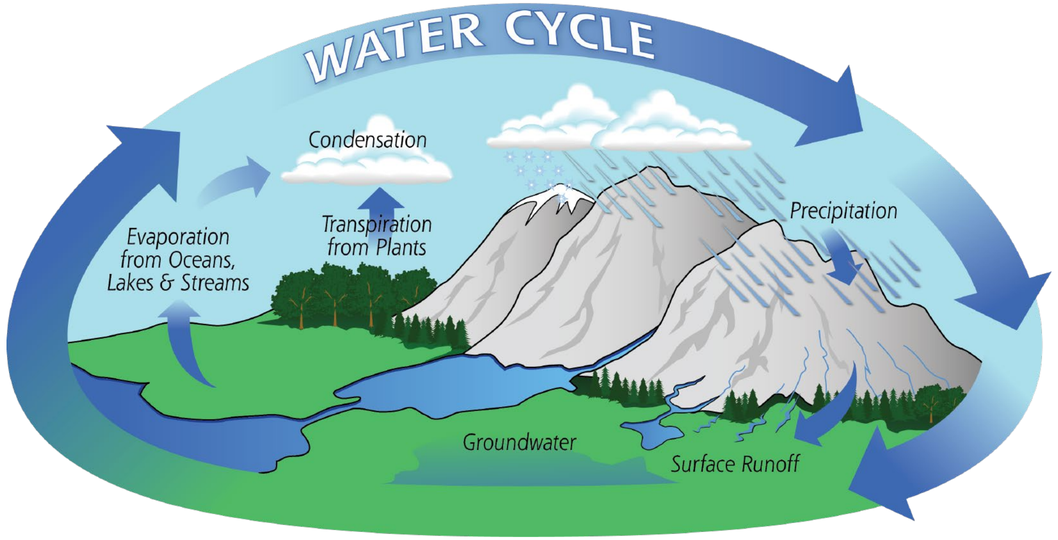


Fig 2.4 Hydrological cycle (NASA, n.d.)

2.2 The cause of Australian drought

<u>Extreme whether events</u> <u>(Bureau of Meteorology, 2010)</u>

Under normal circumstances (Fig 2.5), trade winds travel across the tropical Pacific Ocean from the east to west, warm moist air and surface water are brought to the western Pacific, which maaintains a cool condition for the central Pacific Ocean. The thermocline in the west is deeper than the east.

The warm temperature of the sea surface in the western Pacific delivers heat and moisture to the atmosphere. During atmospheric convection, towering cumulonimbus clouds are formed by the warm and moisture air rising to the atmosphere, then the rain is generated. The drier air travels towards the east and comes to the eastern tropical Pacific with cooler temperature. The whole pattern showing the loop is defined as the Walker Circulation.

During El Niño (Fig 2.6), the trade winds are weak and may even reverse, bringing warmer water to the central and eastern parts of tropical Pacific Ocean.The temperature of the sea surface that is warmer than normal is caused by the deepening of the thermocline in the central to eastern Pacific and the weakened descecnd of cool ocean water from below.

Therefore, for the sea surface around northern Australia, the temperature is cooler than normal and the convection centre leaves Australia towards the central tropical Pacific Ocean, which leads to reduced rainfall in Australia, especially for the eastern part including New South Wales.

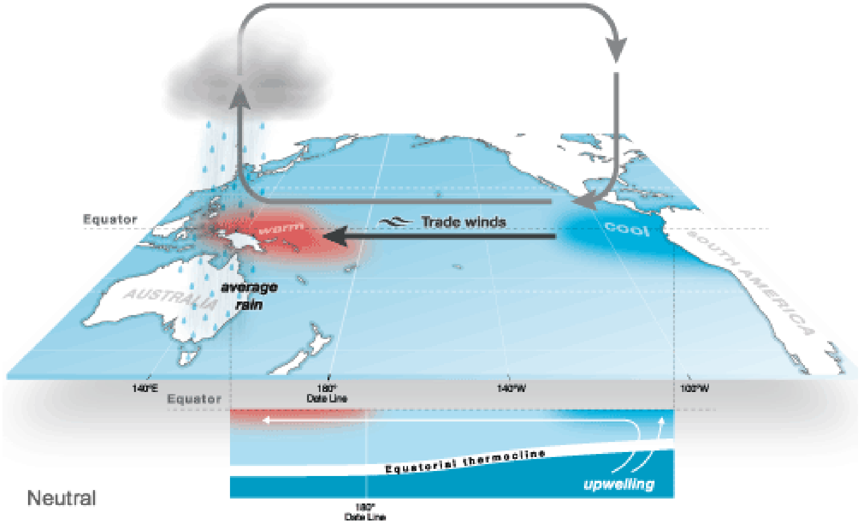


Fig 2.5 Neutral state of Walker circulation (Bureau of Meteorology, 2010)

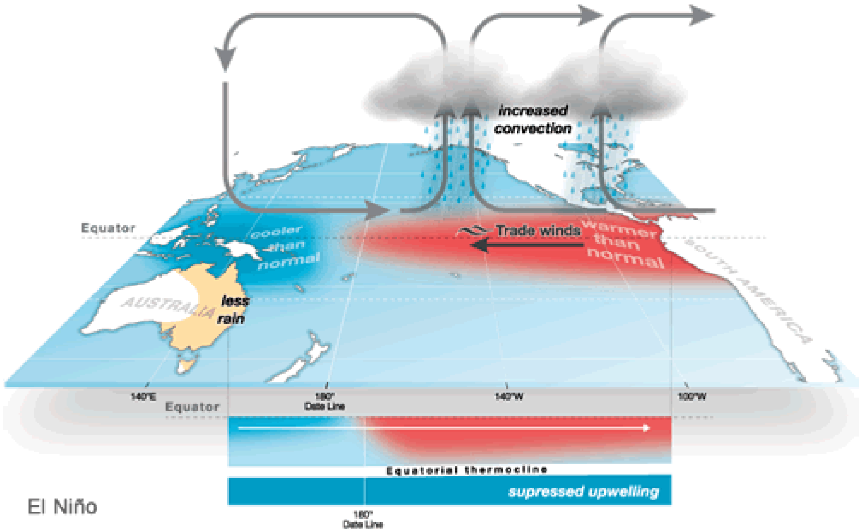


Fig 2.6 El Niño phenomenon (Bureau of Meteorology, 2010)

High evaporation rate

According to the statistics from Bureau of Meteorology (2006), the average annual evaporation collected from 1975 to 2005 in Western Sydney is between 1400 and 1600 milimetres per year (Fig 2.7), which exceeds the global average (Fig 2.8) by 30%-45%. It indicates that **the surface water in Sydney tends to evaporate faster** than the global average.

The evaporation is affected by wind speed, temperature and humidity. Strong wind and higher temperatures are facilitators of liquids' fast evaporation. The wind increases the total amount of air flowing over the water surface, and holding moisture. As temperatures rise, more moisture evaporate into the air. Conversely, high humidity decreases evaporation by limiting the amount of additional moisture that can be carried away. This means that higher humidity levels reduce the rate of liquid-to-gas transformation. As Sydney is a coastal city, it experiences strong prevalent winds by the coast and in-land. Meanwhile, in the western district, the temperature is significantly higher throughout the year and less moistured than the eastern area, the surface water is evaporated fast compared to other area.

Risks that catchment areas are facing

The impact of climate change also leads to a rise in extreme precipitation events which increases the **flooding risk** and also have impact on the performance of the surface water catchment area (NSW Department of Planning and Environment, 2022). Addtionally, the **storms and bushfires causing increased hazards in inflows** to dams that are negative to maintain water quality and create difficulties in water treatment, thus the qualified water cannot be supplied in time, particularly during periods of high demand and facing with increased population.

Controversy in groundwater storage

Currently, groundwater sources account for around 27% of the metered water usage in NSW, with approximately 17% of the total estimated groundwater drawn from metered systems being consumed by domestic use (potable and non-potable) and irrigation (NSW State of Environment, n.d.). The groundwater also supports ecosystems including "highly specialised and endemic subterranean systems, surface water systems (wetlands, rivers and lakes) connected to groundwater, and some land-based ecosystems (NSW State of

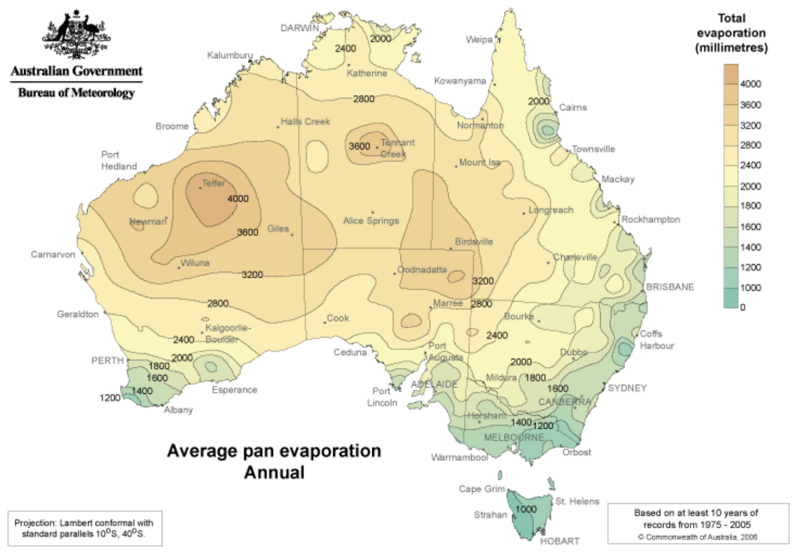


Fig 2.7 Average pan evaporation in Australia (Bureau of Meteorology, 2006)

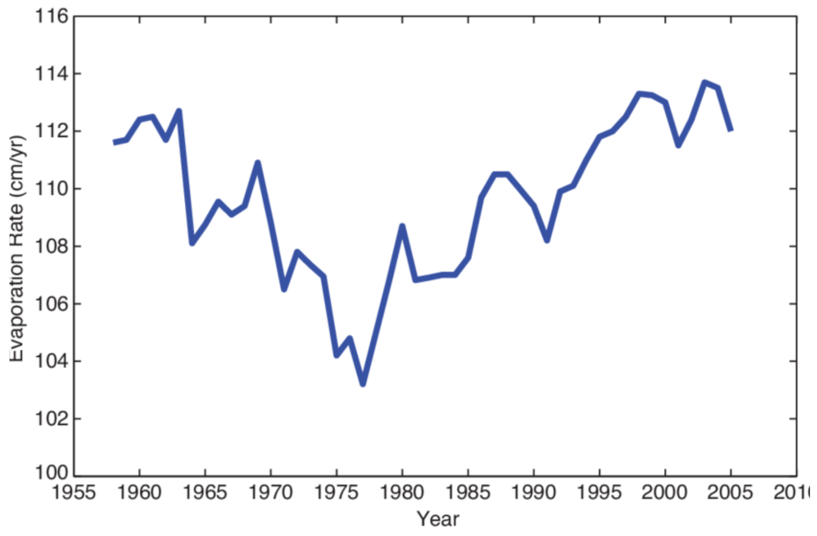


Fig 2.8 Global average annual evaporation rate (Schmitt, 2008)

Environment, n.d.)”

However, the groundwater situation is under pressure and the extraction is disputable. The long-term integrity of the groundwater source can be downgraded by continuous extraction that exceeds its recharge rate (NSW State of Environment, n.d.). This can lead to permanent impacts on all ecosystems that depend on it. Competition for groundwater resources can also pose a threat to the long-term security of these resources. Besides, the groundwater quality is detrimentally affected by saline intrusion that is caused by high groundwater extraction and coastal water (for the aquifers that are close to the coast) , groundwater contamination by industrial activities is also a common problem spotted and reported in various site of Sydney (NSW State of Environment, n.d.).

Considering groundwater’s importance to ecosystem, its role as backup water resource when surface water is insufficient, and its importance in aboriginal connection, the NSW government is drafting all-rounded plans and strategies with extensive range of techniques and solutions for the next 20 to 40 years that integrates the updated climate data (NSW State of Environment, n.d.). Although some progress has been made, there is still limited knowledge regarding groundwater-dependent ecosystems. Therefore, it is crucial to gain a better comprehension of their location and characteristics, developing it as a more secured back-up resource and storage room.

2.3 Sydney's need for sustainable water supply

At present, more than 75% of the water supply for Greater Sydney comes from storm-water, but the **precipitations are more and more unpredictable** in recent years and in the future (Fig 2.9). Meanwhile, **the demand for potable and non-potable water is still increasing** because of population growth and planning for extra greenery (Fig 2.10). Therefore, the current stormwater-dependent system is insecure to supply the future pop-ulation and household consumption, other solutions should be prepared as supple-ments whenever needed.

At the First Peoples of Australia Dialogue Forum in 2019, the agreement was achieved that "Sustainability, carbon neutrality, water positive and global warming action" was a priority aspiration for Sydney's future (CITY OF SYDNEY, 2021). In this objective, water plays a central role because it is the most basic supply of daily life and production, secured, and sufficient water can also help to achieve the other objectives. Thus, it is important to regard the solution to potential water shortage as a priority in urban devel-op-ment. According to Greater Sydney Water Strategy (2022), **the Western Sydney area is at more risk than others in the shortage of stormwater, especially the Illawarra and Macarthur region**. As the Macarthur region is also a fast-growing and expected densi-fied area and is exposed to overheating issues, it is more urgent to be focused on.

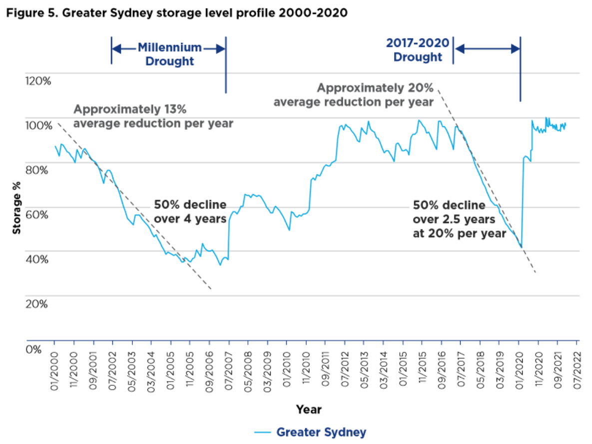


Fig 2.9 Greater Sydney dam storage level overview (NSW Department of Planning and Environment, 2022)

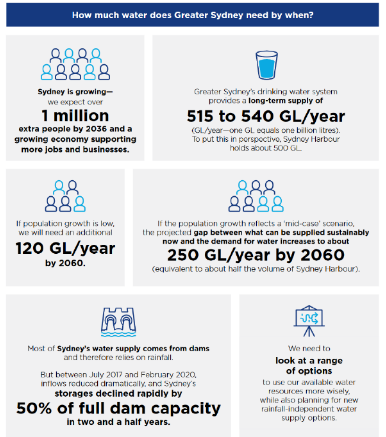


Fig 2.10 Information related to high water demand (NSW Department of Planning and Environment, 2022)

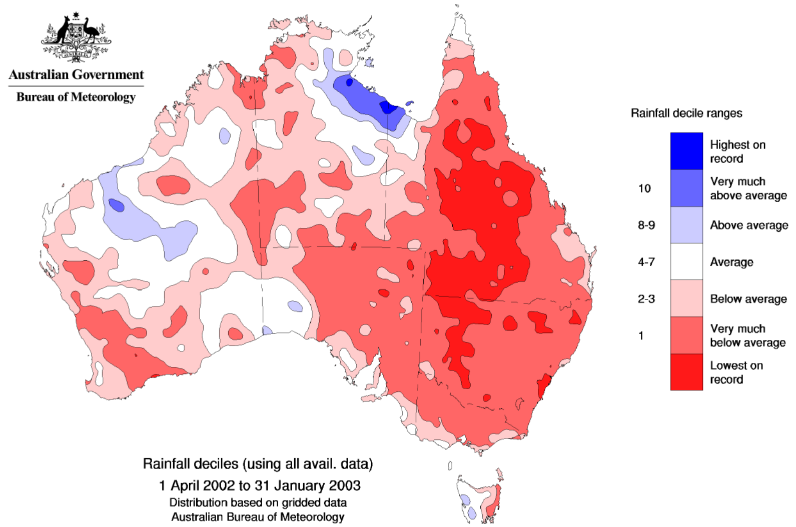


Fig 2.11 Rainfall decile in the drought period 2002 - 2003
(Australian Government Bureau of Meteorology, 2021)

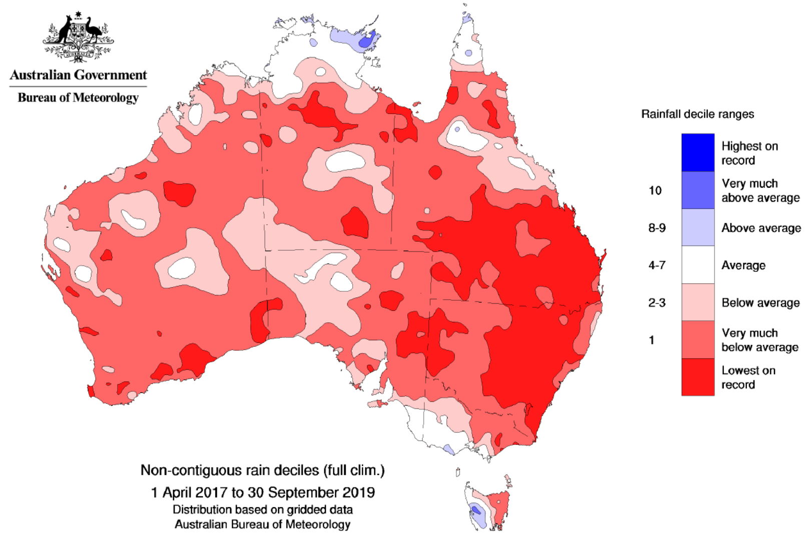


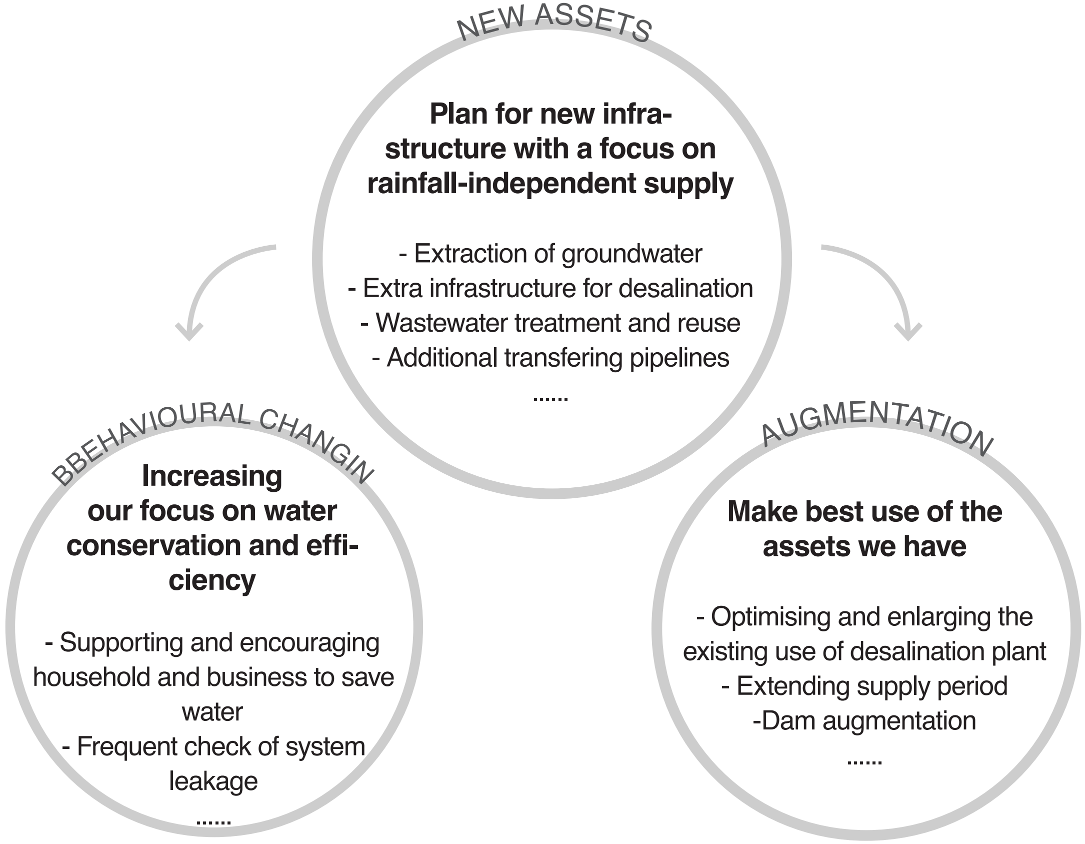
Fig 2.12 Rainfall decile in the drought period 2017 - 2019
(Australian Government Bureau of Meteorology, 2021)

From year 2000 to 2020, Sydney has experienced 2 times of drought (Fig 2.11, Fig 2.12), the most recent one happened from 2017 to 2020, accompanied with intolerable heat flow in summer (from December to February) and severe wildfire. It is clear that insufficient precipitation not only limits water use, but also generates negative side-effects to social and natural order.

Having suffered from droughts, Sydney finally welcomed heavy rainfall in 2021 and 2022, which were the wettest years in history since the record began in 1858 (CNN, 2022). Especially in 2022, when “La Niña” (a weather system causing wet, windy summers, extra information in page 20-21: “The cause of Australian drought”) visited Sydney, Sydney Observatory Hill received 2100 mm of rainfall during the first 9 months, reaching upon around 175% of the average. Most dams got full capacity during that time (CNN, 2022). However, this does not mean that Sydney has got rid of the threats from drought. The abnormally abundant precipitation is a sign that the climate is more and more unpredictable and fast-changing. The less preparation we have, the more frantic we shall get when the changes come out of a sudden, and more loss will happen. **Water scarcity is still the long-term trend based on all the knowledge at hand, but the occurrence of different situations should also be considered**. What shall be expected is a set of flexible, all-rounded and farsighted plans that reduce the dependence on stormwater by exploring other available sources and promoting water re-use.

2.4 Methods to fight against drought in Sydney

According to the Department of Planning and Environment (2022), the existing framework of solutions that responds to societal development while being resilient to unpredictable drought in the future is discussed in four aspects mainly. the solutions range from behaviour adjustments to the investment and management in new assets, which can be summarised in three pillars: *“Increasing our focus on water conservation and efficiency”, “Make best use of the assets we have by optimising use of the Sydney Desalination Plant”, and“Plan for new infrastructure with a focus on rainfall-independent supply”.* It is obvious that there is a strong tendency to **apply reducing the dependence on rainwater as the predominant focus**.



2.5 Motivation in promoting decentralised wastewater treatment (DEWATS)

Public opinions in water recycle

Based on the set of researches conducted by Dolnicar and Schäfer (2009) that compare people's perception of recycled water and desalinated water, the public interests and concerns in recycled water use can be categorised in three aspects: environmental effects and healthy levels.

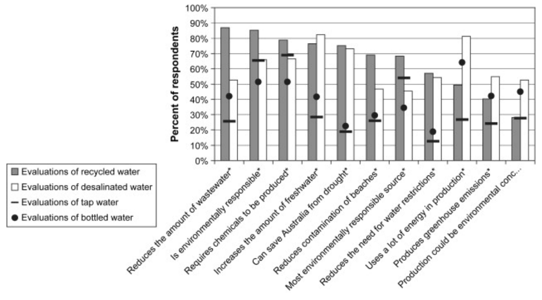


Fig 2.13 Comparative perceptions/knowledge about environmental issues (Dolnicar & Schäfer, 2009).

Recycled water resource are rated as as more environmentally friendly and energy saving by the respondants. Based on their comparison with tap water and bottled water (Fig 2.13), people also perceive that both recycled and desalinat-ed water more environmentally friendly than tap and bottled water. The reason for that could be the awareness of drought and believing that alternative water sources take the pressure off natural resources (Dolnicar & Schäfer, 2009).

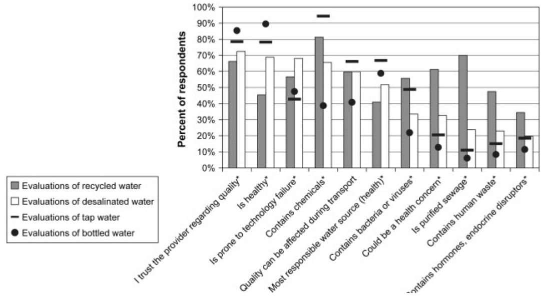


Fig 2.14 Comparative perceptions/knowledge about health issues (Dolnicar & Schäfer, 2009).

The lack of knowledge can be seen in public perception about health concerns with the sources of water (fig 2.14), 24% of the answers hold the believe that desalinated water is purified sewage, and more than 60% people had concerns about drinking recycled water resulting in healthy problem. However, the worriness also indicates that **more efforts should be put in experimenting, securing and proving the quality of recycled water to the public**.

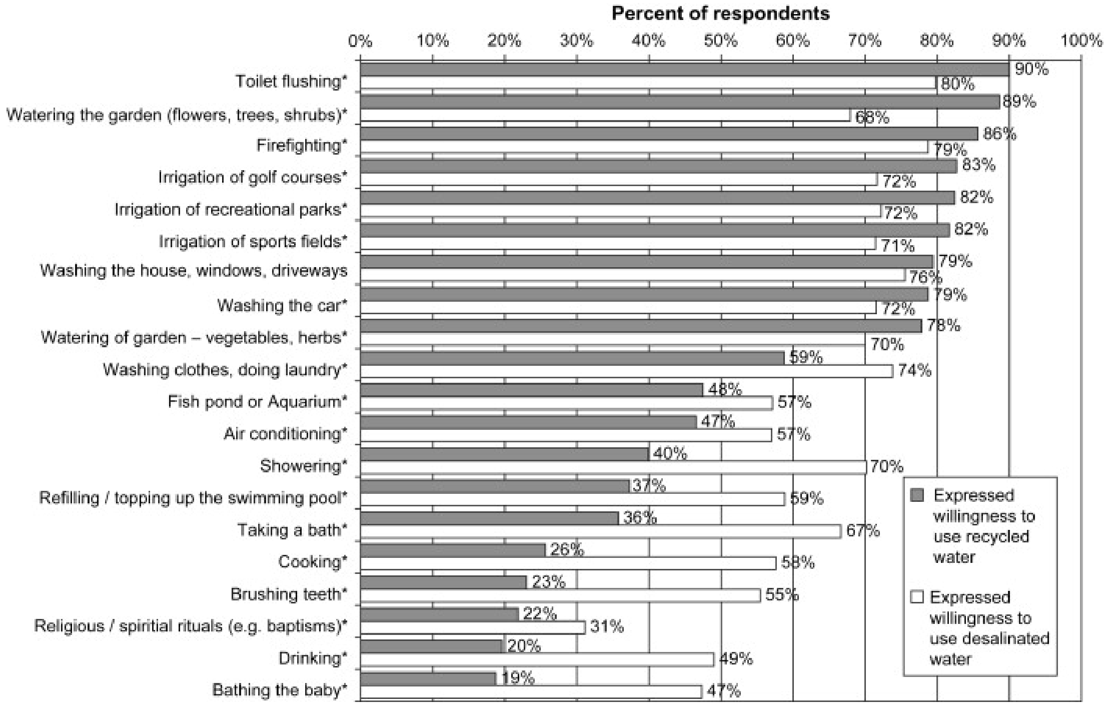


Fig 2.15 Comparative likelihood of using recycled and desalinated water. (Dolnicar & Schäfer, 2009).

The result of comparing the likelihood for different purposes where people would like to use recycled water or desalinated water (fig 2.11) indicates that, for most non-drinking and non- body contact purposes, most respondents prefer to use recycled water, assuming it is more energy-saving and environmental friendly. While dsalinated water is considered more drinkable and sanitary. With the exception of "washing the house, windows, and driveways," the differences between recycled and desalinated water in terms of likelihood of use are highly statistically significant (Dolnicar & Schäfer, 2009).

The results show a clue of people's acceptance level of recycled water currently, and **the necessity of a combinated supply of recycled water and desalinated water for different purposes** when surface water is not sufficient enough for household use.

Public opinion about DEWATS

Historically, centralised wastewater treatment is always the most popular way of water sanitation recycling. As urbanisation continues, more treatment plants are required and the limitations of that are exposed, such as the large occupation of on-ground area, high energy consumption in operation and long-term constructive process, etc. Therefore, the demand for smaller scale, more flexible and natural based way of water treatment comes out, which stimulates the idea of DEWATS.

While being in primary stage of development and realisation, DEWATS is still controversial as a substitute of the traditional centralised way, because it has higher requirement of environmental factors such as temperature and soil quality and the process is hard to be monitored. Therefore, many people concern about the sanity of water after fully treated by DEWATS, the popular suggestion up to date is to adopt DEWATS on-site where there is less density and where houses are scatterly located, or to regard DEWATS as an interim solution for developing districts.

Sydney's superiority in developing DEWATS and a (potentially) successful case

With the characters of subtropical climates, Sydney provides an ideal environment for various plants to grow, which is an advantaged condition for the constructed wetlands (a main component in DEWATS) to operate with high efficiency. Additionally, large open space availability for both individual household and public also support interventions with different scales to happen on site. Therefore, it is certain that DEWATS is highly possible to be well-developed in Sydney.

Catching the advantages, Sydney started to put DWTS in practice in high density area in the Central Park Recycled Water Scheme (CRC for Water Sensitive Cities, 2018) (fig). The project collects wastewater from the buildings of various functions on site and treats the water with membrane bioreactor (MBR) reverse osmosis (RO) to the highest Australian standards. The water after treatment is then delivered to multiple uses within a 5.8ha high density area (CRC for Water Sensitive Cities, 2018). Although the project is still under construction, it is a sign that **Sydney's willingness to promote decentralised water reuse in high density area**, if it succeeds, it will bring more possibilities for Sydney to solve the drought problem in new urbanised districts.

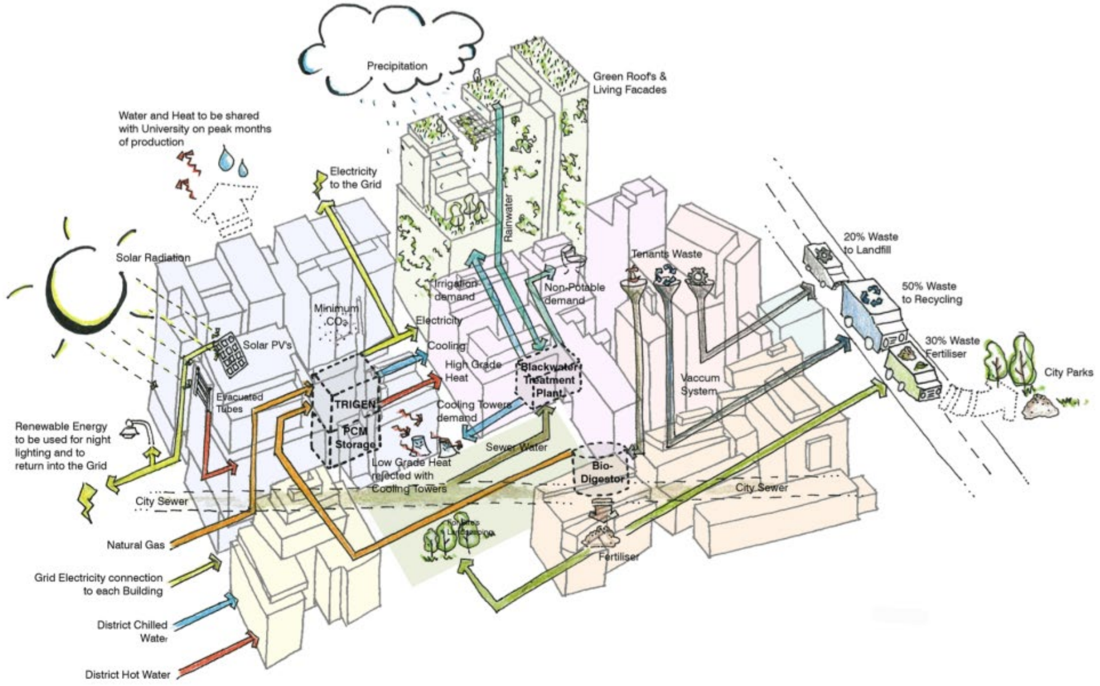
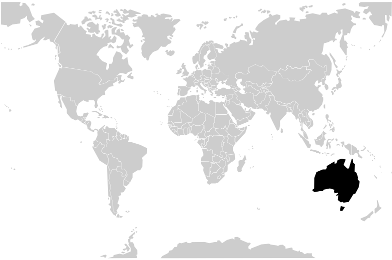


Fig 2.16 Diagram illustrating the DEWATS concept in Sydney Central Park (Finding Infinity, n.d.)

2.6 Project location - Campbelltown



Introduction to Campbelltown

Campbelltown is a suburb that located in the south-west of the Greater Sydney. The district incorporates different administrative layers, **in this report, the local government area (LGA) will be the predominant focus**, while how it will contribute to the overall development of the Greater Sydney is also explored and evaluated.

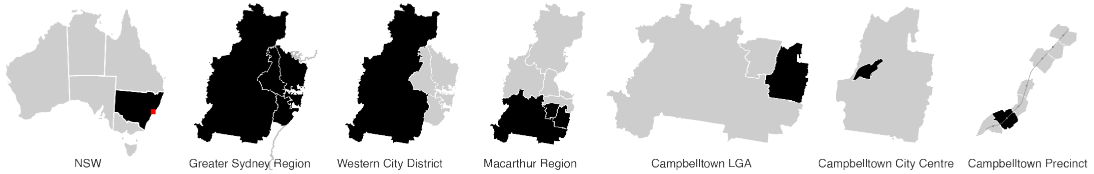


Fig 2.17 Location of the site with its adminnistrative layers

Campbelltown has a vulnerable water network, which is reflected in its landscape and the report from the government. According to NSW Department of Planning and Environment (2022), the fast-growing Macarthur region and the Illawarra region are more at risk to long term and severe drought. Meanwhile, the Macarthur region (including Campbelltown) is also a focus for urban sprawl in vision 2040 and accomodates an important nature reserve, it captures my motivation to face the water scarcity challenge and the redevelopment of Campbelltown. However, as Campbelltown is an indivisible part of the Greater Sydney, the water system of the suburb is not working independently, but supported by the network of the whole city and the state, it reminds me to have a broader vision during

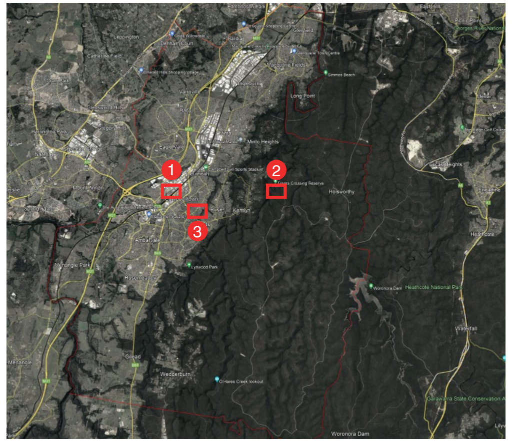


Fig 2.18 Location of the selected views (Google Earth, n.d.)

analysis and design. Therefore, in the following chapters, the location is positioned with a dynamic and comparative manner to serve the different needs of the stages in research and design.

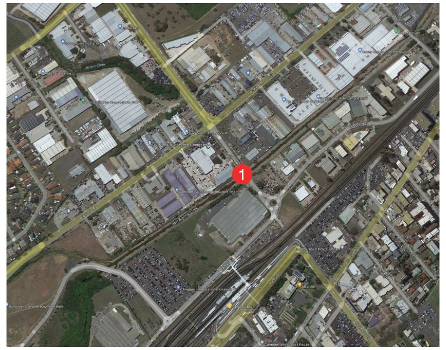


Fig 2.19 Map showing current city centre of Campbelltown precinct (Google Earth, n.d.)

Fig 2.22 Bowbowing Creek in streetview (Google Map, 2021)
At present, the creek is dry and full of dirt, which has scarce ecological existence. The surfaces with it is impervious and poorly-cared.

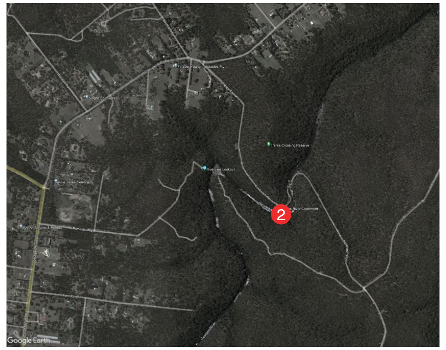


Fig 2.20 Map showing Freres Crossing Reserve in Campbelltown LGA (Google Earth, n.d.)

Fig 2.23 Georges River in Freres Crossing Reserve (Google Map, 2021)
Because of urbanisation, many pollutants are discharged to Georges River with urban creeks directed into, making the riverline eroded.

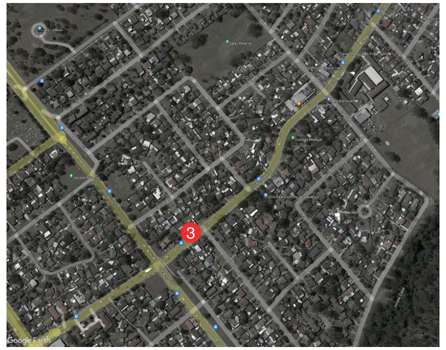


Fig 2.21 Map showing residential area in Campbelltown LGA (Google Earth, n.d.)

Fig 2.24 Typical housing type in Campbelltown (Google Map, 2021)
Existing houses in Campbelltown LGA are mostly single and detached houses with large courtyard and setbacks.

Strategic importance of Campbelltown (Fig 2.25, Fig 2.26)

According to Campbelltown City Council (2020), Campbelltown Local Government Area (LGA) will become a focal point for westward urban sprawl of Greater Sydney. The area has a renewal corridor with two metropolitan centres and a metropolitan cluster, laying the foundation for future land release of the Greater Macarthur area. In addition, Campbelltown will become a transportation node that links to the existing CBD in the eastern coast and starts the lightrail connected to Melbourne and Wollongong.

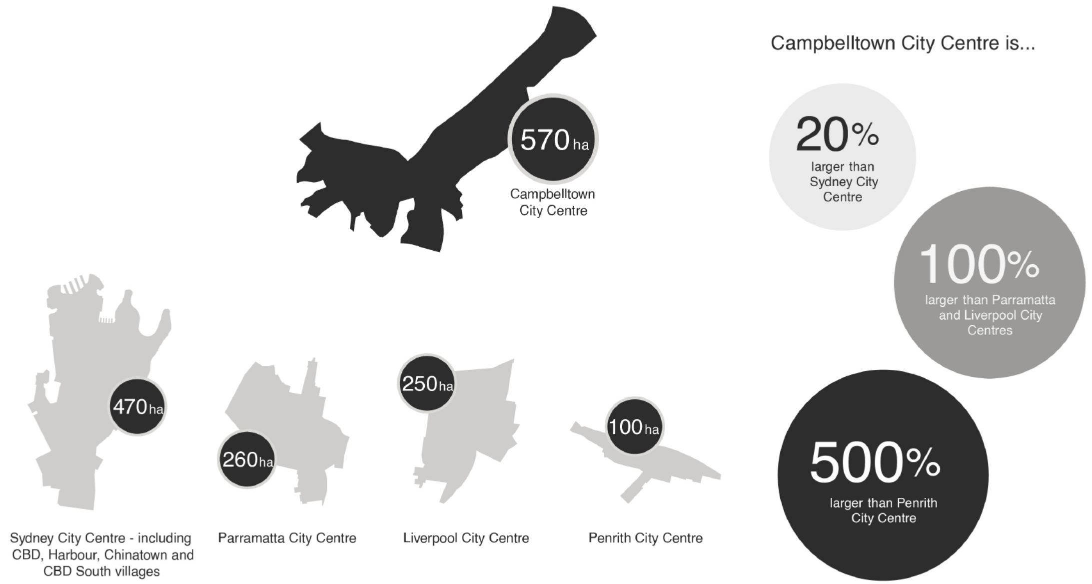


Fig 2.25 Comparison between the sizes of the city centres in Greater Sydney, adapted from Campbelltown City Council (2020b)

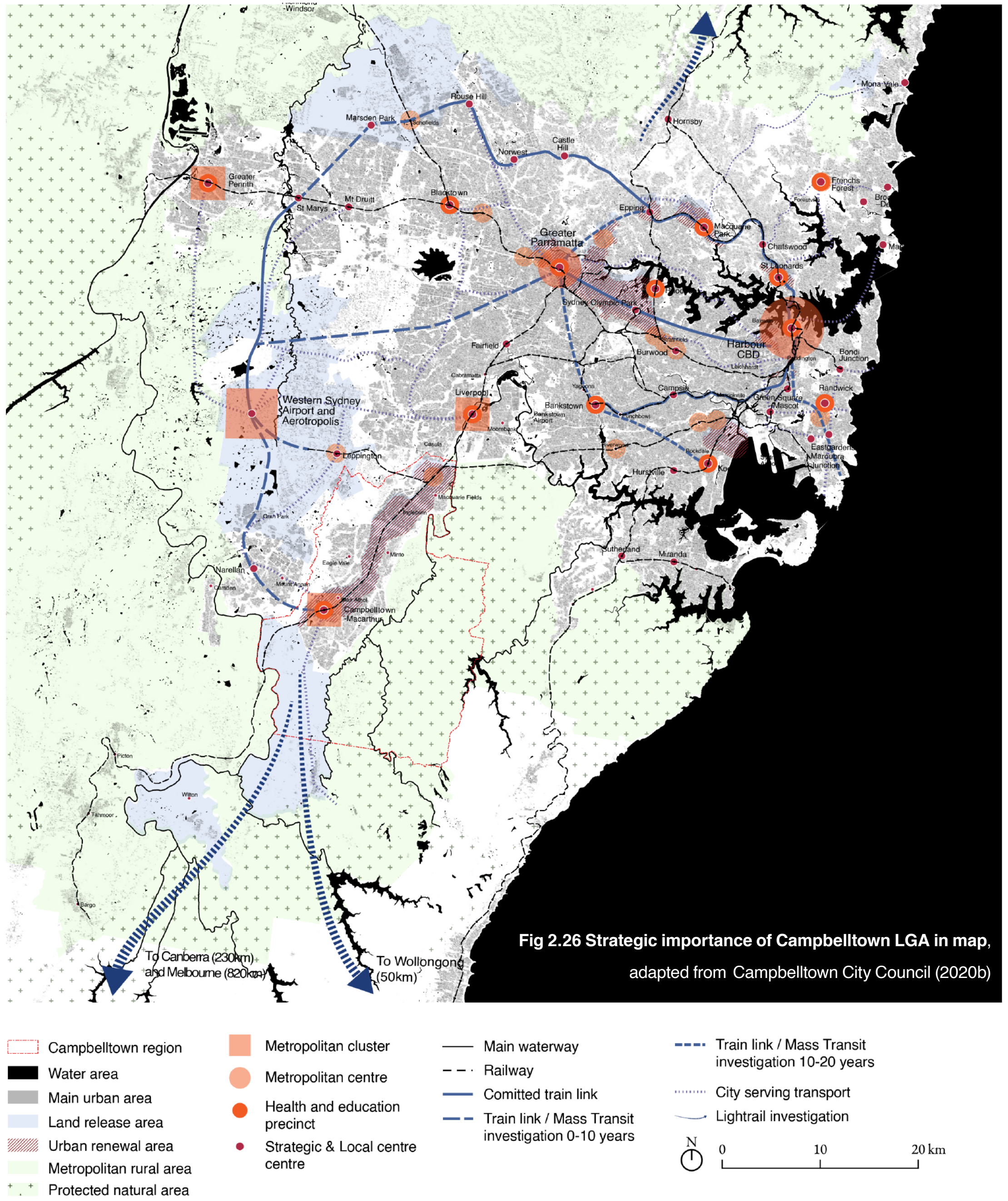


Fig 2.26 Strategic importance of Campbelltown LGA in map, adapted from Campbelltown City Council (2020b)

3. Theory

3.1 Introduction to domestic wastewater
3.2 Parameters for wastewater assessment
3.3 Guidelines for water quality evaluation and re-use
3.4 Decentralised wastewater treatment system (DEWATS)

3.1 Domestic wastewater composition and re-use

Introduction to domestic wastewater in Australia

The production of liquid waste is an inevitable byproduct of human activity, the quantity and quality of such waste varies depending on multiple factors such as behavior, lifestyle, living standards, as well as the governing technical and legal regulations, especially concerning household wastewater production (National Institute of Urban Affairs, New Delhi, 2019).

The wastewater that is addressed in this thesis includes the following types:

- Greywater: **Wastewater generated from plumbing fixtures other than toilets, like sinks, showers, and faucets** (Fane, 2010). Greywater can be re-used both indoor and outdoor for specific purposes if treated properly, including residential gardening, car washing, toilet flushing and laundry; irrigation for urban open space and agriculture; fire protection; and industrial uses (The Natural Edge Project, 2009).

- Blackwater: **Wastewater from toilets with faecal matter and urine, which might be contaminated with pathogens and grease**. In Australia, water from kitchen is also categorized as blackwater (Fane, 2010). In the actual situation, the re-use of blackwater is not carried out for individual households in Sydney as it may contain harmful organisms (Central Coast Council, 2023), while some commercial and industrial facilities in Sydney are allowed to treat and reuse blackwater under certain conditions and regulations set by the local government. However, as technologies are developed and the happening of recent drought events (Page 27-28), the importance of popularising water re-use came into public views, blackwater re-use after high-standard treatment is also possible for mixed-use buildings and residential buildings.

In Sydney, the current most common practice of recycling the wastewater is to collect these two kinds of wastewater together (mixed) in septic tanks that are close to the residential palce and delivering to the local treatment plants by sewerage, the water is mostly not re-used by household and are dischaged to waterways or the ocean, while small amount of the treated water are re-used for industrial purposes and agricultural

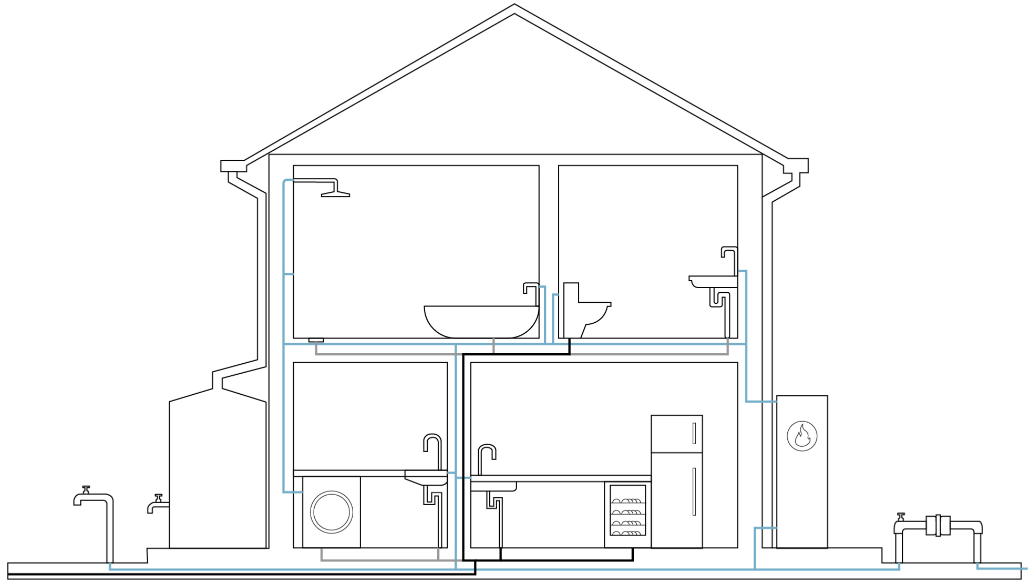


Fig 3.1 Illustration of fresh water and wastewater routes in household, a dapted from Sydney Water (2022)

irrigation. According to Australian Bureau of Statistics (2022), from year 2020 to 2021, the supply of reuse water was 4% of total wastewater, to 297 GL in total, the key users are Water supply, sewerage and drainage services (85 GL), Agriculture (76 GL) and Manufacturing (25 GL) As water conservation practices are promoted, the technologies of greywater diversion and greywater treatment (Sydney Water, 2023) are small-scale applied based on personal needs, where the greywater are separately collected from the blackwater and re-used for some non-potable purposes.

Treating domestic wastewater for re-use purposes

Although blackwater is not commonly treated for household re-use, because it is more costly than treating greywater to the same class based on extra biological, chemical and disinfection treatment (The Natural Edge Project, 2009), some advanced methods still provide the potential including the following options that are most popular in use:

- Special units for wastewater recycling with continuous deflection separation to separate gross and fine solids from raw sewage. The separated material then undergoes submerged aerated filters, fine sand filtering, UV disinfection (The Natural Edge Project, 2009). The process is already standardly used in Sydney's centralised wastewater treatment plant.

- Using flat sheet membrane panels (that are aerated) within an activated sludge treatment tank to treat various effluents, including greywater and blackwater, the treated water meets the standard for toilet flushing and irrigation (The Natural Edge Project, 2009).

- Using a simulated soil matrix (also known as a worm farm) or an in-ground tank that contains a fully aerobic, humic biological filtration matrix that utilizes vermicultural activity to expedite the decomposition of organic matter (The Natural Edge Project, 2009). The treated water can be reused on-site or exported to a pressurized reticulation network.

Although the process that is taken in the thesis is different from above, but it incorporates similar filtration, bio-treatment and disinfection, thus it leads to a good direction for research and experiment.

3.2 Parameters for wastewater assessment

The parameters of the household wastewater that are critical for health and the environment can be categorised in to three: physical, chemical, and biological parameters (National Institute of Urban Affairs, 2019). This chapter mainly discusses the constituents that are targeted to be removed by this project.

Solids (TSS)

Total suspended solids (TSS) include both settleable and colloidal solids. Settable solids can settle within one hour, while colloidal solids (between 0.01 micrometer and 1 micrometer) are more stable that they do not settle and are continuously in Brownian motion. In general, TSS refers to solid particles that are unable to pass through a filter of 0.2 micrometers. If those particles are haighly contained in untreated wastewater and are thus released to the environment, the oxygen from the water body tends to be depleted by turbidity and the organic contents. (National Institute of Urban Affairs, 2019).

Organic constituents

Organic substances are ubiquitous in nature and are made up of carbon-based compounds that are essential components of most living organisms. Found in wastewater, organic matter source from plants, animals, or synthetic compounds, and can enter the wastewater stream from a range of paths, including human consumption, industrial and commercial activities.

The combination of carbon, hydrogen, oxygen, nitrogen, and other elements composes the organic compounds. They can take the forms of proteins, carbohydrates, or fats, and are biodegradable, meaning that they can be decomposed by living organisms. The level of organic matter in a substance can be determined by analyzing certain characteristics, such as BOD (biochemical oxygen demand) and COD (chemical oxygen demand).

(National Institute of Urban Affairs, 2019).
However, if the organic materials are released untreated into the environment, the depletion of natural oxygen and the development of septic conditions can happen because of their biological stabilization. The results of BOD tests can be utilized to evaluate the amount of oxygen needed for biological stabilization of organic matter in wastewater and the effectiveness of treatment processes, and ensure compliance with wastewater discharge permits. (National Institute of Urban Affairs, 2019).

Nutrients

Domestic wastewater normally contains abundant nitrogen and phosphorus nutrients, which helps plant growth if they are utilised in a positive way. However, in severe conditions, an overabundance of nutrients in the water can stimulate the growth of algae and other aquatic plants, leading to a rapid depletion of oxygen in the water. Further on, fish and other aquatic organisms may die from insuffisient oxygen, producing unpleasant odors. If the nitrogen and phosphorus are leaked excessively on land, the quality of groundwater may also be affected. (National Institute of Urban Affairs, 2019)

Pathogens

Wastewater contains numerous viruses, parasites, and bacteria that can cause diseases and can enter the wastewater stream from all loactions. The pathogens of various diseases can be carried by infected individuals and animals, and both greywater and blackwater from household wastewater can contain enough pathogens that are risky to public health.

The quantity of pathogens in wastewater is often determined through the tests of MPN (most probable number) for total coliforms (TC) and fecal coliforms (FC). Evaluating the amont of coliforms indicates the possibility of other pathogens existing in feces and the water. (National Institute of Urban Affairs, 2019)

3.3 Guidelines for water quality evaluation and re-use

The guideline is based on water reclamation and reuse information sourced from the United States which applys to domestic wastewater after treatment limited elements from industrial waste. As it is difficult to find a well-organised local guidelines in NSW, the US guideline can be referred to for this thesis as it is already well prepared and authorised.

The functions that is considererd to apply reusable water in this thesis include: **urban reuse**, **recreational impoundments** and **environmental reuse**. While **groundwater recharge** is also planned for the Greater Sydney's long term development, the option is also included in case of need.

Type of reuse	Treatment	Reclaimed water quality	Reclaimed water monitoring
Urban Reuse All types of landscape irrigation, (e.g., golf courses, parks, cemeteries) - also vehicle washing, toilet flushing, use in fire protection systems and commercial air conditioners, and other uses with similar access or exposure to the water.	Secondary Filtration Disinfection	pH = 6-9 ≤ 10 mg/l BOD ≤ 2 NTU No detectable fecal coli/100 ml 1 mg/l Cl_2 residual (minimum)	pH - weekly BOD - weekly Turbidity - continuous Coliform - daily Cl_2 residual - continuous
Recreational impoundments incidental contact (e.g. fishing and boating) and full body contact with reclaimed water allowed			

Fig 3.2 Guideline for water re-use, adapted from U.S. Environmental Protection Agency (2004)
Detailed information in Appendix

Type of reuse	Treatment	Reclaimed water quality	Reclaimed water monitoring
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation.	Variable Secondary and disinfection (minimum)	Variable, but not to exceed: ≤ 30 mg/l BOD ≤ 30 mg/l TSS ≤ 200 fecal coli/100 ml	BOD - weekly TSS - daily Coliform - daily Cl_2 residual - continuous
Groundwater recharge By spreading or aquifers not used for publlic water supply.	Site-specific and use dependent Primary (minimum) for spreading Secondary (minimum for injection)	Site-specific and use dependent	Site-specific and use dependent
Indirect potable reuse Augmentation of surface supplies	Secondary Filtration Disinfection Advanced treatment	Includes, but not limited to the following: pH = 6.5 - 8.5 ≤ 2 NTU No detectable total coli/100 ml 1 mg/l Cl_2 residual (minimum) ≤ 3 mg/l TOC Meet drinking water standards	Includes, but not limited to the following: pH - daily Turbidity - continuous Total coliform - daily Cl_2 residual - continuous Drinking water standards - quarterly Other - depends on constituents

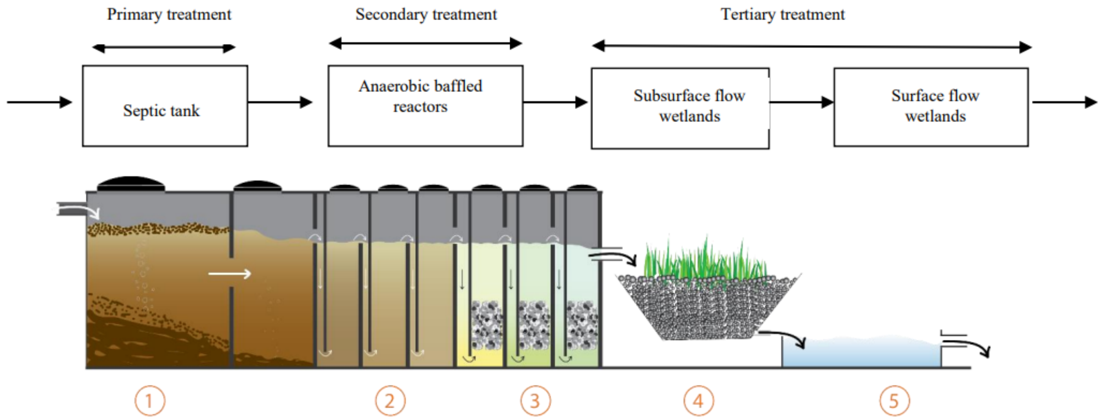
Fig 3.3 Guideline for water re-use, adapted from U.S. Environmental Protection Agency (2004)
Detailed information in Appendix

3.4 Decentralised wastewater treatment system (DEWATS)

Concept of Decentralised wastewater treatment system (DEWATS)

Decentralized wastewater treatment systems (DEWATS) is a way of delivering, recycling and reusing wastewater, it is currently mainly used for small and low-density districts, remote residential areas, individual buildings and newly developed area (Wikipedia contributors, 2022). The predominant purpose of DEWATS is to provide **a flexible, sustainable, low-consumption way to promote water reuse** that can reduce the pressure from water scarcity.

Typical DEWATS flow requires four main stages (Fig 3.4): (a) primary treatment: settlers or septic tanks; (b) secondary treatment: anaerobic baffled reactors (ABR); (c) tertiary treatment: subsurface vertical flow (VF) and/or horizontal flow (HF) wetland systems; and (d) additional tertiary treatment: polishing ponds or surface flow (SF) wetlands (Saeed et al., 2013/2014, pp. 358). The on-site setting can be slightly different according to the environmental and technical conditions.



Section 1	Section 2	Section 3	Section 4	Section 5
Primary treatment	**Secondary treatment**		**Tertiary treatment**	**Post-treatment**
Septic tank	Baffled reactor	Anaerobic filter	Constructed wetland	Polishing pond/ Surface flow wetland
Sedimentation tank stabilising settled sludge by anaerobic digestion Dissolved and suspended matter leave tank untreated	Anaerobic degradation of suspended and dissolved solids 2–5 chambers depending of treatment required	Water passes through filter media Enhance digestion of organic matter	Open shallow basin filled with gravel/pebbles to support growth of plant/reeds with shallow roots Reduces organic contents and acts as filter mechanism	Open shallow basin for removal of stabilised or inactive suspended substances Exposure to UV rays
Removal of COD 20-25%, BOD 15-20%, TSS 50-55%	Removal of COD 25-30%, BOD 30-35%, TSS 10-15%	Removal of COD 20-25%, BOD 15-20%, TSS 15-20%	Removal of COD 15-20%, BOD 20-25%, TSS 5-10%	Removes odour and pathogens

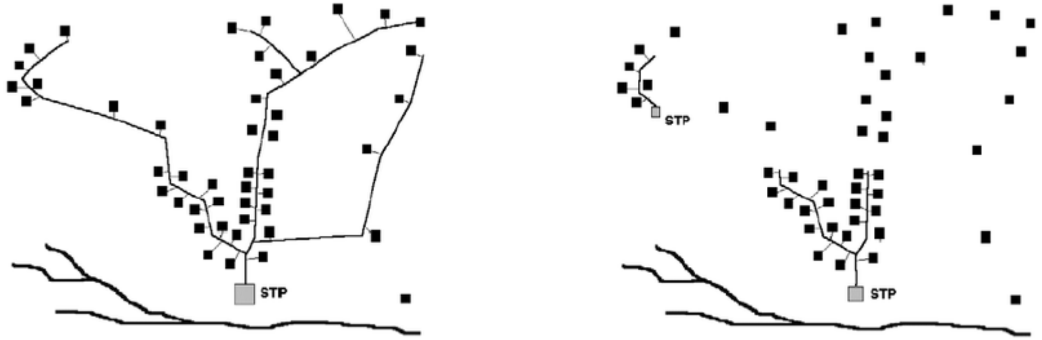
Fig 3.4 Illustration of the typical modules in DEWATS and their performance (Harvey et al., 2017)

COD: Chemical oxygen demand

BOD: Biochemical oxygen demand

TSS: Total suspended solids

Comparison between DEWATS and centralised system in layout and scale of service



Centralised wastewater treatment

Decentralised wastewater treatment system (DEWATS)

Fig 3.5 Conceptual comparison between centralised treatment and DWTS (Rocky Mountain Institute, 2004, p. 4)

*STP is the abbreviation for sewerage treatment plant

Generally, any kind of wastewater treatment can be regarded as both “centralised” and “decentralised” based on different scale of serving area from subjectivity (Fig 3.5). To explain that, there is higher centralised degree of a cluster system than onsite systems. The wastewater treatment plant (WWTP) serving a regional scale with multiple municipalities reflects a higher degree of centralization than a number of “centralized” but smaller municipal or community-scale WWTPs.

This thesis mainly discusses **the schemes for smaller communities from on-site to central system range**, where the role of landscape such as wetlands are largely considered. Meanwhile, the connections between on-site interventions and existing regional scale centralised plants will also be concerned but not as a focus in this report.

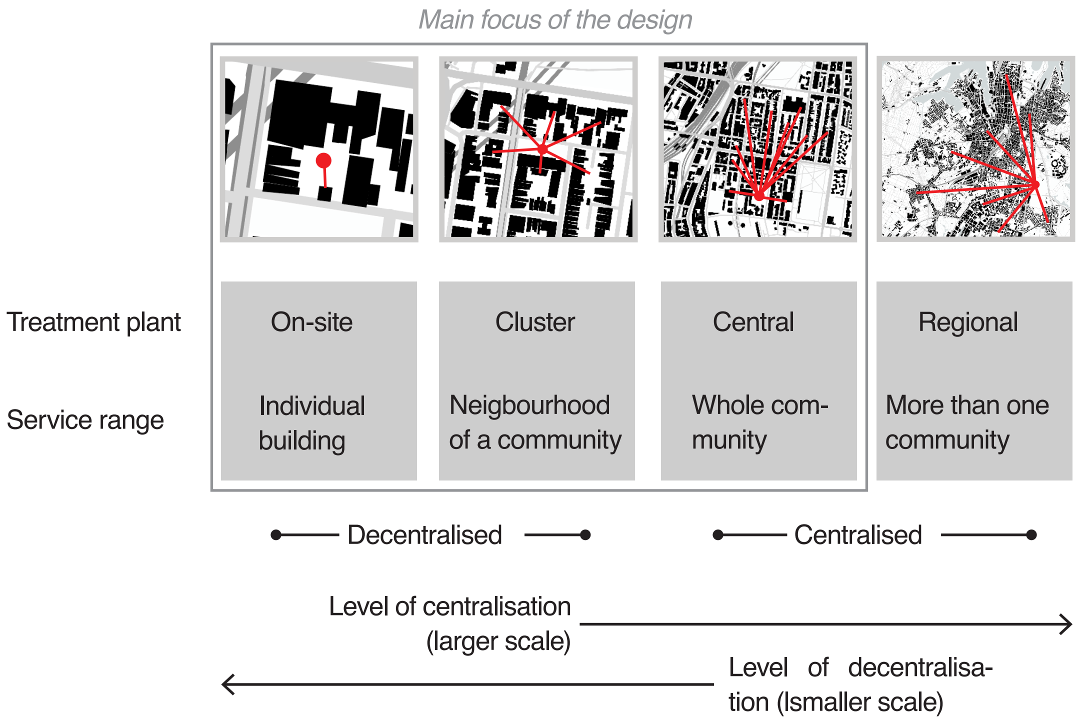


Fig 3.6 The levels of decentalisation and centralisation treatment, adapted from Rocky Mountain Institute (2004)
The maps are conceptual illustration of different scales, they are not actual settings of treatment plants or pipelines.

General area requirement of DEWATS

All of this part including texts and tables is referenced from “Technical guidelines for designing a decentralised waste water treatment system” (Harvey et al., 2017)

For a typical DEWATS with four units, the area requirement is based on the wastewater volume. For the treatment of wastewater per m^3, the required area is illustrated in Fig 3.7 The table indicates the integrated process with a vertical flow (VF) wetland followed by a horizontal flow (HF) wetland (prior to a surface flow wetland). The hybrid of two types of wetland allows nitrification in the aerobic VF wetland, followed by denitrification in the anaerobic HF wetland. The residual pollutants will be removed by the surface flow (SF) wetland in the last module.

Considering wastewater quality and land availability, it is also possible to apply a single VF or HF wetland, instead of the combination of VF and HF. If that is the case, the total area requirement might be lower.

Component	Minimum recommended area (m^2)
Septic tank	0.5
ABR	1.0
VF constructed wetland	3.75
HF constructed wetland	6.5
Polishing pond or SF wetland	1.2
Total area	**12.95 m^2**

Fig 3.7 Minimum area requirement of different DEWATS treatment steps per m^3 wastewater treatment (Harvey et al., 2017)
The numbers in the table are estimated from practical experience, it is reccommended to prepare larger area if land availability is sufficient.

Constructed wetlands in DEWATS

All of this part including texts and tables is referenced from "Technical guidelines for designing a decentralised waste water treatment system" (Harvey et al., 2017)

Constructed wetlands are wetlands that features saturated or unsaturated substrates, emergent/floating/submerged plants, and a diverse range of microbiological communities. Water pollution is intended to be reduced through the wetlands. There are two types of constructed wetlands included in the design of DEWATS: (a) surface flow and (b) subsurface flow wetlands.

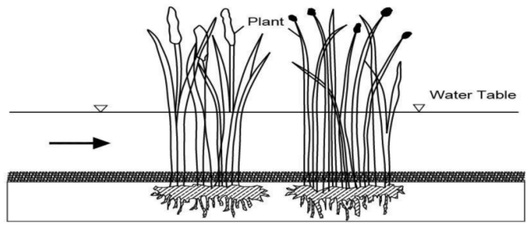


Fig 3.8 Schematic diagram of surface flow systems (Harvey et al., 2017)

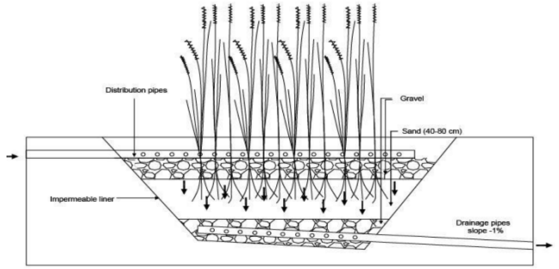


Fig 3.9 Schematic diagram of VSSF systems (Harvey et al., 2017)

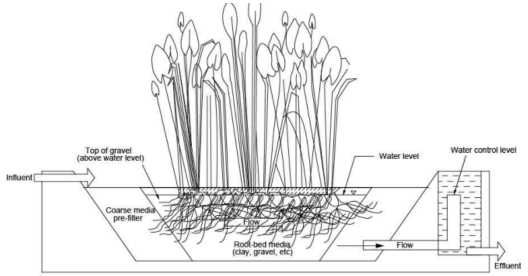


Fig 3.10 Schematic diagram of HSSF systems (Harvey et al., 2017)

Surface flow (SF) wetlands (Fig 3.8) are constructed for shallow flow of wastewater (usually less than 60cm deep) which runs over saturated soil substrate. "The pollutant mechanisms in surface flow systems include: sedimentation, filtration, oxidation, reduction, precipitation and adsorption. (Harvey et al., 2017)"

Subsurface flow wetland systems have two types: (a) vertical subsurface flow (VF) and (b) horizontal subsurface flow (HF) wetlands.

In VF wetlands (Fig 3.9), wastewater flows vertically downwards through the media with plants towards the outlet.

In HF systems (Fig 3.10), the outlet is generally located 60cm above the bottom of the tank. Wastewater flows horizontally through the wetland beneath the media surface that is saturated.

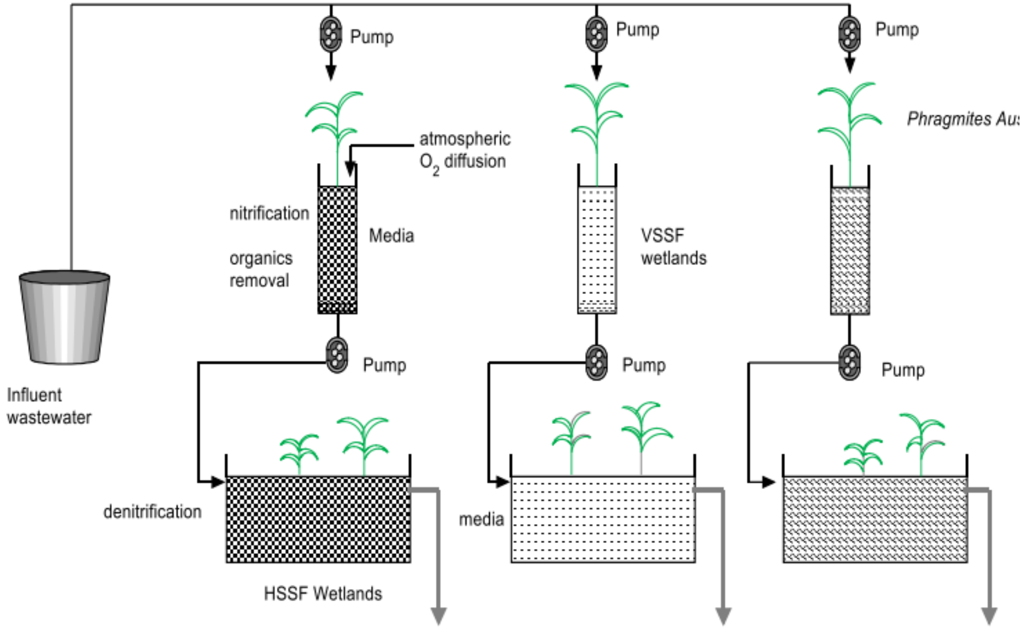


Fig 3.11 Types of hybrid wetland systems (Harvey et al., 2017)

The hybrid wetland system (Fig 3.11) is the combination of VF-HF or HF-VF systems that is processed before the final SF wetland. These systems achieve higher performance in pollutant removal because they are more effective in aerobic and anaerobic phases of VF and HF systems.

Type	Advantages	Disadvantages
Vertical flow wetlands (VSSF)	Smaller area demand.	Short flow distances.
	Good oxygen supply, good nitrification, better organics and solids removal, simple hydraulics.	Poor denitrification, higher technical demand, low nitrate removal.
	Higher purification from the beginning, better than HF beds as water flows from surface to bottom, which enhances oxygen mixing.	Loss of performance in phosphorous removal.
Horizontal flow wetlands (HSSF)	Long flowing distance, nutrients gradients can be established, efficient in the removal of solids, organics. Denitrification possible.	High area demand, clogging problem is observed, sulphur transformation can affect nitrification sensitivity. Careful calculation of hydraulics necessary for optimal oxygen supply, low ammonium oxidation.
	Formation of humic acids for N, P removal.	Equal waste water supply is complicated.

Fig 3.12v Advantages and disadvantages of VF and HF systems (Harvey et al., 2017)

4. Methodology

4.1 Research aims

The general aim for this project is to explore and experiment how the implement of decentralised wastewater treatment system (DEWATS) for different population density contributes to water re-use in Campbelltown. Meanwhile, understanding the upper limit for urban sprawl based on the gap between water supply and consumption. To be specific, the aim can be subdivided as follows:

A1: Experimenting different variants of DEWATS to support different population density in rising metropolitan centre (Campbelltown).
A2: Evaluating whether the changes of the water system in Campbelltown benefits the Greater Sydney region as a whole.
A3: Creating a strong example and foundation of water resilient strategies for future urban sprawl of the Greater Macarthur area.
A4: Analysing the water quality that target DEWATS methods provide.
A5: Understanding potential synergy that DEWATS brings.

4.2 Research question

Main question: How to implement nature-based Decentralised Wastewater System (DEWATS) as a means to facilitate water re-use for future household in Campbelltown?

- Q1: Can the design be applied to different urban densities equally well?
- Q2: What are the treated water quality required for different purposes of reuse?
- Q3: What are the spatial requirements and potential synergies for the selected DEWATS system in the case study area?
- Q4: How can the existing infrastructure and landscape participate in the case study area?
- Q5: How can the interventions contibute to the resilience of the water system in other parts of the Greater Sydney region?

4.3 Research framework

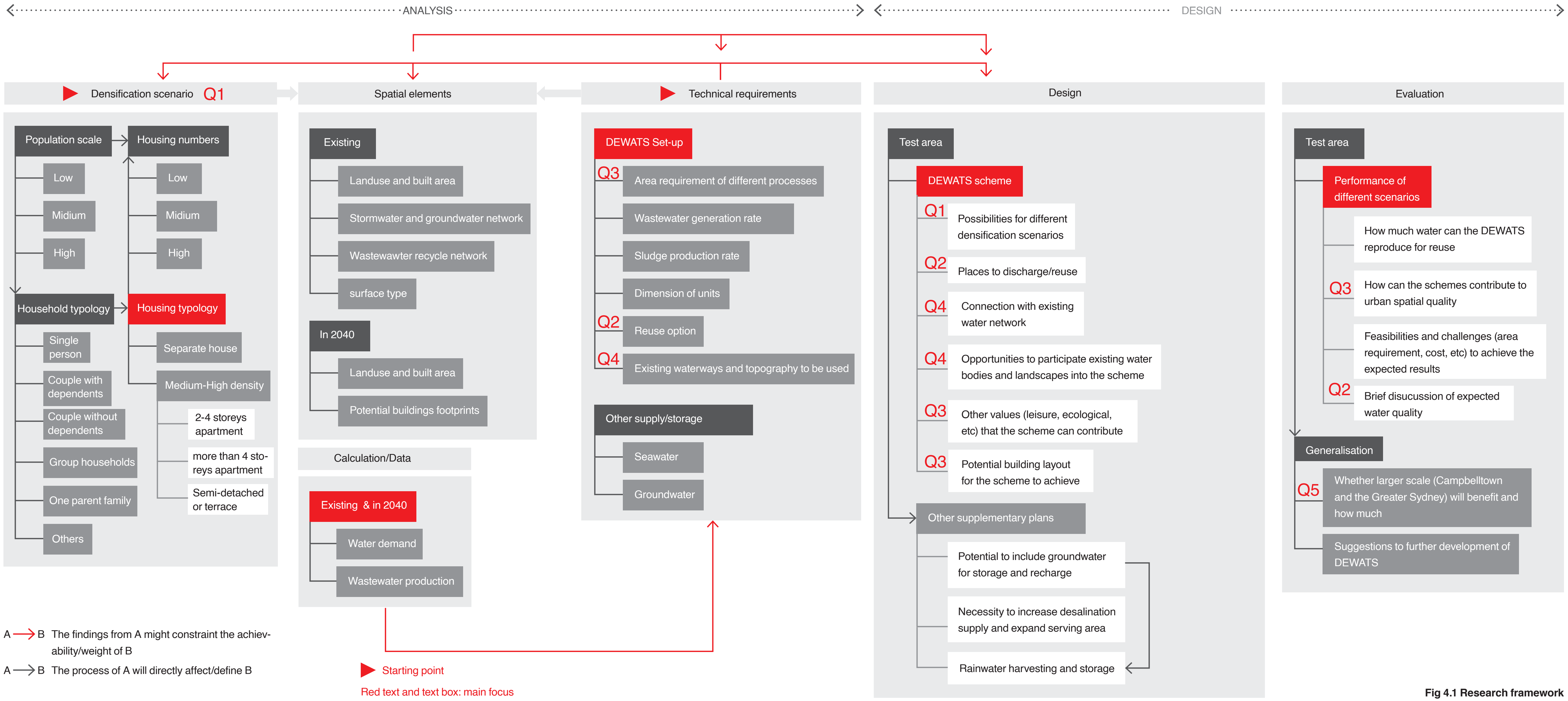


Fig 4.1 Research framework

5. Analysis

5.1 Theoretical analysis

Historical and current domestic water consumption in Campbelltown

With the lack of public open sources for this data, the only way to analyse this part is through calclation and assumption based on the historical records and researches. There are three variations that will affect the process and lead to different outcomes. As an experimental project, the realibility of the results cannot be secured, but all of them may provide reference value in different aspects. The three variations are defined as: number of dwellings, housing typology and population intensity (level of densification).

Start from Western City District

		1987	1991	1996	2001	2002	2003
		Western Sydney	Western Sydney	Western Sydney	Western Sydney	Western Sydney	Western Sydney
Areas predominantly flats in a block of 4 or more storeys	Total Consumption (kL)	370,004	434,577	484,984	622,695	620,890	535,335
	Total Dwellings	2,321	2,448	2,621	2,835	2,838	2,602
	Consumption per Dwelling (kL)	**159**	**178**	**185**	**220**	**219**	**206**
Areas predominantly flats in a block of less than 4 storeys	Total Consumption (kL)	365,104	422,631	417,158	439,554	422,007	353,207
	Total Dwellings	1,899	2,115	2,252	2,129	2,126	1,887
	Consumption per Dwelling (kL)	**192**	**200**	**185**	**206**	**198**	**187**
Areas predominantly semi detached dwellings	Total Consumption (kL)	306,725	400,874	353,846	521,488	551,812	426,656
	Total Dwellings	1,180	1,559	1,635	1,996	2,151	1,795
	Consumption per Dwelling (kL)	**260**	**257**	**216**	**261**	**257**	**238**
Areas wholly separate houses	Total Consumption (kL)	1,026,659	1,229,933	967,023	1,231,935	1,350,321	1,158,769
	Total Dwellings	3,230	3,294	3,346	4,111	4,406	4,293
	Consumption per Dwelling (kL)	**318**	**373**	**289**	**300**	**306**	**270**

Fig 5.1 Average annual water consumption per dwelling in Western Sydney from 1987 to 2003, adapted from Troy et al. (2005)

Fig 5.2 Map showing the range of Western City

The table (Fig 5.1) shows large variations between the consumption in the selected years. This outcome might come from the water use restriction and affordability during the respective droughts. For example, year 2002 to 2003 is an extreme dry period during the millennium drought from 1997 to 2009 (bureau of meteorology, 2020), some clues can be seen that for most types of dwellings, the consumption per dwelling is decreased in 2003 compared to previous sampled years. While this difference could indicate short-term lower limit for water use during drought, it should be excluded when calculating normal water demand.

Calculation with housing typologies:

The catogrised housing typologies from Troy's (2005) research regarding Western City District can be aligned with the current and future housing typologies in Campbelltown in the following way:

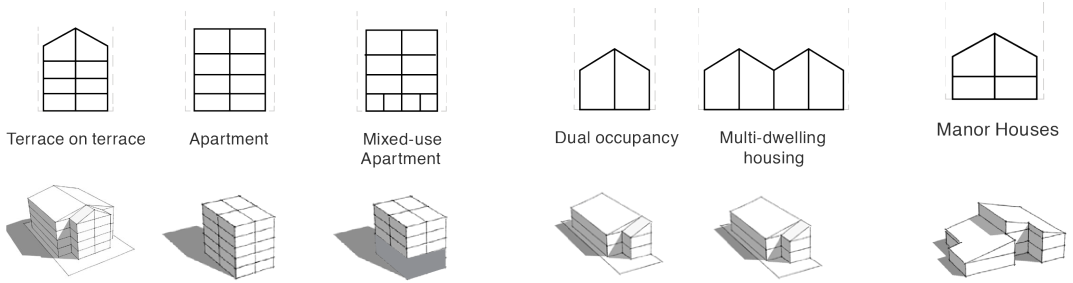


Fig 5.3 Illustration of housing types, adapted from Campbelltown City Council (2020b)

Flats in a block of 4 or more storeys: High density

Flats in a block of less than 4 storeys, Semi-detached dwelling: Medium density

Wholly seperate houses: Low density

To summarise, for the household water c very) are excluded, and the average of the rest is regarded as a standard reference for the next steps. The highest and lowest number of each housing type in all the sampled years (including 2002 and 2003) is retained for elasticity range consideration.

Typology			Average of year 1987, 1991, 1996 and 2001	Highest	Lowest	Highest year	Lowest year
High density	Areas predominantly flats in a block of 4 or more storeys	Consumption per Dwelling (kL)	186	220	159	2001	1987
Medium density	Areas predominantly flats in a block of less than 4 storeys	Consumption per Dwelling (kL)	196	206	185	2001	1996
	Areas predominantly semi detached dwellings	Consumption per Dwelling (kL)	249	261	216	2001	1996
Separate house	Areas wholly separate houses	Consumption per Dwelling (kL)	320	373	270	1991	2003

Fig 5.4 Average, highest and lowest water consumption of different housing types

Calculation for Campbelltown based on year 2021

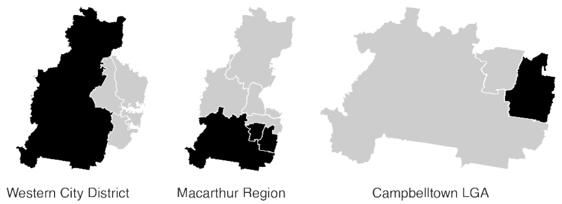


Fig 5.5 Location of Campbelltown LGA in Western City District

Based on the calculation of water consumptions with housing typologies in the previous page and the housing profile for Campbelltown LGA in 2021, the consumption of different dwelling types in Campbelltown LGA can be calculated roughly as follows based on the average scenario (Fig 5.6)

		2021	Sum (kL)
High density	**Total Consumption (kL)**	**471,138**	Low scenario: **17,277,646**
	Total Dwellings	2,533	
	Consumption per Dwelling (kL)	186	
Medium density (low scenario)	**Total Consumption (kL)**	**2,187,948**	
	Total Dwellings	11,163	
	Consumption per Dwelling (kL)	196	
Medium density (high scenario)	**Total Consumption (kL)**	**2,779,587**	High scenario: **17,869,285**
	Total Dwellings	11,163	
	Consumption per Dwelling (kL)	249	
Separate house	**Total Consumption (kL)**	**14,618,560**	
	Total Dwellings	45,683	
	Consumption per Dwelling (kL)	320	

Fig 5.6 Assumed water consumption per housing type in 2021

Looking into the different composition of the households and compare it with the total number of the existing dwellings, it is clear that there is a small gap between them. Roughly 6% of the existing dwellings are not in active use. Therefore, the active dwelling numbers of different housing types should be 94.3% of the total housing number.

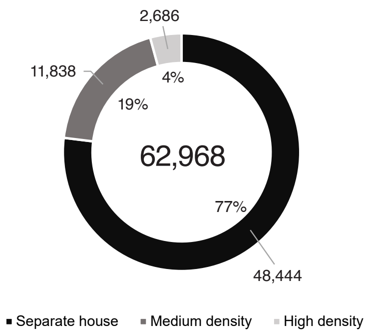


Fig 5.7 Numbers of different types of dwellings in Campbelltown in 2021, data from idcommunity (n.d.)

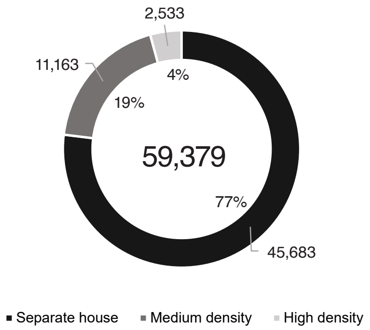


Fig 5.8 Numbers of different types of active dwellings in Campbelltown in 2021, data from idcommunity (n.d.)

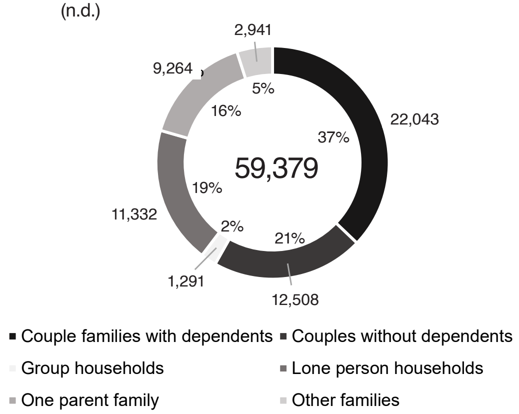


Fig 5.9 Numbers of different types of household in Campbelltown in 2021, data from idcommunity (n.d.)

Assumption for Campbelltown in year 2040

Taking the statistics from the medium densification scenario as the start, the comparison between the forecast of household in 2040 and that in 2021 indicates that the percentage of each household type to the total is almost the same respectively. Therefore, it is safe to assume that **the possible distribution of dwelling types in 2040 can be the same as 2021.**

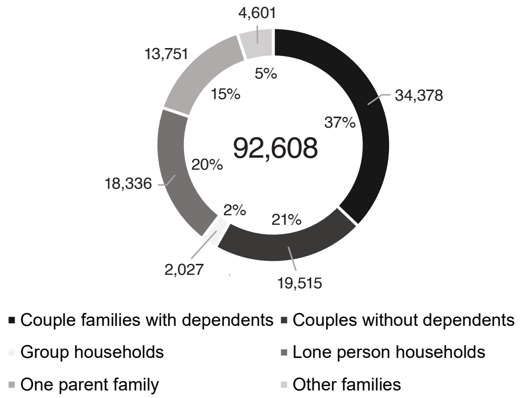


Fig 5.10 Estimation of the numbers of different types of household in Campbelltown in 2040, data from idcommunity (n.d.)

		2040	Sum (kL)
High density	**Total Consumption (kL)**	**688,944**	Low scenario: **26,956,320**
	Total Dwellings	3,704	
	Consumption per Dwelling (kL)	186	
Medium density (low scenario)	**Total Consumption (kL)**	**3,448,816**	
	Total Dwellings	17,596	
	Consumption per Dwelling (kL)	196	
Medium density (high scenario)	**Total Consumption (kL)**	**4,381,404**	High scenario: **27,888,908**
	Total Dwellings	17,596	
	Consumption per Dwelling (kL)	249	
Separate house	**Total Consumption (kL)**	**22,818,560**	
	Total Dwellings	71,308	
	Consumption per Dwelling (kL)	320	

Fig 5.11 Assumed water consumption per housing type in 2040

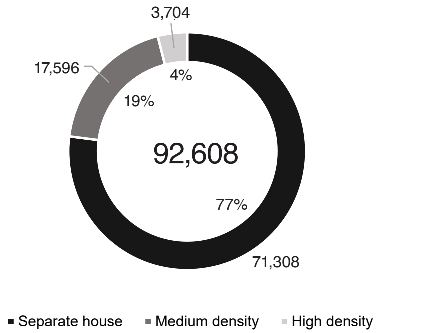
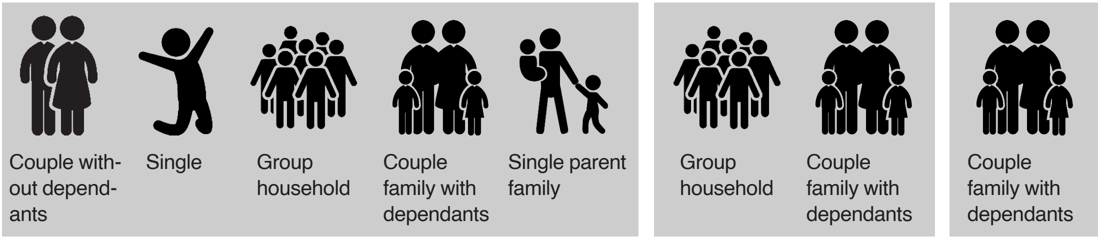


Fig 5.12 Estimation of the numbers of different types of houses in Campbelltown in 2021, data from idcommunity (n.d.)

Potential household setup with housing typology:



High density & Medium density (low scenario)

Medium density (high scenario)

Separate house

Fig 5.13 Potential household relation with housing typology

Generalisation for the three densification scenarios

Scenario		Housing typology	Categories		Sum (kL)	Total population	Consumption per person (kL)
2036	**Low**	High density	**Total Consumption (kL)**	**614,172**	Low scenario: **24,028,912**	**233,150**	Low scenario: **103**
			Total Dwellings	3,302			
			Consumption per Dwelling (kL)	186			
		Medium density (low scenario)	**Total Consumption (kL)**	**3,074,260**			
			Total Dwellings	15,685			
			Consumption per Dwelling (kL)	196			
		Medium density (high scenario)	**Total Consumption (kL)**	**3,905,565**	High scenario: **24,860,217**		High scenario: **107**
			Total Dwellings	15,685			
			Consumption per Dwelling (kL)	249			
		Separate house	**Total Consumption (kL)**	**20,340,480**			
			Total Dwellings	63,564			
			Consumption per Dwelling (kL)	320			
	Medium	High density	**Total Consumption (kL)**	**644,490**	Low scenario: **25,212,142**	**256,041**	Low scenario: **98**
			Total Dwellings	3,465			
			Consumption per Dwelling (kL)	186			
		Medium density (low scenario)	**Total Consumption (kL)**	**3,225,572**			
			Total Dwellings	16,457			
			Consumption per Dwelling (kL)	196			
		Medium density (high scenario)	**Total Consumption (kL)**	**4,097,793**	High scenario: **26,084,363**		High scenario: **102**
			Total Dwellings	16,457			
			Consumption per Dwelling (kL)	249			
		Separate house	**Total Consumption (kL)**	**21,342,080**			
			Total Dwellings	66,694			
			Consumption per Dwelling (kL)	320			
	High	High density	**Total Consumption (kL)**	**694,896**	Low scenario: **27,186,036**	**275,778**	Low scenario: **99**
			Total Dwellings	3,736			
			Consumption per Dwelling (kL)	186			
		Medium density (low scenario)	**Total Consumption (kL)**	**3,478,020**			
			Total Dwellings	17,745			
			Consumption per Dwelling (kL)	196			
		Medium density (high scenario)	**Total Consumption (kL)**	**4,418,505**	High scenario: **28,126,521**		High scenario: **102**
			Total Dwellings	17,745			
			Consumption per Dwelling (kL)	249			
		Separate house	**Total Consumption (kL)**	**23,013,120**			
			Total Dwellings	71,916			
			Consumption per Dwelling (kL)	320			
2021		High density	**Total Consumption (kL)**	**471,138**	Low scenario: **17,277,646**	**176,519**	Low scenario: **98**
			Total Dwellings	2,533			
			Consumption per Dwelling (kL)	186			
		Medium density (low scenario)	**Total Consumption (kL)**	**2,187,948**			
			Total Dwellings	11,163			
			Consumption per Dwelling (kL)	196			
		Medium density (high scenario)	**Total Consumption (kL)**	**2,779,587**	High scenario: **17,869,285**		High scenario: **101**
			Total Dwellings	11,163			
			Consumption per Dwelling (kL)	249			
		Separate house	**Total Consumption (kL)**	**14,618,560**			
			Total Dwellings	45,683			
			Consumption per Dwelling (kL)	320			

Fig 5.14 Generalisation for the three densification scenarios with the calculation of water consumption per housing type for 2021 and 2036

Difference in water consumption and population between 2021 and 2036

Scenario	Housing typology		Difference	Difference in sum (kL)	Difference in population	Difference in the total number of dwellings
Low	High density	**Total Consumption (kL)**	**143,034**	Low scenario: **6,751,266**	**56,631**	**23,172**
		Total Dwellings	769			
	Medium density (low scenario)	**Total Consumption (kL)**	**886,312**			
		Total Dwellings	4,522			
	Medium density (high scenario)	**Total Consumption (kL)**	**1,125,978**	High scenario: **6,990,932**		
		Total Dwellings	4,522			
	Separate house	**Total Consumption (kL)**	**5,721,920**			
		Total Dwellings	17,881			
Medium	High density	**Total Consumption (kL)**	**173,352**	Low scenario: **7,934,496**	**79,522**	**27,237**
		Total Dwellings	932			
	Medium density (low scenario)	**Total Consumption (kL)**	**1,037,624**			
		Total Dwellings	5,294			
	Medium density (high scenario)	**Total Consumption (kL)**	**1,318,206**	High scenario: **8,215,078**		
		Total Dwellings	5,294			
	Separate house	**Total Consumption (kL)**	**6,723,520**			
		Total Dwellings	21,011			
High	High density	**Total Consumption (kL)**	**223,758**	Low scenario: **9,908,390**	**99,259**	**34,018**
		Total Dwellings	1,203			
	Medium density (low scenario)	**Total Consumption (kL)**	**1,290,072**			
		Total Dwellings	6,582			
	Medium density (high scenario)	**Total Consumption (kL)**	**1,638,918**	High scenario: **10,257,236**		
		Total Dwellings	6,582			
	Separate house	**Total Consumption (kL)**	**8,394,560**			
		Total Dwellings	26,233			

Fig 5.15 The difference between the calculation of water consumption per housing type for 2021 and 2036 in three scenarios

Area requirement for DEWATS in Campbelltown

Taking the medium densification scenario in 2036 as example, the estimated extra population compared to 2021 is 79,522. If all the extra population can be served with DEWATS, the process of determining total area requirement for DEWATS will be as follows:

Calculating water consumption rate
Assuming typical water consumption rate to be 100 L/P/d (Harvey et al., 2017), total water consumption rate by
79,522 people can be calculted as: 79,522 x 100 L/P/d = 7,952,200 L/d = 7,952.2 m^3/d

Calculating waste water generation rate
Around 80% of the consumed water becomes wastewater (Harvey et al., 2017). As such, total waste water generation from the households can be calculated as: 7,952,200 L/d x 80% = 6,361,760 L/ d = 6,361.76 m^3/d

The area of the septic tank and the area and volume of the ABR for generated waste water
The area of the septic tank can be calculated following Fig 3.7 (page 51): 6,361.76 m^3 x 0.5 m^2 = 3,180.88 m^2
The area of the ABR can be calculated following Fig 3.7 (page 51): 6,361.76 m^3 x 1.0 m^2 = 6,361.76 m^2
To achieve the retention time of 24 hours, the volume of the ABR unit can be calculated as: 6,361.76 m^3/d x 1 d = 6,361.76 m^3

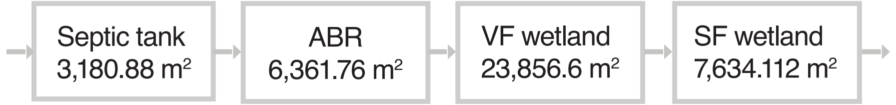
Calculating sludge generation rate
The generated sludge rate may be approximately 0.1 L/P/d, for desludging interval of one year. As such, sludge production volume can be calculated as: 79,522 x 0.1 L/P/d = 7,952.2 L/d
Sludge production yearly can be calculated as: 7,952.2 L/d x 365 d = 2,902,553 L = 2,902.553 m^3

Calculating the area of the wetlands
the required area of VF, HF and SF wetlands can be calculated following Fig 3.7 (page 51):
Area of the VF wetland: 6,361.76 m^3 x 3.75 m^2 = 23,856.6 m^2
Area of the HF wetland: 6,361.76 m^3 x 6.5 m^2 = 41,351.44 m^2
Area of the SF wetland: 6,361.76 m^3 x 1.2 m^2 = 7,634.112 m^2

Different options
The options of the DEWATS composition can be illustrated below (Fig 5.16). Option A is the best choice for better treated water quality with most pollutant removal, because sequential aerobic-anaerobic proocesses of VF and HF wetlands are sequentially arrange. However, option B and C is also considerable due to insufficient land or other limitations.

Option A: Total area requirement of **82,384.792** m^2

Option B: Total area requirement of **41,033.352** m^2



Option C: Total area requirement of **58,528.192** m^2

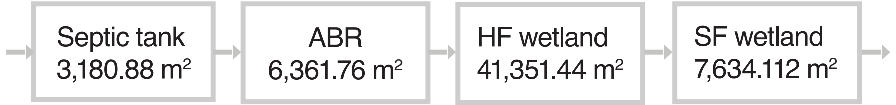


Fig 5.16 Options for DEWATS scheme, adapted from Harvey et al. (2017)

Discussion
If all the extra population in 2036 (compared with 2021) are served with DEWATS, the minimum area for DEWATS related infrastructures and landscapes is around **41,034** m^2 (with lowest treated water quality), while the recommended area requirement is **82,385** m^2 (with best treated water quality). **Currently, the area of open space (28,019,700 m^2) in Campbelltown LGA can support the area required by DEWATS,** therefore it can be confirmed that **the DEWATS scheme with option A is completely feasible to implement in whole area of Campbelltown LGA.**

5.2 Spatial analysis

Layers overview

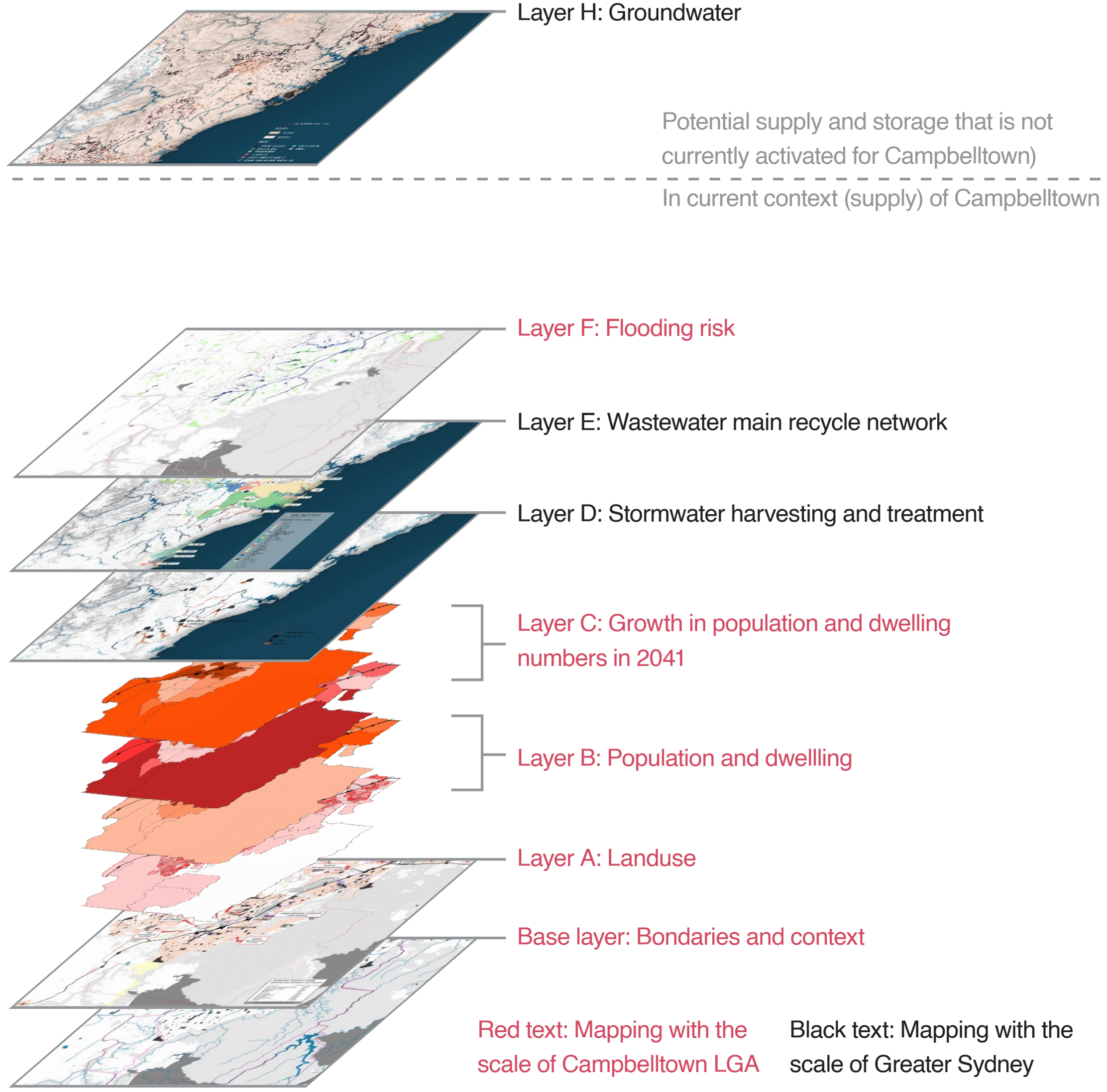


Fig 5.17 Layers of spatial anlysis

Elements overview

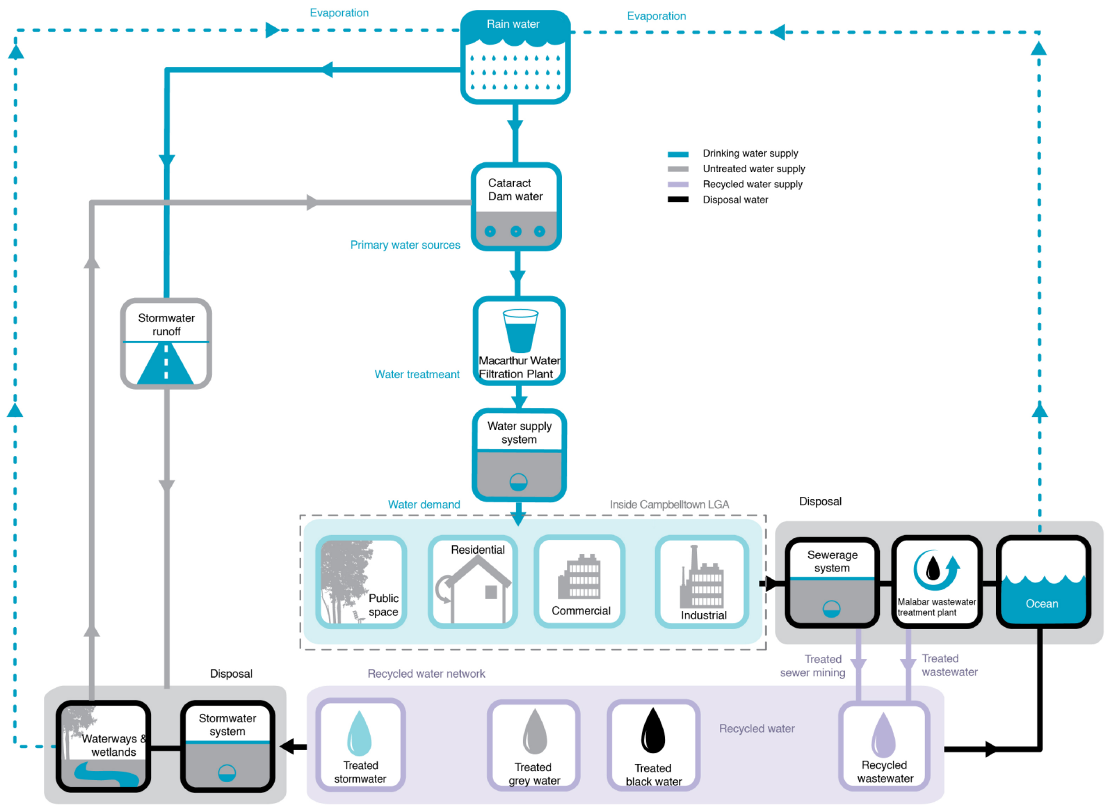


Fig 5.18 Overview of existing water network in Campbelltown

Bondaries and context

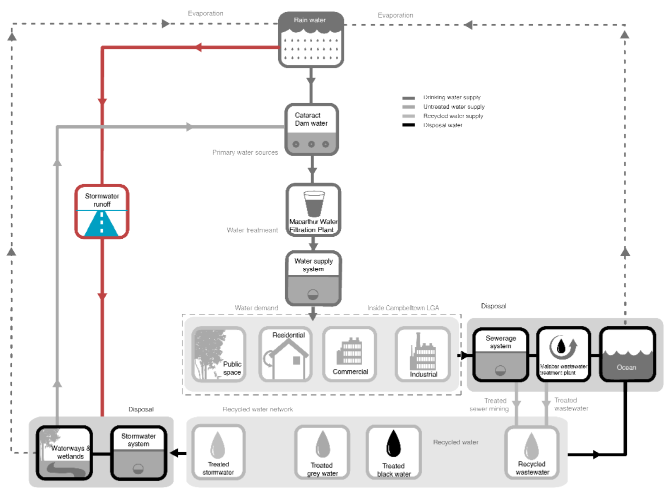


Fig 5.19 Highlight of the part in overview

Figure 5.20 shows the boundary of Campbelltown LGA and its catchment boundaries as well as the location of public open spaces.

Campbelltown LGA is made up of 3 sub-catchments that collect the stormwater and drain to three rivers: Nepan River, Georges River, and Woronora River that deliver water to the dams respectively. The three catchments are formed and defined by natural topography.

Relevance to design: Identifying the catchments helps to contextualise the problems and the opportunities to connect decentralised wastewater treatment with existing water network, and water flow simulation that are tailored to the local fabric.

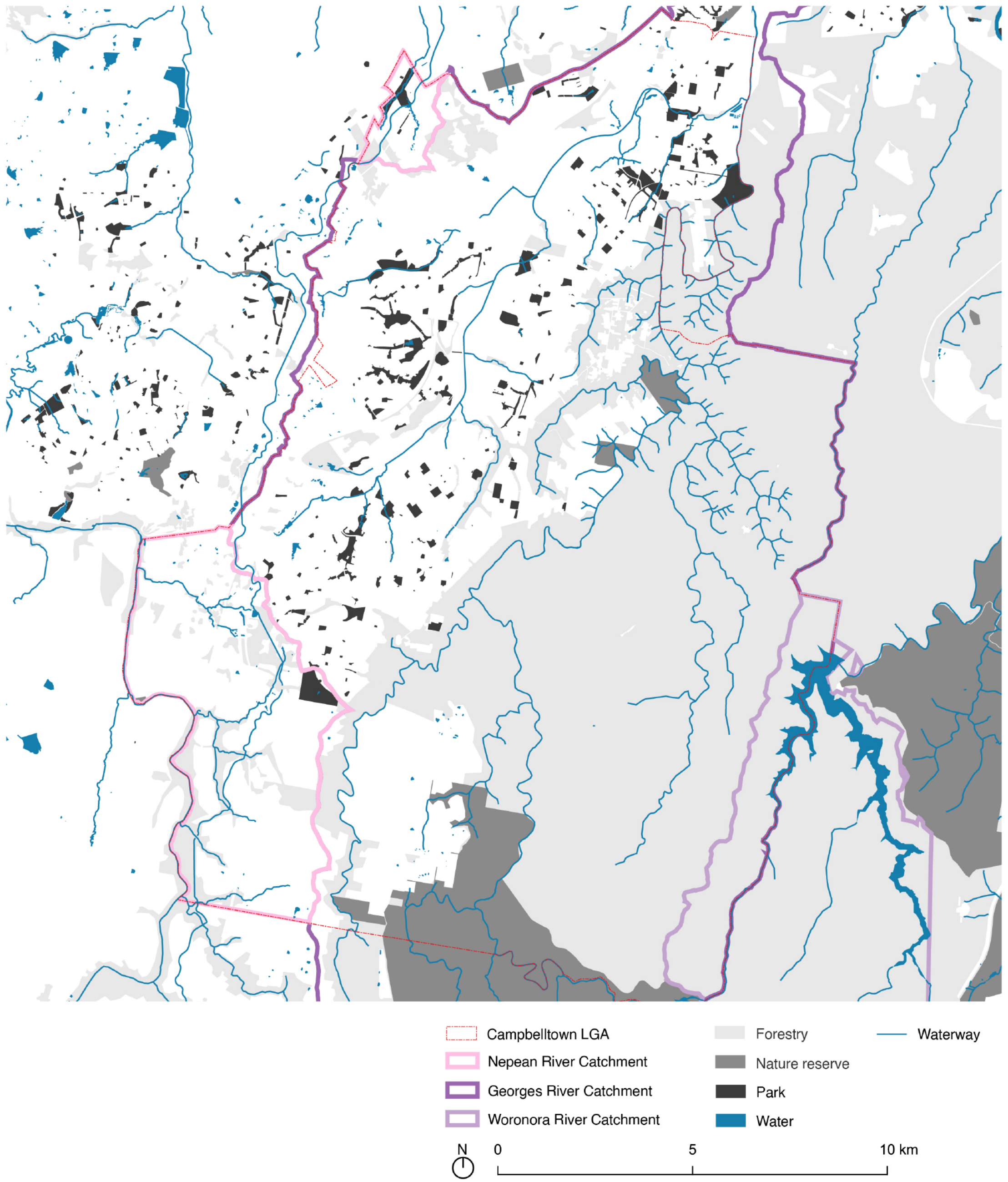


Fig 5.20 Map showing the boundaries and context

Land use

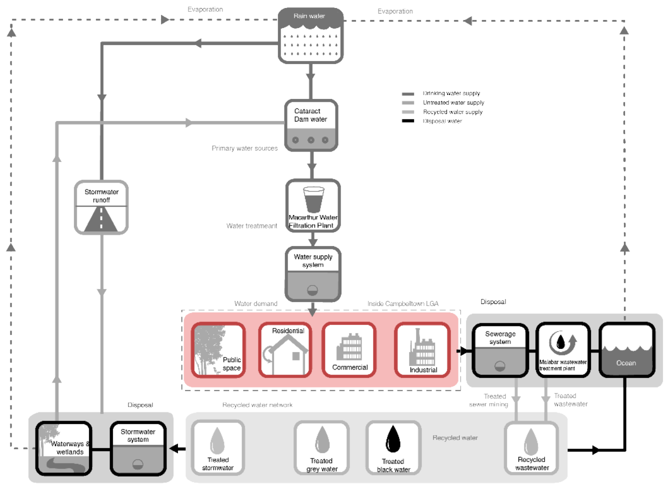


Fig 5.21 Highlight of the part in overview

Relevance to design: This layer of information shows the scale of different uses across the LGA. It helps analysing the current location and scale of residential area, and identifying the other area of purposes that might constraint the expansion of residential area and densification. Additionally, while the main focus is household water use, it is also helpful to basically understand the different water demand profile of other functions.

The Ground space index (GSI) mapping is also important for understanding the unbuilt area of each block/neighbourhood. This informaiton will be updated in the further study.

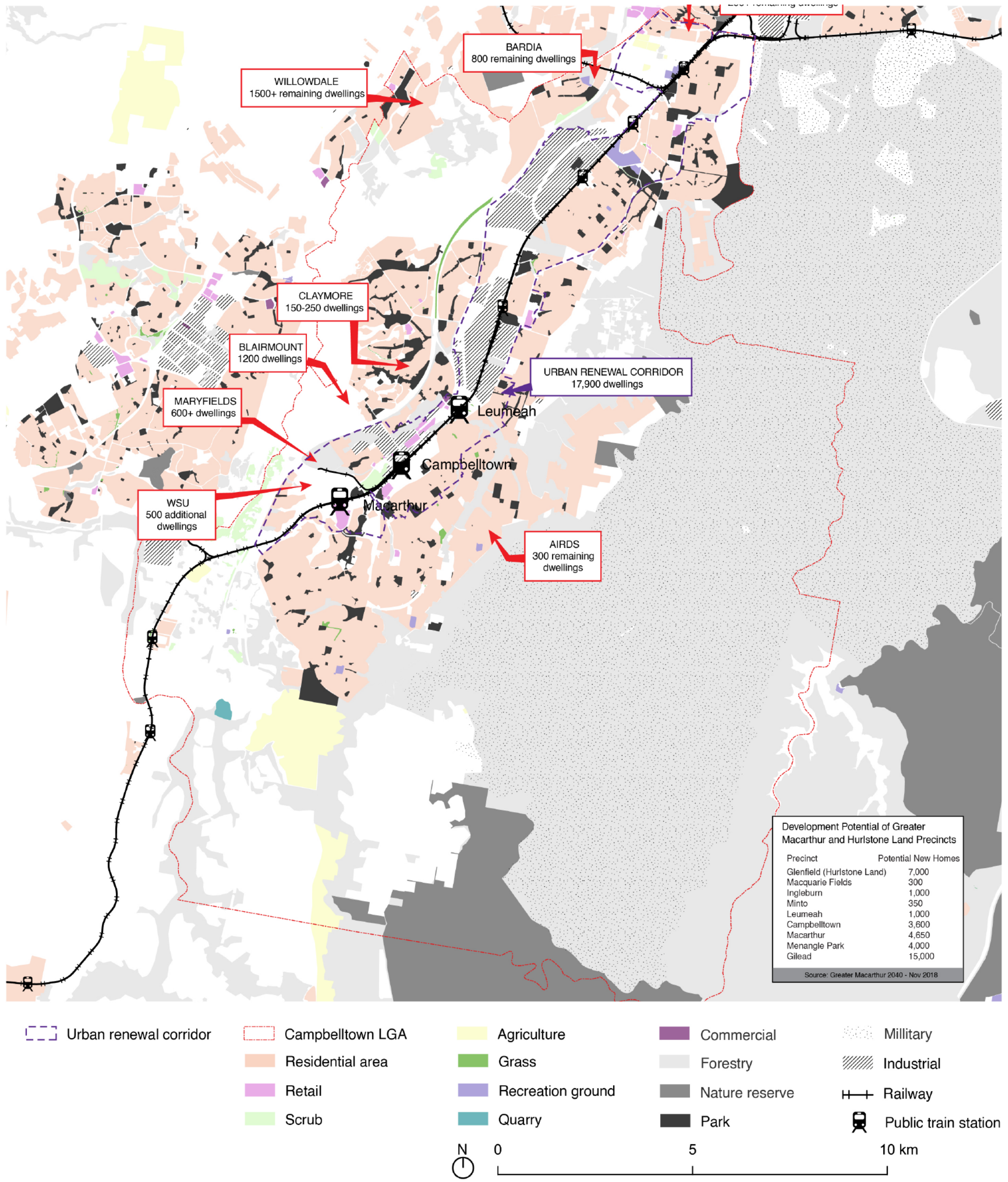


Fig 5.22 Map showing land use

Population density

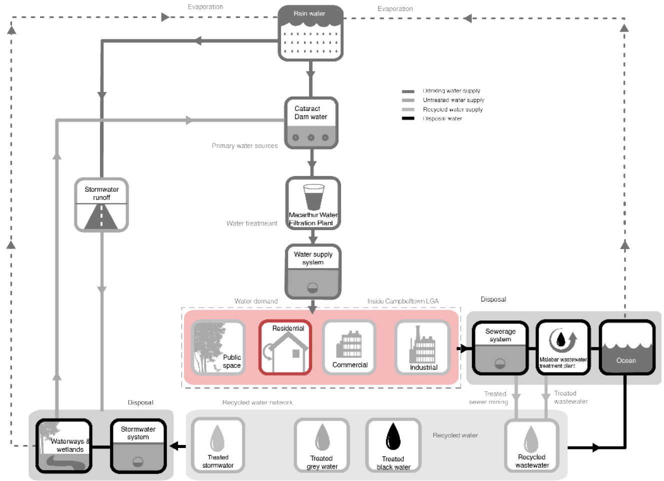


Fig 5.23 Highlight of the part in overview

Up to date, the highest population density and number of dwellings are projected close to the city centre and public transportation corridor, which is basically supported by the three core train station: Leumeah, Campbelltown and Macarthur. There is no dwelling in the eastern part within the forestry zone.

In 2041, the peripheral area especially the forestry area will accommodate most intensive population growth, indicating that part of the wild land will be exploited, people have to explore an urbanising way that has least negative impact on the ecological system.

Relevance to design: While the city centre is still a target area for accommodating population growth, it is highly possible that high-density dwellings will be more common in the area of growth corridor in 2041. While for the eastern part, most of the new dwellings might still be separate or medium density houses.

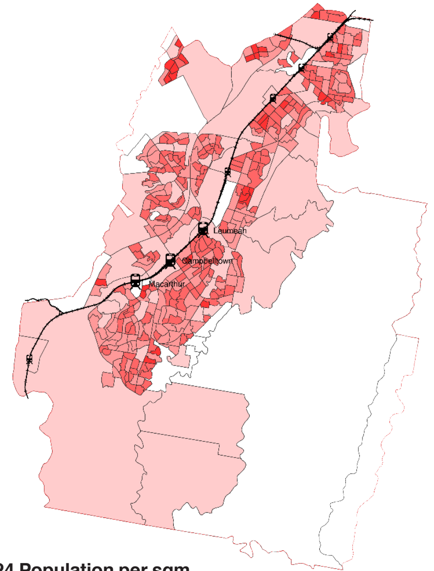


Fig 5.24 Population per sqm in 2021, data from idcommunity (n.d.)

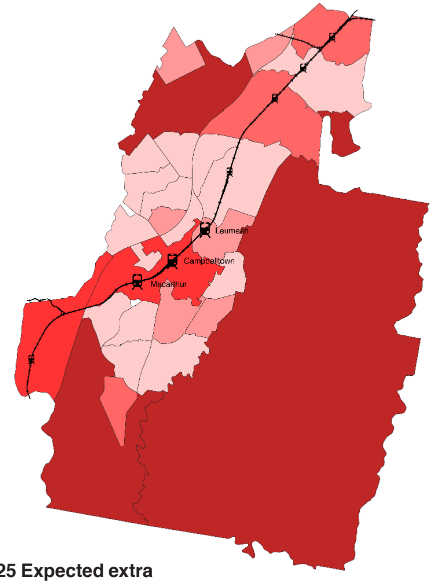


Fig 5.25 Expected extra population in 2041, data from idcommunity (n.d.)

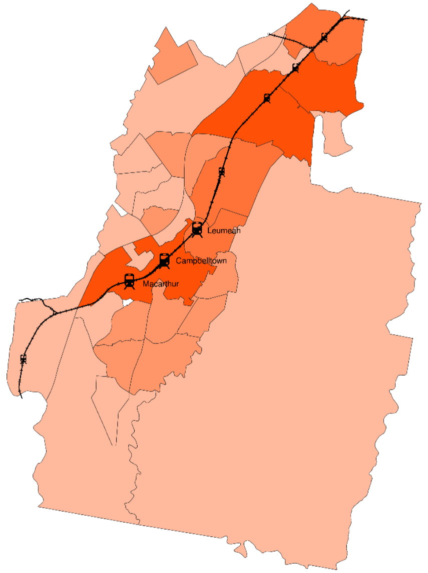


Fig 5.26 Dwelling numbers in 2021, data from idcommunity (n.d.)

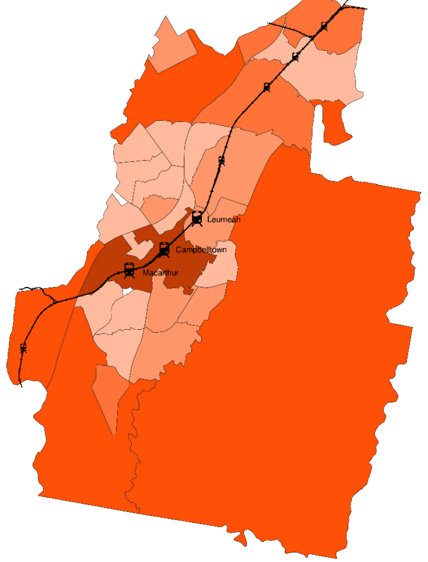


Fig 5.27 Expected extra dwellings in 2041, data from idcommunity (n.d.)

Flooding risk

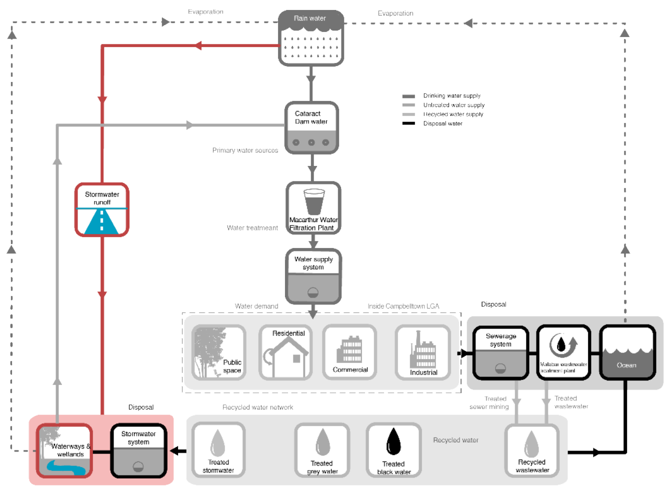


Fig 5.28 Highlight of the part in overview

Campbelltown LGA is prone to natural hazards and climate change, including localised flooding, bushfire and heat. Historically, the flooding happened mainly to the Bowbowing Creek and the surrounding area, although the creek is mostly dry thorughout the year.

Relevance to design: The flooding risk indicates that Bowbowing Creek may need dredging, improved connectivity with other water bodies and water-holding capacity, which should be considered for the other local waterbodies as well. The design of DE-WATS might be constraint by the flooding risk but can also become a medium for upgrading the waterways to improve its water-holding capacity, connectivity and channeling.

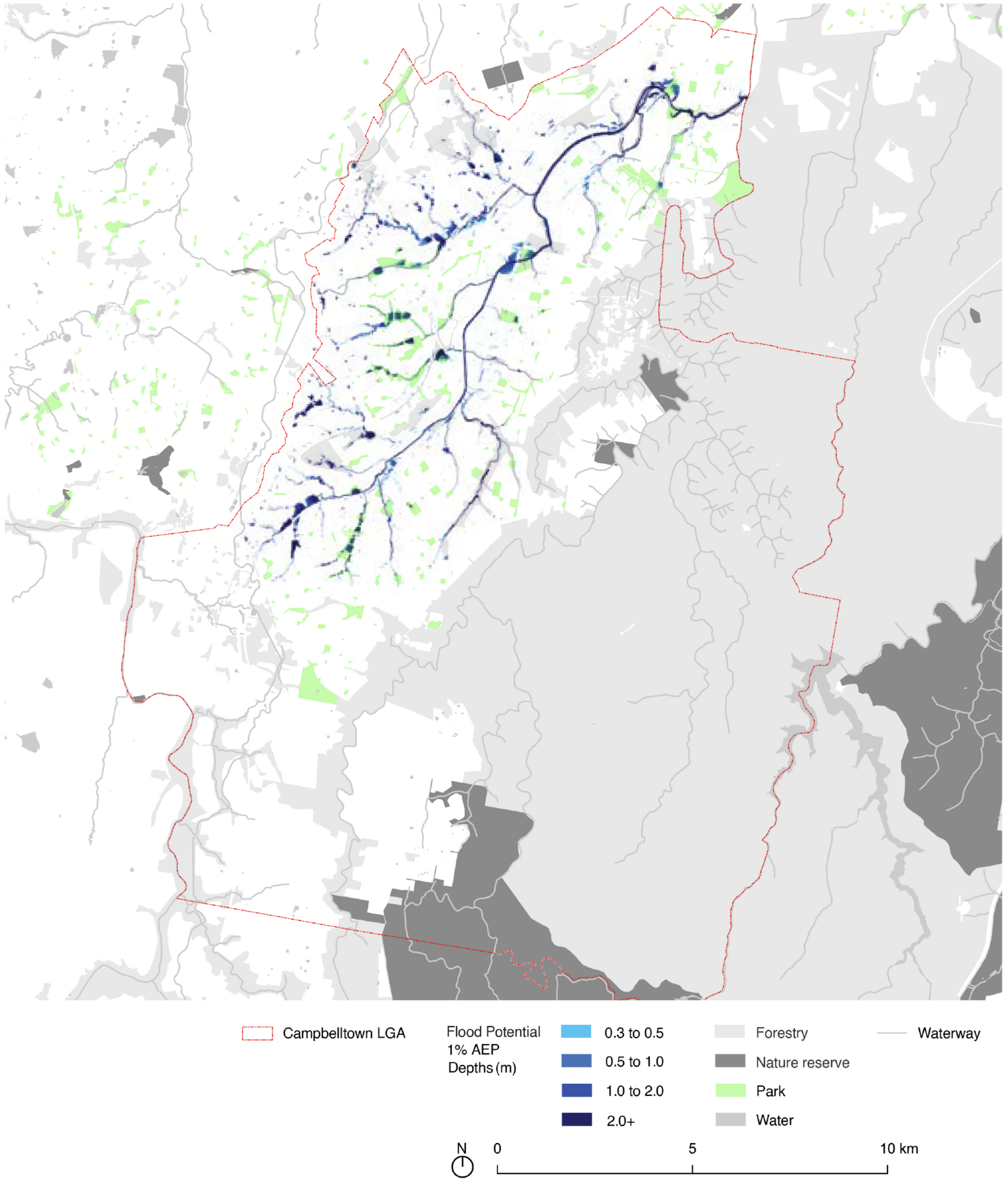


Fig 5.29 Map showing flooding risk

Water filtration of the Greater Sydney area and Campbelltown

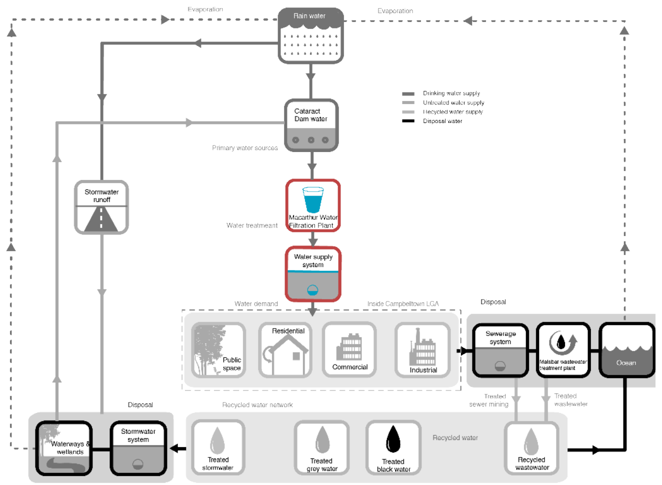


Fig 5.30 Highlight of the part in overview

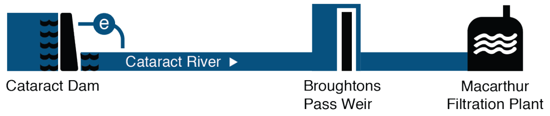


Fig 5.31 The route of harvested stormwater before treated

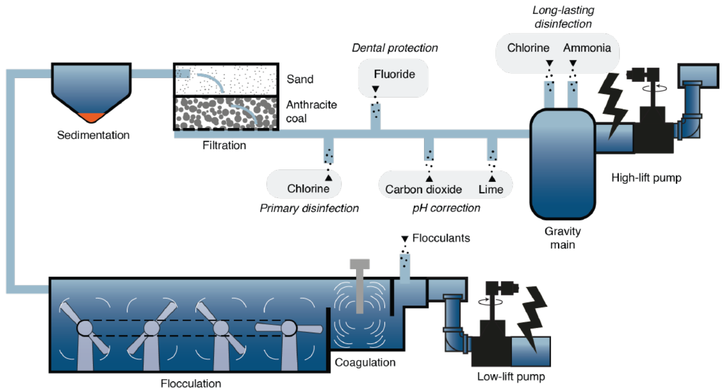


Fig 5.32 The route of harvested stormwater before treated

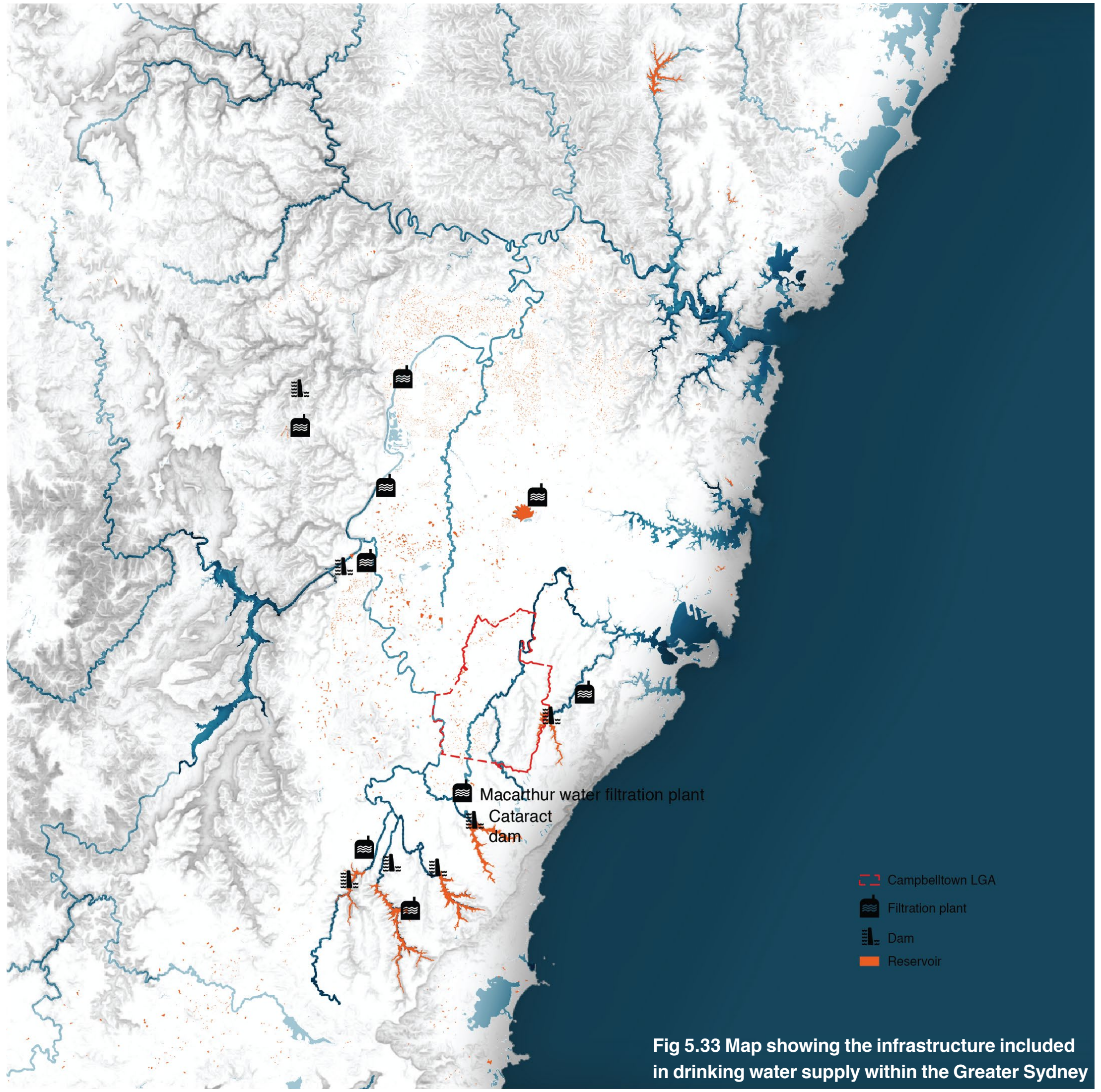


Fig 5.33 Map showing the infrastructure included in drinking water supply within the Greater Sydney

Wastewater treatment of the Greater Sydney area and Campbelltown

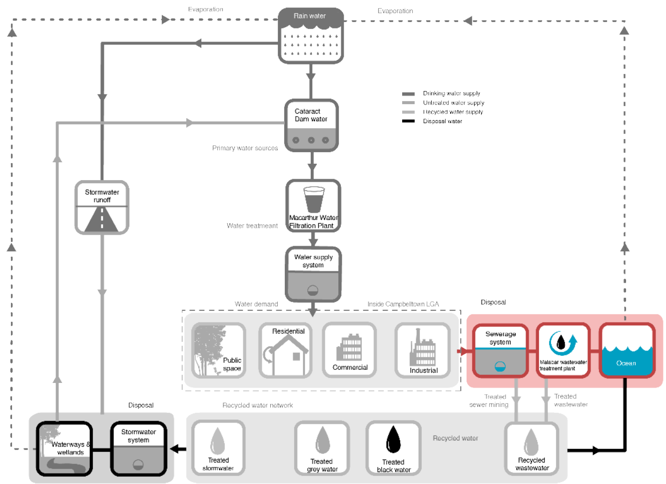


Fig 5.34 Highlight of the part in overview

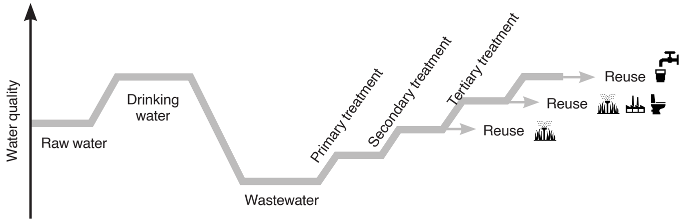


Fig 5.35 Treatment levels with water quality in traditional process, adapted from S. Eslamian (2016)

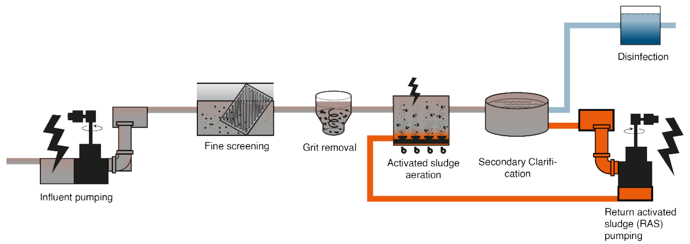


Fig 5.36 Process of wastewater treatment in Malabar Water Filtration Plant

Over 1.3 billion litres of wastewater is treated by the water resource recovery facilities in Greater Sydney everyday. Each facility treats the water with different process and treatment level before the water is reused or discharged to waterways. There are three levels of treatment, which is similar to the DEWATS the higher the level is, the more purposes the water is prepared for reused for. The level of treatment depends on three factors: location of the facility, the place where the water is discharged or reused, the quality of wastewater (Sydney Water, n.d.).

The wastewater in Campbelltown is treated in Malabar Wastewater Treatment Plant, which only provides primary treatment. Most treated water is outlet to the deepwater ocean.

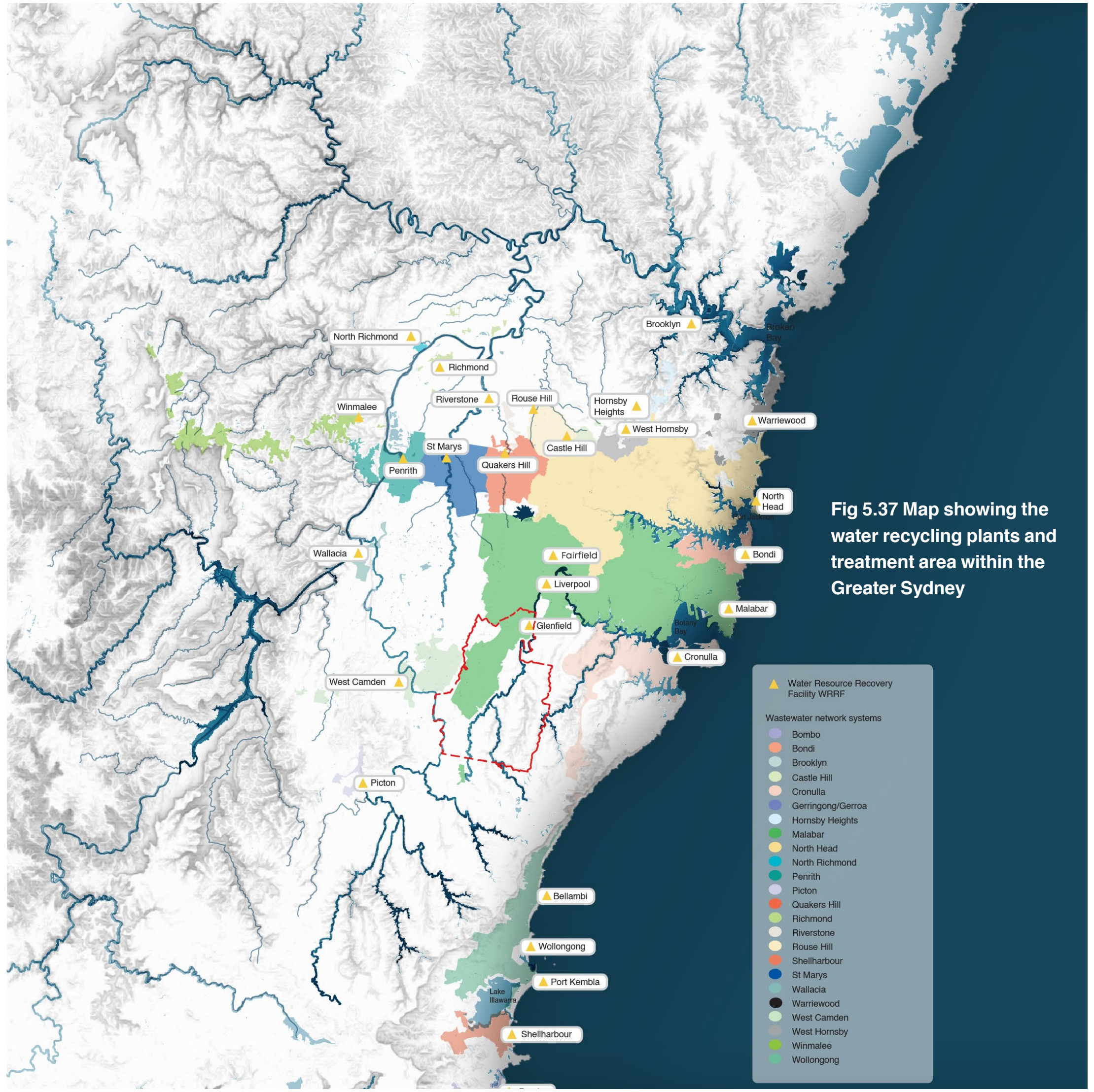


Fig 5.37 Map showing the water recycling plants and treatment area within the Greater Sydney

Groundwater

Fig 5.38 shows that upper and middle aquifers exist in the Campbelltown LGA, and numerous bores exist localised for monitoring and bores for other purposes in Greater Sydney. The aquifer is relevant to this study as a potential water source and storage area for recycled wastewater.

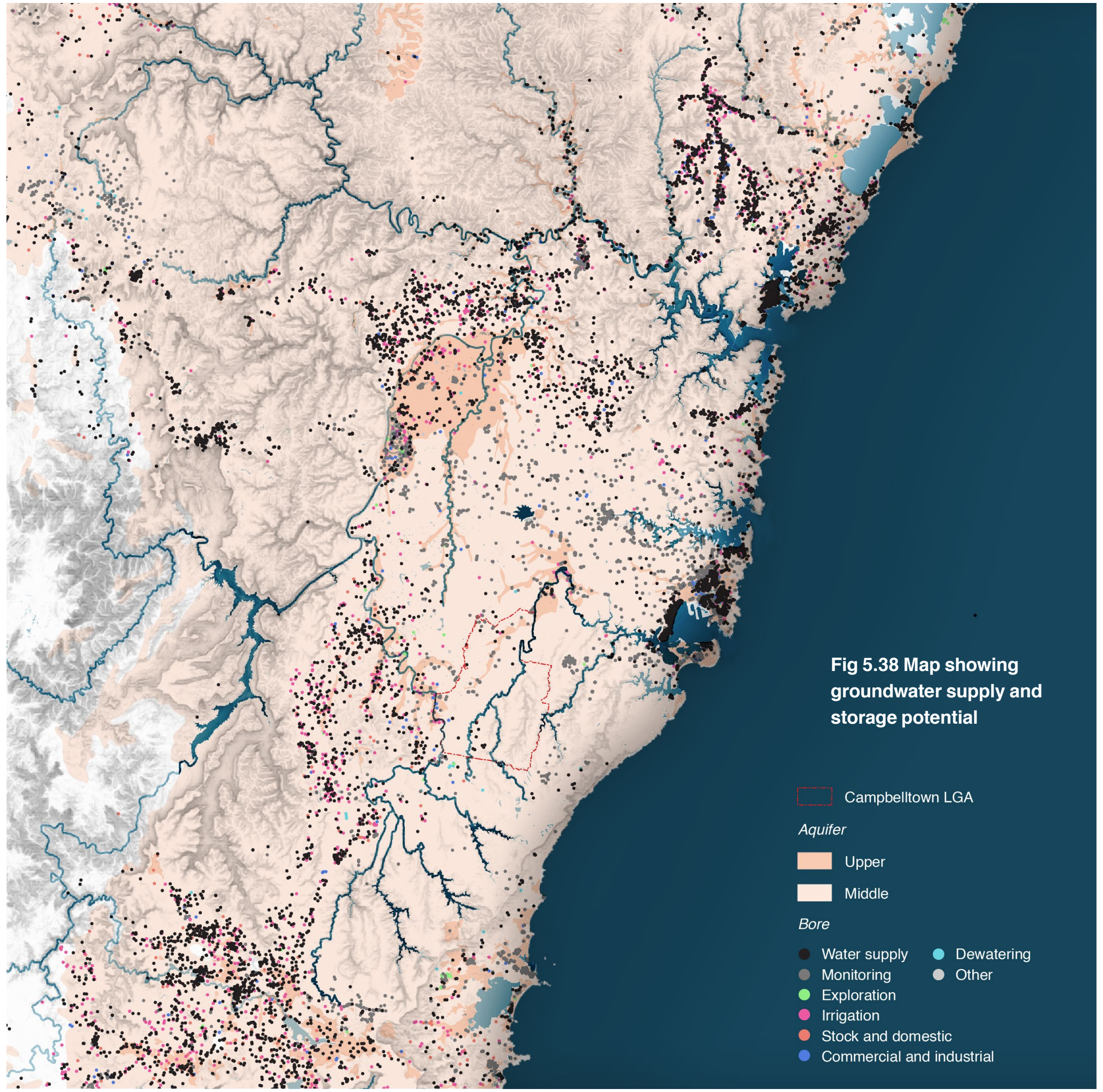


Fig 5.38 Map showing groundwater supply and storage potential

6. Overview of the experiment site and design frame-work

6.1 Conceptual framework

Current situation

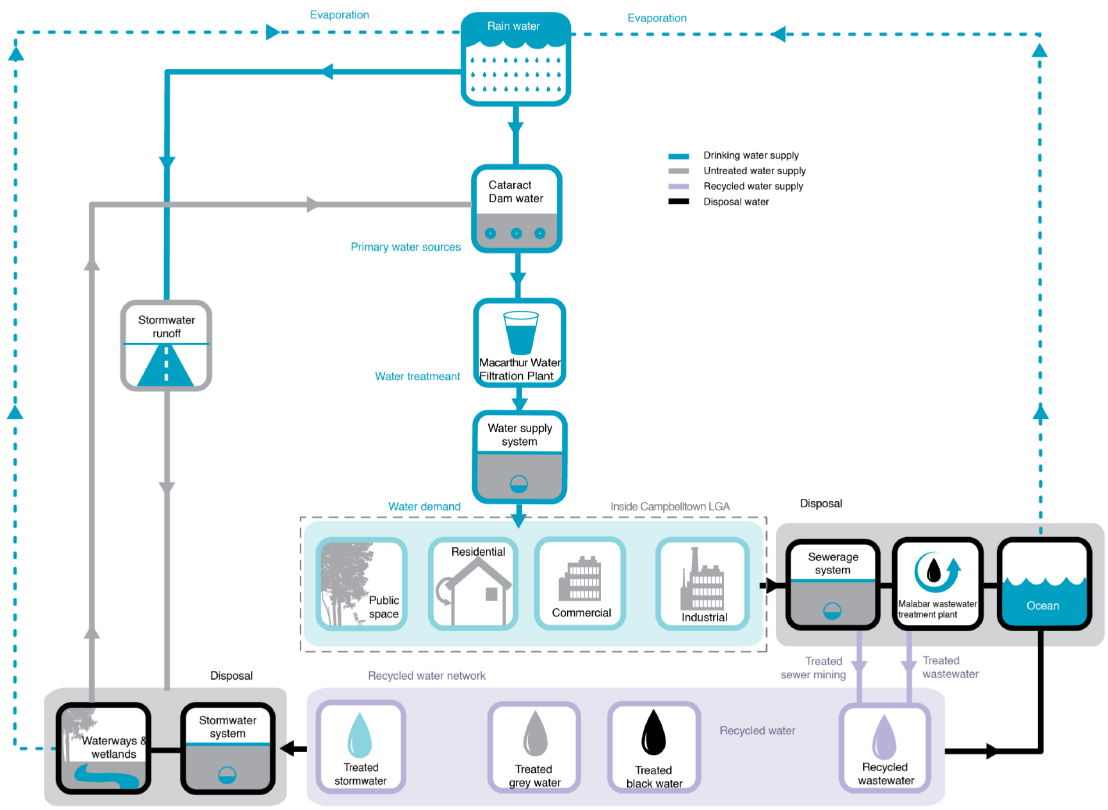


Fig 6.1 Overview of existing water network in Campbelltown

Proposition (potential development)

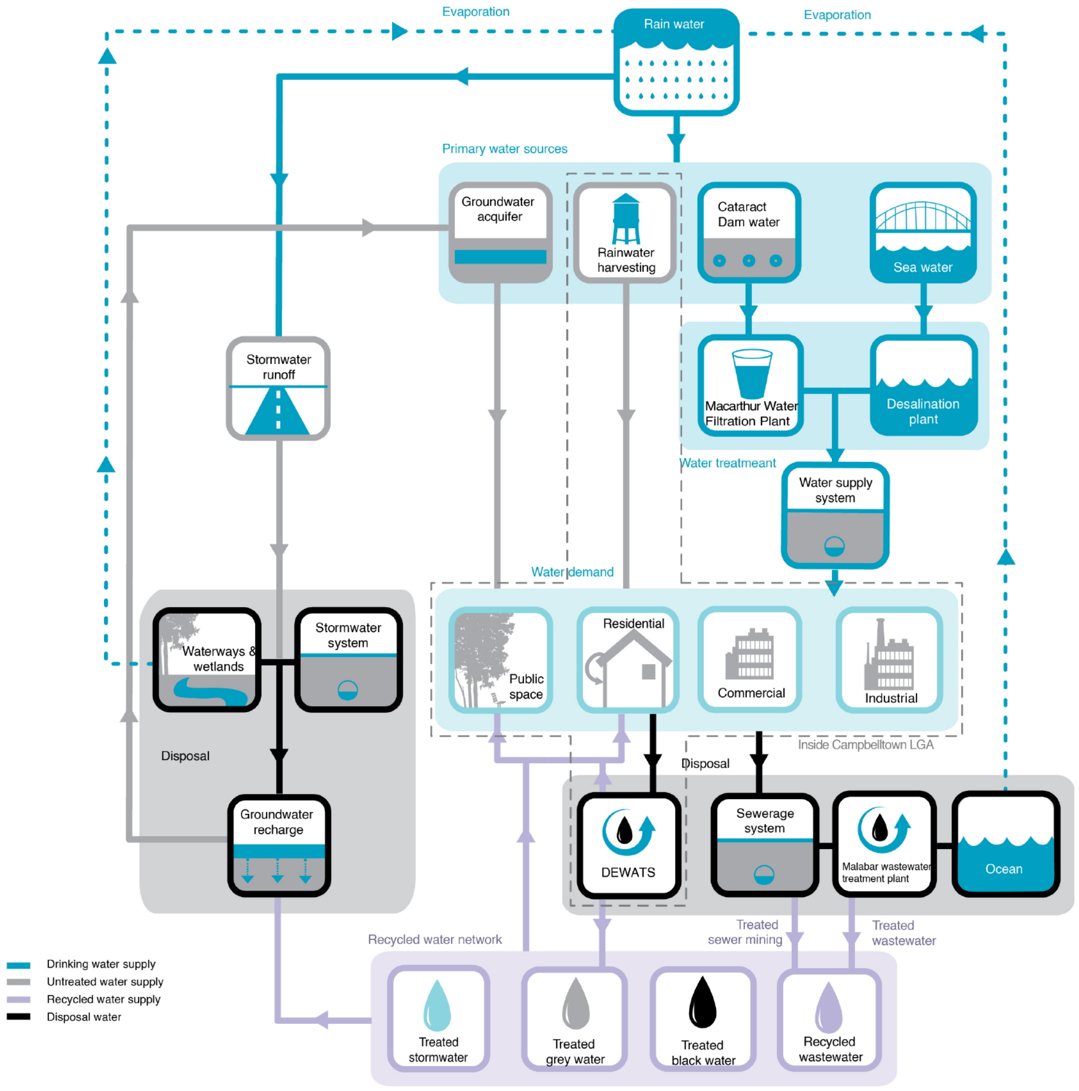


Fig 6.2 Overview of proposed water network in Campbelltown

Intervenions highlight

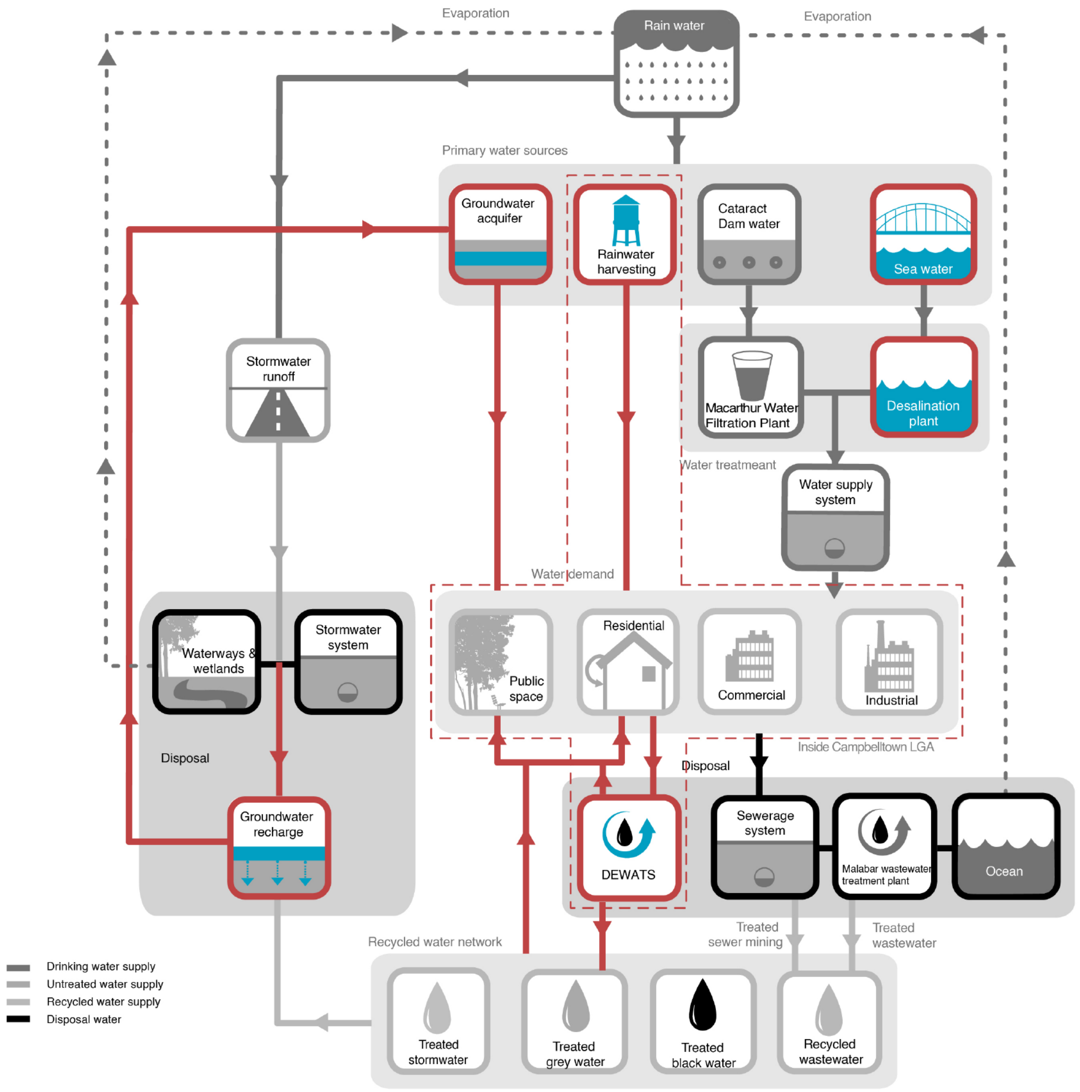
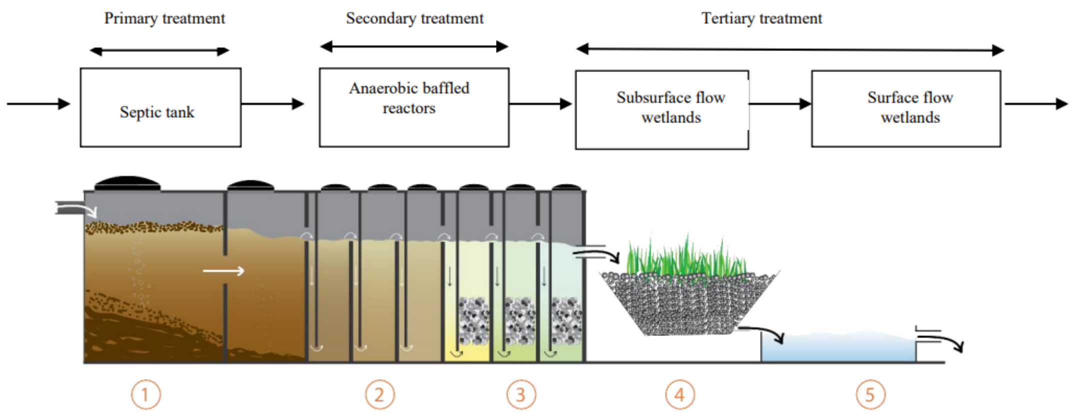


Fig 6.3 Highlight of design elements

This framework is an overview of possible interventions that can help Sydney and Campbelltown LGA to overcome potential water scarcity, which is drafted for long-term and all-rounded preparation, this project does not cover all of the interventions in the framework. The central scheme to be discussed in this thesis is “DEWATS”, which is explored for the city centres Leumeah, Campbelltown and Macarthur centres shown in the next pages. The other interventions are more related to the larger scale area (Greater Sydney) and are regarded as back-up solutions to solve the drinking water shortage if required. The aquifers might be explored as a storage media for the treated water by DEWATS in the later stage, or briefly discussed about opportunities to be connected with DEWATS.

6.2 Technical framework

Components of DEWATS



Section 1	Section 2	Section 3	Section 4	Section 5
Primary treatment	Secondary treatment		Tertiary treatment	Post-treatment
Septic tank	Baffled reactor	Anaerobic filter	Constructed wetland	Polishing pond/ Surface flow wetland
Sedimentation tank stabilising settled sludge by anaerobic digestion Dissolved and suspended matter leave tank untreated	Anaerobic degradation of suspended and dissolved solids 2–5 chambers depending of treatment required	Water passes through filter media Enhance digestion of organic matter	Open shallow basin filled with gravel/pebbles to support growth of plant/reeds with shallow roots Reduces organic contents and acts as filter mechanism	Open shallow basin for removal of stabilised or inactive suspended substances Exposure to UV rays
Removal of COD 20-25%, BOD 15-20%, TSS 50-55%	Removal of COD 25-30%, BOD 30-35%, TSS 10-15%	Removal of COD 20-25%, BOD 15-20%, TSS 15-20%	Removal of COD 15-20%, BOD 20-25%, TSS 5-10%	Removes odour and pathogens

Fig 6.4 Illustration of the typical modules in DEWATS and their performance (Harvey et al., 2017)

COD: Chemical oxygen demand

BOD: Biochemical oxygen demand

TSS: Total suspended solids

Referenced dimension of components in plan

All the images shown in this part are illustrations of dimensions or simply to give an overview of how the components might look like in volume/section/plan, the detailed structures of those components in the images are not the focus of this chapter.

The ratio and view of the components in plan might also be changed for adding spatial quality in later design, but currently the ratios are kept to calculate the area requirement of each component. The ratios of each component are also considered together with the minimum area requirement (calculated based on the population increase).

Primary and secondary treatment

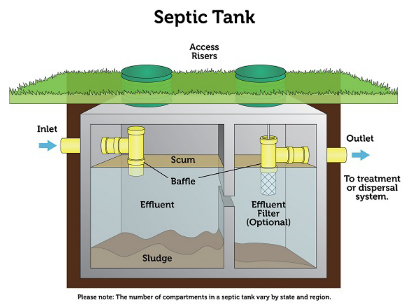


Fig 6.5 Structure of septic tank (US EPA, 2018)

Septic tank
Length : Width ≈ 3:1

"The septic tank should be rectangular in shape, with length and width ratio **3:1**. All chambers should have equal depth; however, the depth of the first chamber can be deeper since most of the sludge accumulates in this zone (Harvey et al., 2017)."

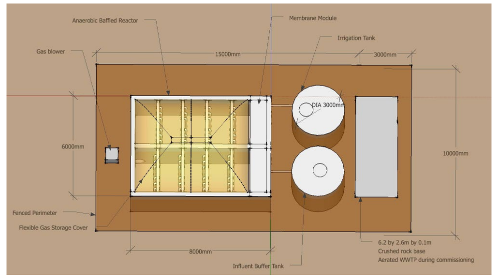


Fig 6.6 Structure of ABR (Mason, 2021)

Anaerobic Baffled Reactor (ABR)
Length : Width ≈ 4:3

"Anaerobic Baffled Reactor. This is a rectangular concrete below ground tank 3 m deep, **6 m wide and 8 m long**. This structure is formed in place and uses permanent formwork (Mason, 2021)."

The image with ABR shows the integrated system of an mABR system design in NSW, the only dimension ratio that is referenced for Campbelltown's DEWATS design is that of the "Anaerobic Baffled Reactor (ABR)" as annotated in the image, which is used for the secondary treatment. The other components shown in the image are not related to this thesis.

Tertiary treatment

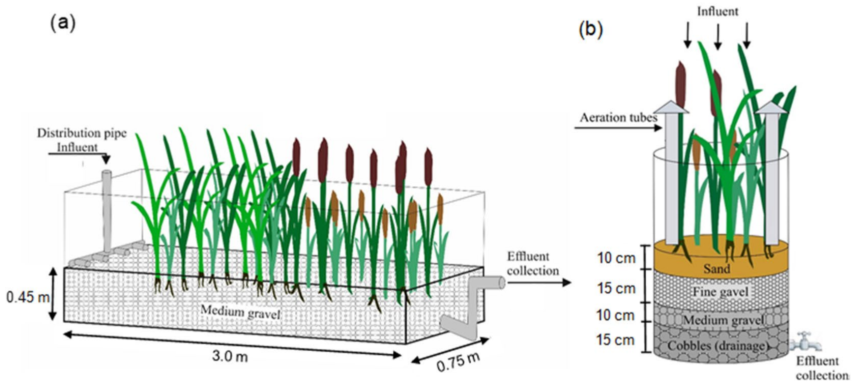


Fig 6.7 Structure of horizontal and vertical flow sub-surface wetland

Horizontal Sub-surface Flow Wetland (HF)
Length : Width ≈ 4:1

Vertical Sub-surface Flow Wetland (VF)
Length : Width ≈ 1:1

"Each HSF-CW was a rectangular tank **3 m long, 0.75 wide** and 1 m deep (Gikas et al., 2021)."

"The VF-CWs pilot-scale units were cylindrical plastic tanks with **a diameter of 0.82 m** and a height of 1.5 m (Gikas et al., 2021)."

The dimensions of HF and VF are not restricted, but according to their definitions and functions, the listed ratios are reasonable to be used in the design. Although the VF shown in the image is rounded in plan, but it can also be safely converted to be squared in plan for easier arrangement.

Post treatment

As surface flow wetlands can be designed with more variations based on the need to fit local territory, there is no dimension requirement for this stage of treatment, which allows possibilities to explore participating local water networks into post treatment.

More detailed definnition about the constructed wetlands (VF, HF, SF) in page 52-53: "Constructed wetlands in DEWATS"

6.3 Site overview

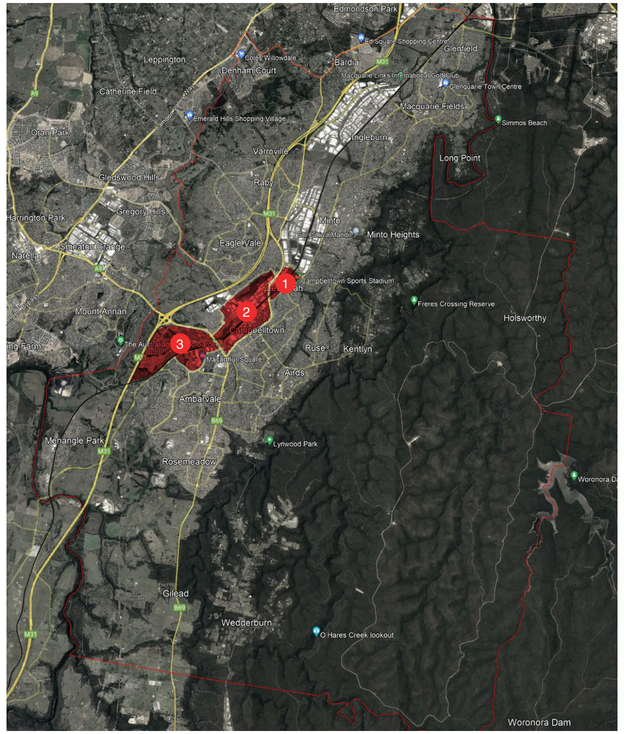


Fig 6.8 Map showing the three sites for detailed design, adapted from Google Earth (2023)

Detailed scenario designs are only done for Leumeah centre and Campbelltown centre due to the limitation of time. However, the Macarthur centre is also included in *6.4 Design strategy* (page 99-104) that points out the development direction for the three sites as a whole grounded on the local surface water network. The scenario design for Macarthur centre can also follow the methods applied in the design for the other two sites.

Reason to choose these sites

- The sites are in the urban renewal corridor and are within the focal point for population growth and dwelling increase, each of the site demands different housing composition and has emphasis on different housing type, which is closely related to the focus of the thesis.
- The sites are within the Campbelltown city centre, which is prioritised to develop by the government. The data and provision for these areas are more complete, updated and open to the public.
- Bowbowing Creek (the main water body in city centre) runs through the areas, creating opportunities to connect DEWATS with the existing water network.
- The sites all have mix-use high density dwellings, which places extra challenge to the design.

Fig 6.9 Map showing the three sites for detailed design, adapted from Google Earth (2023)

6.4 Design strategy

The values of the wetlands in the scheme

Functional: Wastewater treatment plant
Ecological: Providing habitat/shelter for wild animals
Leisure/Educational: (depending on the charater and zoning of the location): A pleasant place for stay and stroll, or promoting the concept and knowledge of wastewater treatment.

In order to maximise the performance of the wetlands in those values, it is ideal to connect them spatially with existing water bodies such as the streams to expend the wetland area for treatment and purify the surface water at the same time, while for the individual target sites, different characters can be applied for the wetlands.

Therefore, the scheme will be explored with both seperate parts and connected parts: for both three sites, vertical flow and horizontal subsurface flow wetlands can be remained on-site with the various level of centralisation, while for the surface flow wetlands (the final stage of treatment), the existing surface water networks can become both water holder, carrier and “treatment plant”. In other words, the treatment by vertical flow and horizontal subsurface flow wetlands are designed in relatively **decentralised** ways including schemes of different levels of centralisation, because these two steps deserve an exploration of how they work in different scale of units and they contribute more to the **functional** value (wastewater treatment). While for surface flow, it has greater potential for **ecological** and **leisure** values as it is less restricted by dimensional ratios and filtration media, it also displays a better combination of water and plants visually, therefore the surface flow wetlands can be **overall centralised** located. The detailed strategies are differently designed based on the availability of surface water flow and collective open space.

Functional value

- VF and HF wetlands are the main roles to remove the impurities in the water
- SF wetlands are considered as extra purification and water quality stablisation area that target the treatment at pathogens and nutrients, the detailed functional zones including:
  Pathogen removal
  Nutrient removal
  Aeration and bio-purification
  Water retaining and comprehensive purification
  Water quality stablisation and control

In addition, to ensure the safety for water re-use, there will be small artificial area for final filtration, disinfection and clean water impoundment after the water is treated by the wetlands.

Leisure & Educational value

The main design element that contributes to this value will be the spatial design that shows how the constructed wetlands play different roles in the urban landscape and public space. Additionally, a promenade network will be created along Bowbowing Creek and selected VF+HF points with demonstrative purposes, especially for Campbelltown city centre.

Ecological value (to be updated)

Plants selection for each treatment stage, including the catogories of:
Free floating
Rooted floating
Emergent
Submerged
Shrub and trees
Discusion of their main functions in treatment and the applicability for the selected sites.

Functional design of the integrated wetland system

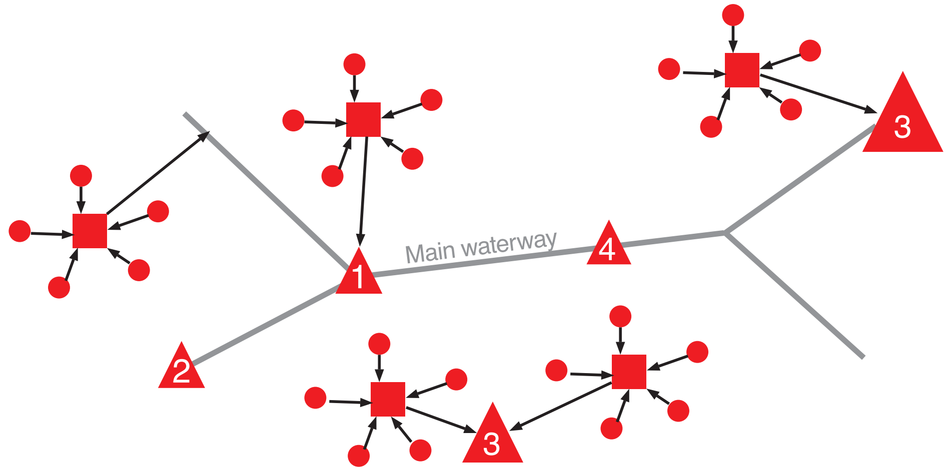


Fig 6.10 Diagram showing the basic design logic of the three sites as a whole

Lowest spatial impact

Highest spatial impact

Stage 1: Primary + Secondary + Tertiary treatment

- Septic tank (underground) + ABR (underground)
- Pipeline or direct outlet
- Potential pipeline or direct outlet (more research required)
- Vertical flow wetlands + Horizontal flow wetlands with different levels of centralisation

Stage 2: Post treatment

1. Joints / Key points of the existing surface water network
2. Adding value to the existing ponds
3. New constructed surface flow wetland on-site
4. Revival and redesign of the surface water stream

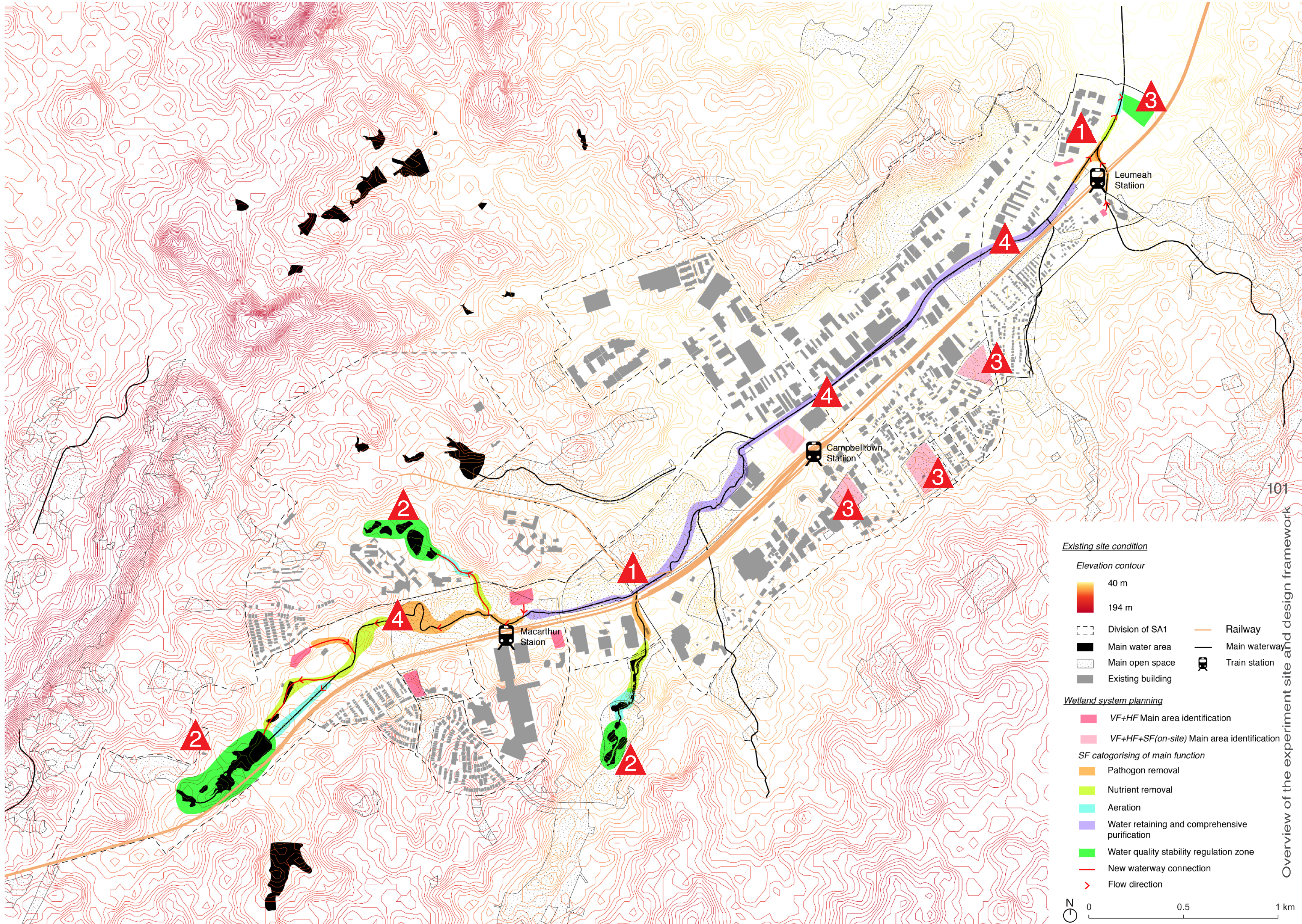


Fig 6.11 Diagram showing the application of the strategy on site

Main direction of SF development for each target site and for the overall area

Overall area: Redesign the Bowbowing Creek to equip it with surface flow wetlands related character.
Leumeah centre: Modify the joint of the creeks and enlarge it to become surface flow wetlands.
Campbelltown centre: Surface flow treated on-site decentralised (although the Fishers Ghost Creek connects the northern and southern parts of the site across the railway, **the creek is hard to be further developed because there is a large part underground**, therefore it is hard for this site to have centralised surface flow treatment by modifying existing water network, but for the high densification scenario, the northern part of the site can still redevelop the surface waterways to equip surface flow treatment functions.
Macarthur centre: Directing to existing water bodies (ponds in the parks), modify the water bodies to become SF.

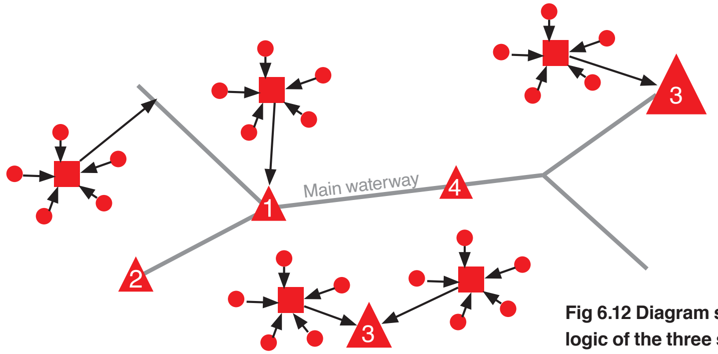


Fig 6.12 Diagram showing the basic desig logic of the three sites as a whole

1 Joints / Key points of the existing surface water network

2 Adding value to the existing ponds

3 New constructed surface flow wetlands on-site

4 Revival and redesign of the surface water stream

Macarthur: 1 + 2 + 4

Campbelltown: 3 + 4

Leumeah: 1 + 3 + 4

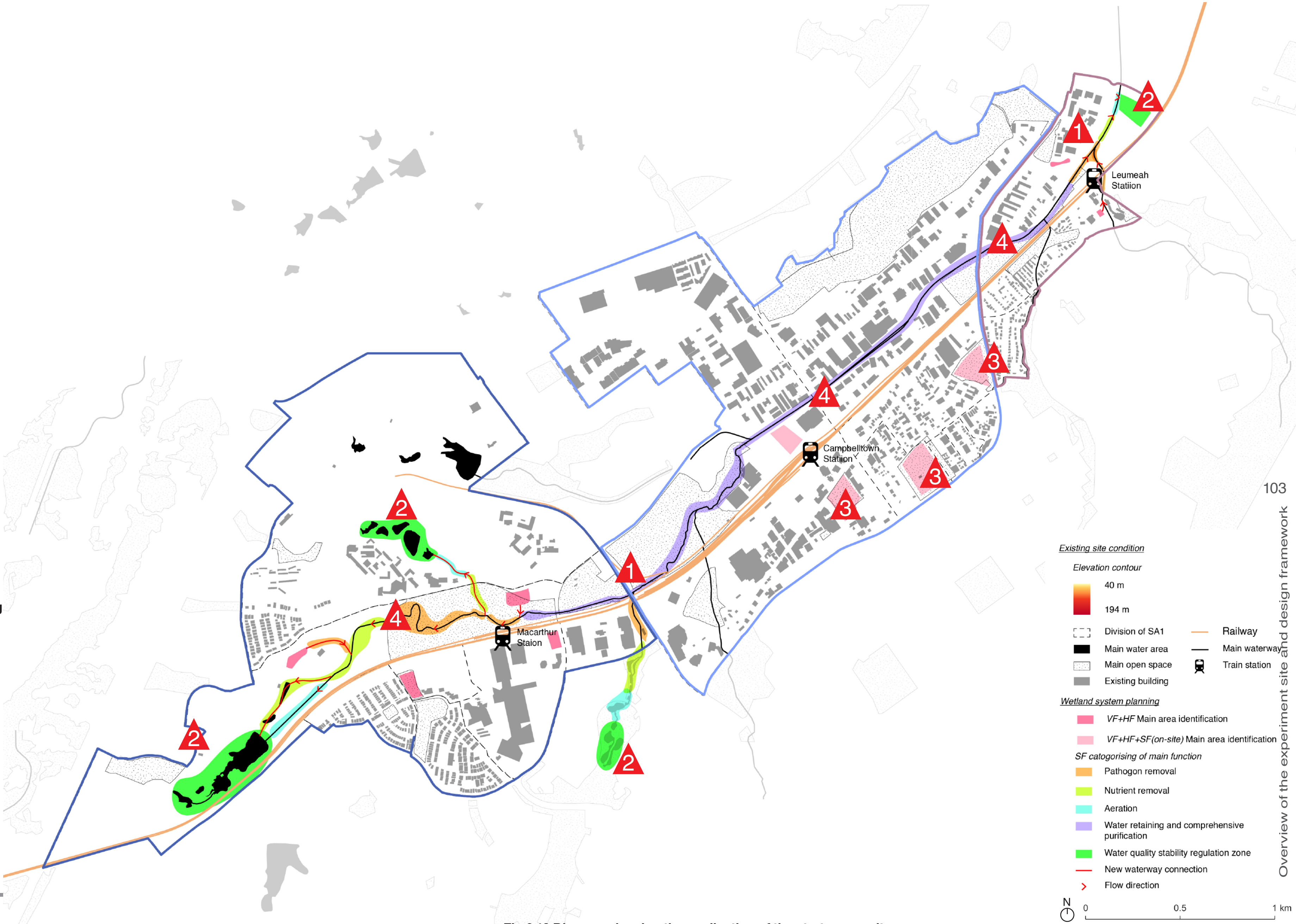


Fig 6.13 Diagram showing the application of the strategy on site

6.5 Division of the site and residential development

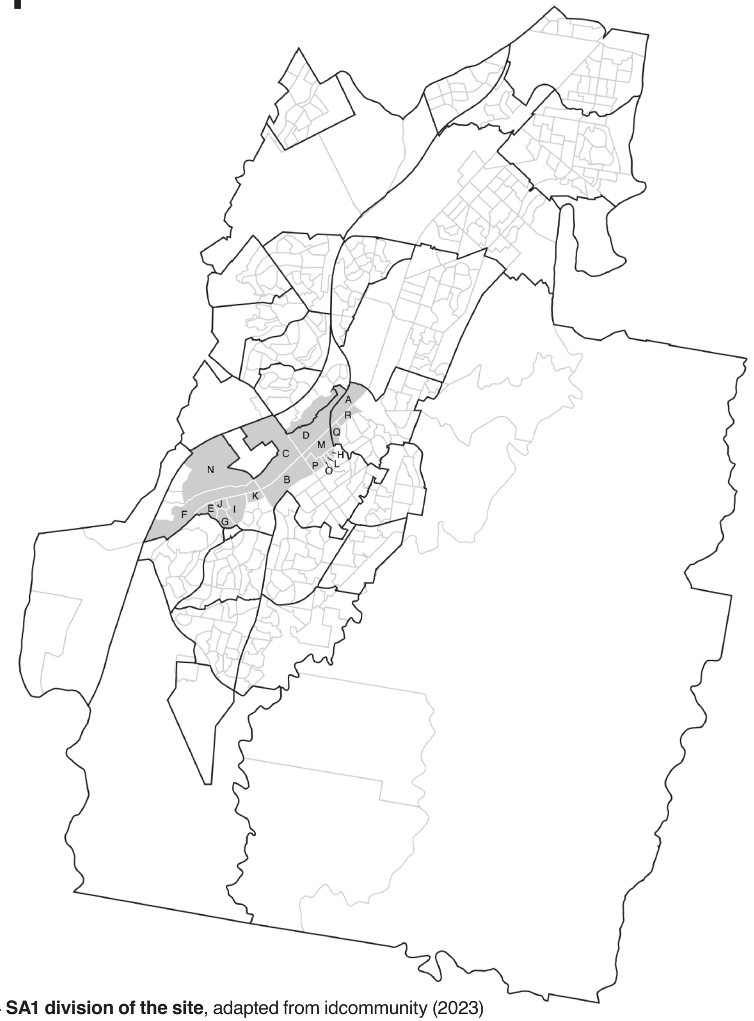


Fig 6.14 SA1 division of the site, adapted from idcommunity (2023)

The selected corridor for design can be divided in relative SA1s (Statistical Area Level 1), the census of residential populations and dwelling types are conducted for each of the SA1 for the convenience of further calculation. Some of the SA1s are not fully included in the target design area, such as C, D, F, N, Q. The statistics for these areas are re-estimated respectively.

Fig 6.15 SA1 division of the site and basic housing situation, adapted from idcommunity (2023)

6.6 Site condition

Open green space in Leumeah Centre

It is clear that most of the collective green area in Leumeah suburb is underdeveloped or neglected in management. Some part of the reserves are currently unfavourable for public entrance and the skatepark is seemingly isolated with the surroundings, but **the large amount of area creates potential to implement nature-based interventions.**

The place accommodates two joints of waterways: Bowbowing Creek with Smmith Creek (northern located) and Bowbowing Creek with Leumeah Creek (southern located). The joints are promising to be developed with functional landscape.

Fig 6.16 **Map and photos showing the open space in Leumeah centre**, adapted from Google Earth (2023)

Buildings in Leumeah Centre

Currently, all the residential buildings are located in the southern part of railway, with mostly separate houses (low-density) and semi-detached houses (medium-density), some of them are out-dated and deserves rennovated. High-rise apartments are located adjacent to the train station, where there is large area without property, which is targeted as new high density development area according to the vision from the government.

Located in the northern part to the railway are shops for industrial, repair and construction use, including tool-renting shops, furniture shops and car repairs. Buildings in this part can be potentially developed as mixed-use with retails on the ground and lower floors and dwellings on upper floors to support densification.

Fig 6.17 Map and photos showing the buildings in Leumeah centre, adapted from Google Earth (2023)

Open green space in Campbelltown Centre

Compared to that in Leumeah centre, the green space in Campbelltown centre is more diversified in quality and development, they can be categorised in three as followings:

Parks already developed in layout - Koshigaya Park: a park named after Campbelltown's sister city in Japan, which is also dedicated to displaying Aboriginal culture (Campbelltown City Council, 2023), and Mawson Park.

Public undeveloped open space - the Campbelltown Showground and the open space next to Campbelltown Rd, these space are often used to hold outdoor events, and are also available for development.

Undeveloped open space that is not accessible for public - the area next to Farrow Rd with Bowbowing creek goes across is currently unoccupied and is not prepared for public visit. However, it has larger collective area and has more existing vegetation.

Fig 6.18 Map and photos showing the open space in Campbelltown centre, adapted from Google Earth (2023)

Buildings in Campbelltown Centre

Around the Campbelltown station, most of the buildings are commercial or retail, some apartments can be seen in the corners in the southern part (divided by railway) of the Campbelltown.

The buildings are mostly low-medium rise with single function even in the busiest area (around Queen St), where there are still empty space that can be developed, indicating that multi-functional buildings can be developed here by redesigning existing low-rise buildings and new construction on available lands. Besides, there are large area used as car parking in several spots, if that can be transfered underground, more potentials can be created for extra dwellings in the city centre.

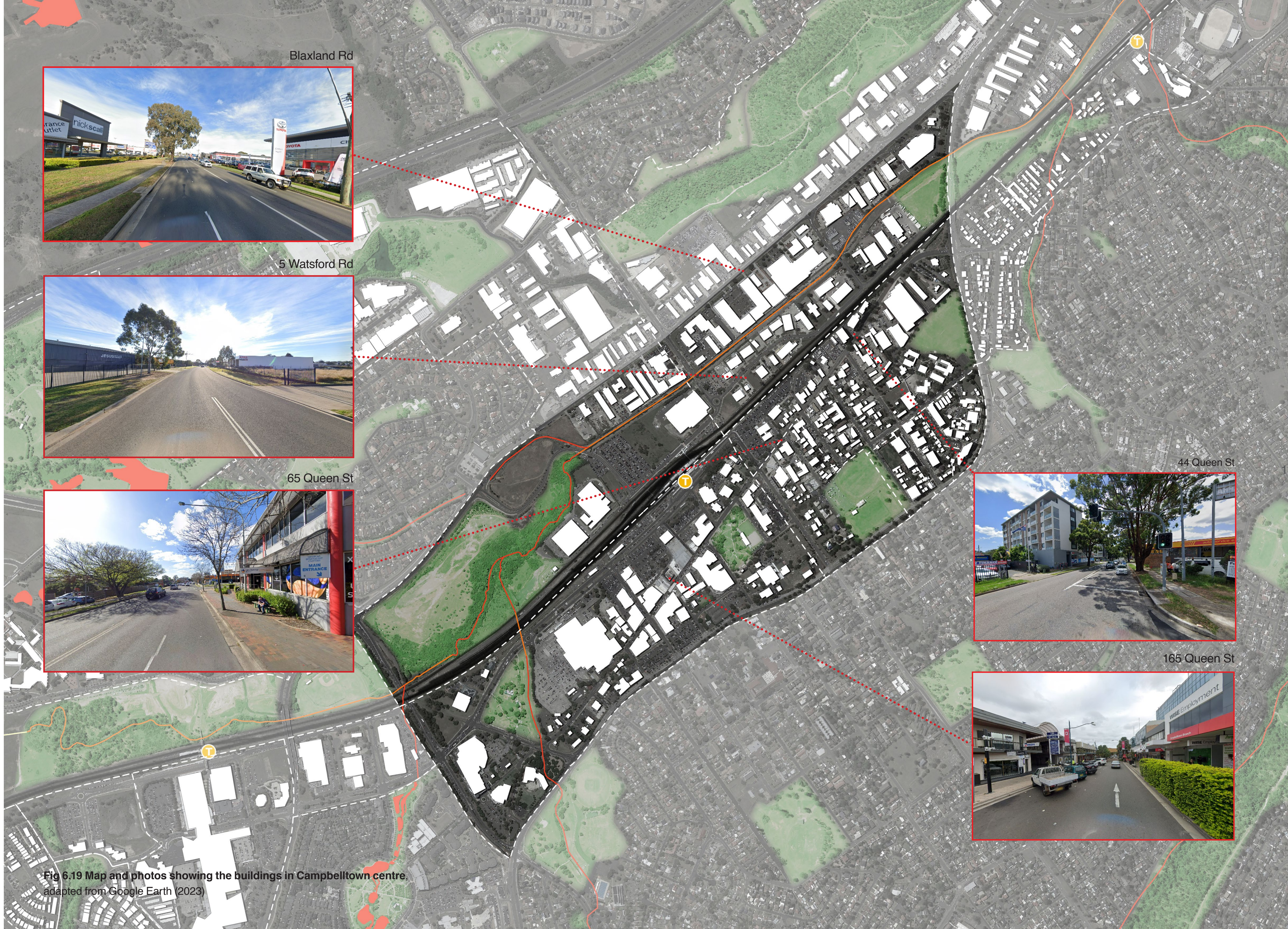


Fig 6.19 Map and photos showing the buildings in Campbelltown centre, adapted from Google Earth (2023)

6.7 Visioning and current residential development

Leumeah city centre

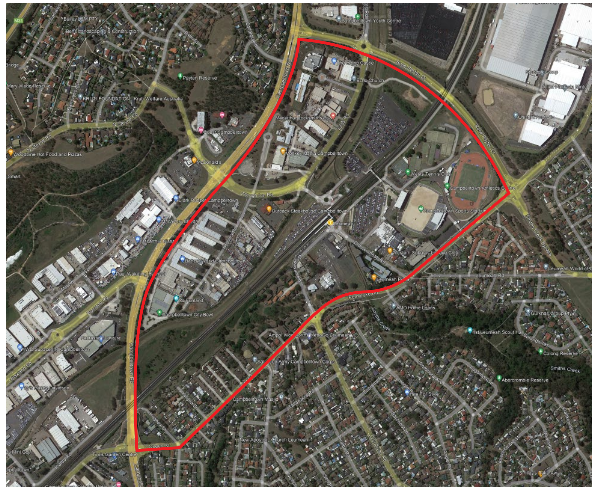


Fig 6.20 Map showing the satellite view of Leumeah centre, adapted from Google Earth (2023)

Assuming that the building layout shown in thie vision 2040 by the government is designed based on elaborate analysis and is an ideal and feasible target to achieve (it satisfies the expected GSI and visual quality etc.), the layout and planar contour will be directly referenced as building footprints for the three sites in the thesis. Slight change might happen to support the design of DEWATS if needed.

The actual designed new building footprints for the three densification scenarios subjects to the drawings in the next sections, which are results from a synthetic analysis and calculation based on “expected building position” and “Expected building density and height distribution” in this section.

Expected building position

Fig 6.21 Vision of Leumeah centre in 2040, adapted from Campbelltown City Council (2020b)

Expected building density and height distribution

	Dwelling Type	2021	2031	2036
Medium + Low density	Low Rise	150	500	700
High density	Medium Rise	0	50	250
High density	High Rise	0	30	50
	Total Dwellings	150	580	1,000

Figure 35: Projected dwelling growth in Leumeah

Low rise: 1-2 storeys
Medium rise: 3-6 storeys
High rise: 7+ storeys
(According to local definition)

Fig 6.22 Vision of dwelling growth in Leumeah centre, adapted from Campbelltown City Council (2020b)

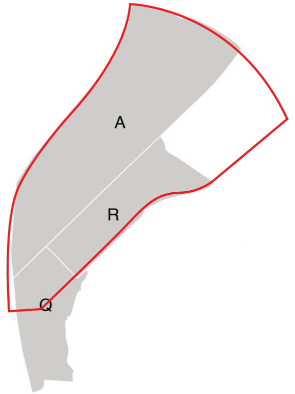


Fig 6.23 SA1 division of Leumeah centre, adapted from Campbelltown City Council (2020b)

Fig 6.24 Expected housing type distribution in Leumeah centre, adapted from Campbelltown City Council (2020b)

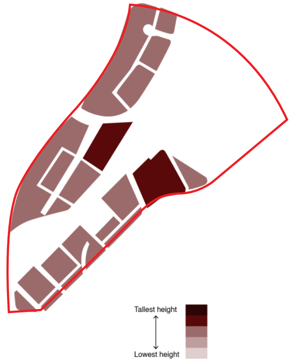


Fig 6.25 Expected building heights in Leumeah centre, adapted from Campbelltown City Council (2020b)

Current dwelling distribution

A

SA1: 12302143705
Area (km²): 0.42
Residents: 5
Low density: Not available
Medium density: Not available
High density: Not available

Q

SA1: 12302144137
Area (km²): 0.12
Residents: 104
Low density: 28
Medium density: 8
High density: 0

R

SA1: 12302144138
Area (km²): 0.14
Residents: 565
Low density: 8
Medium density: 189
High density: 171

Fig 6.26 Current dwelling type distribution in Leumeah centre by SA1, adapted from idcommunity (2023)

Campbelltown city centre

Fig 6.27 Map showing the satellite view of Campbelltown centre, adapted from Google Earth (2023)

Expected building position

Fig 6.28 Vision of Campbelltown centre in 2040, adapted from Campbelltown City Council (2020b)

Expected building density and height distribution

	Dwelling Type	2021	2031	2036
Medium + Low density	Low Rise	1,000	1,550	1,950
High density	Medium Rise	100	350	600
High density	High Rise	400	800	1,050
	Total Dwellings	**1,500**	**2,700**	**3,600**

Figure 39: Cumulative projected dwelling growth in Campbelltown

Low rise: 1-2 storeys
Medium rise: 3-6 storeys
High rise: 7+ storeys
(According to local definition)

Fig 6.29 Vision of dwelling growth in Campbelltown centre, adapted from Campbelltown City Council (2020b)

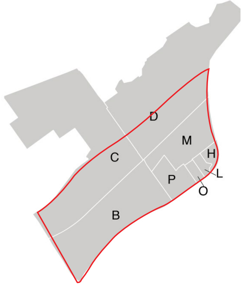


Fig 6.30 SA1 division of Campbelltown centre, adapted from Campbelltown City Council (2020b)

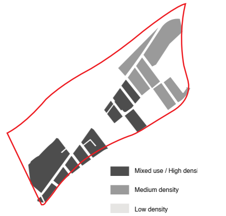


Fig 6.31 Expected housing type distribution in Campbelltown centre, adapted from Campbelltown City Council (2020b)

Fig 6.32 Expected building heights in Campbelltown centre, adapted from Campbelltown City Council (2020b)

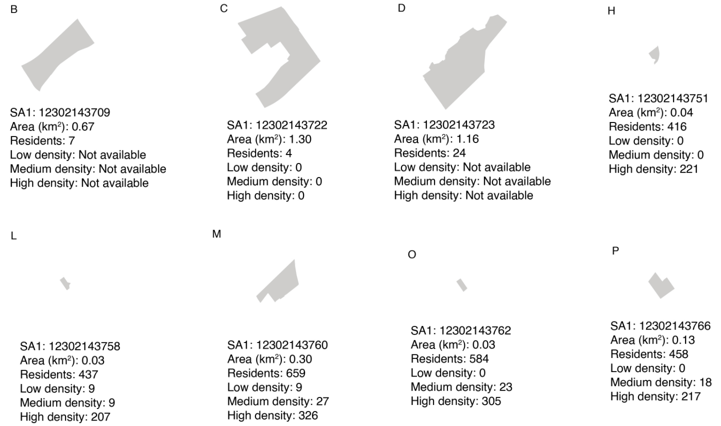


Fig 6.33 Current dwelling type distribution in Leumeah centre by SA1, adapted from idcommunity (2023)

7. Design for low densification sce-nario

7.1 Leumeah centre
Design stage 1: Primary + Secondary + Tertiary treatment

Basic pattern

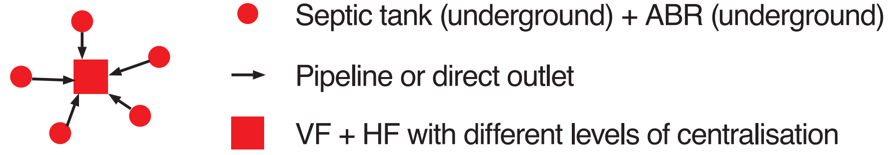


Fig 7.1 Basic pattern of the "Primary + Secondary + Tertiary treatment strategy" in Leumeah centre

In the three designs, the locations and area of septic tanks and ABR are the same, because these two components are most important for removing impurity (page 48: "Fig 3.4 Illustration of the typical modules in DEWATS and their performance"), it is assumed that these two componets should be placed where it is closest to the target buildings to avoid the long distance of delivering raw grey water. Meanwhile, as the dimention ratio of these two steps are fixed, there is no need to change their area. Therefore, the only variable of designing different level of centralisations is the area of the constrcted wetlands (vertical flow and horizontal flow subsurface wetlands).

Low centralisation of treatment

Moderate centralisation of treatment

High centralisation of treatment

Fig 7.2 Overview of the treatment schemes for Leumeah centre's low densification sceanrio

Low centralisation

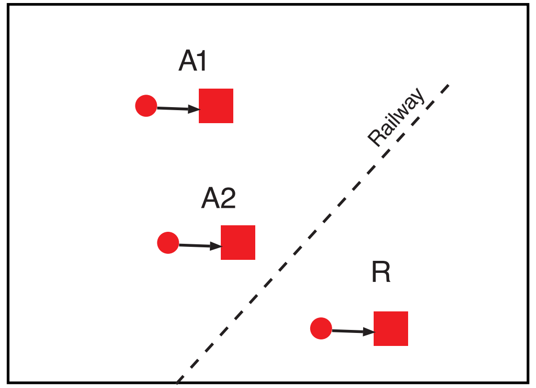


Fig 7.3 Pattern of the low centralisation treatment scheme

Cluster A1, A2 and R have separate wetlands

In this case, no sewer is needed to connect the ABR and subsurface wetlands because they are placed together and the water is treated continuously. The management unit of this case is the smallest, the difficultiy for construction and change is the lowest. However, it may allow less opportunity or value for leisure and public access (for people outside the block).

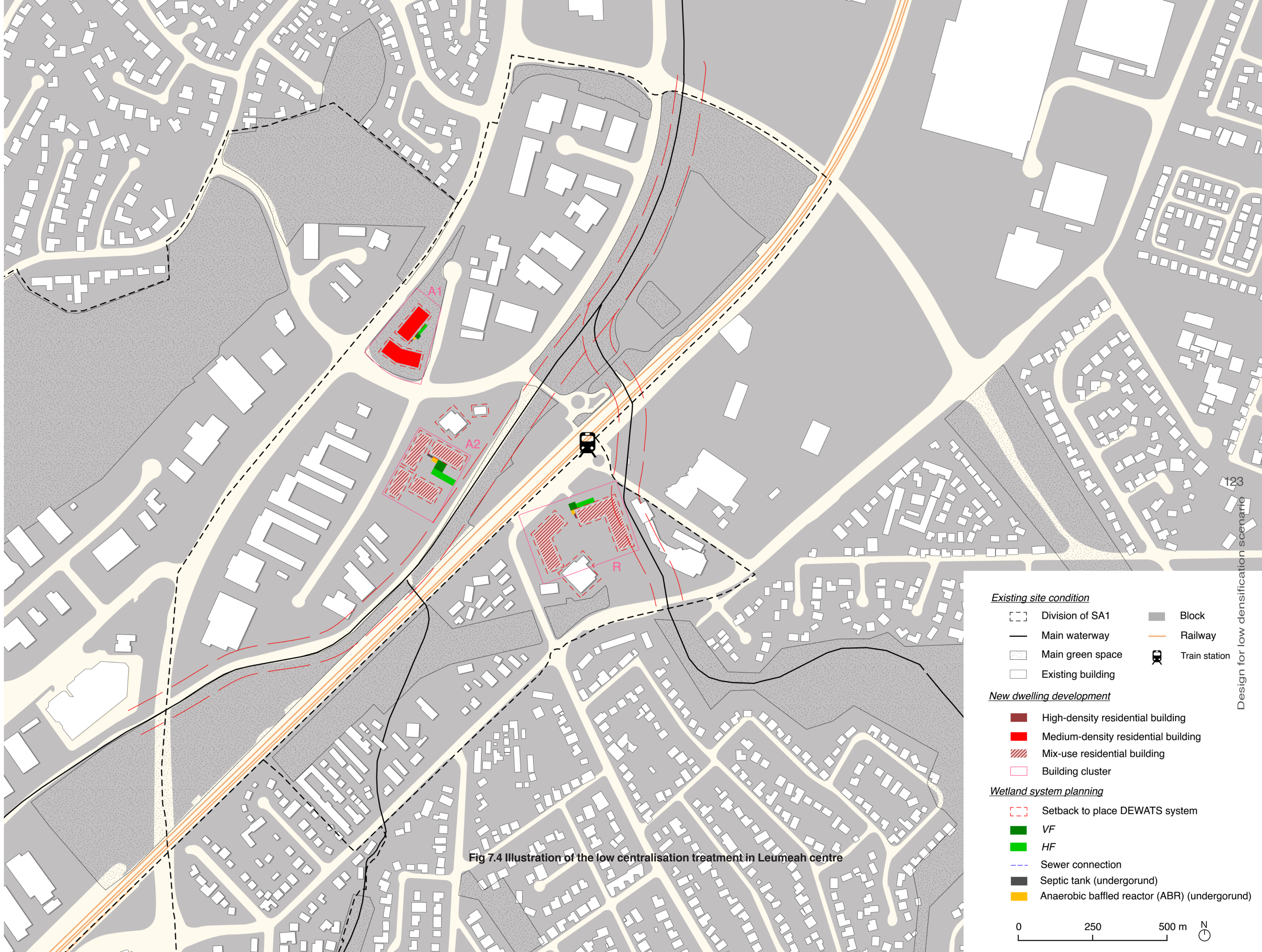


Fig 7.4 Illustration of the low centralisation treatment in Leumeah centre

Moderate centralisation

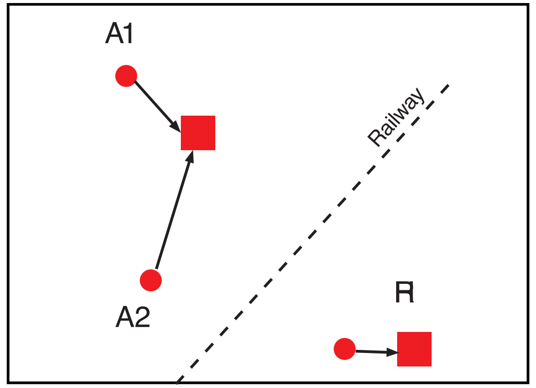


Fig 7.5 Pattern of the moderate centralisation treatment scheme

Clusters A1, A2 have shared wetland, cluster R has separate wetland

In this case, the site is divided into two parts (north-west and south-east) by the railway in between, the wastewater from the building clusters is treated within the side they are located in. No sewer is needed for cluster R, but it is needed for A1 and A2. The scenario has some potential for public sightseeing, which can be most likely developed as street-side gardens next to the main roads.

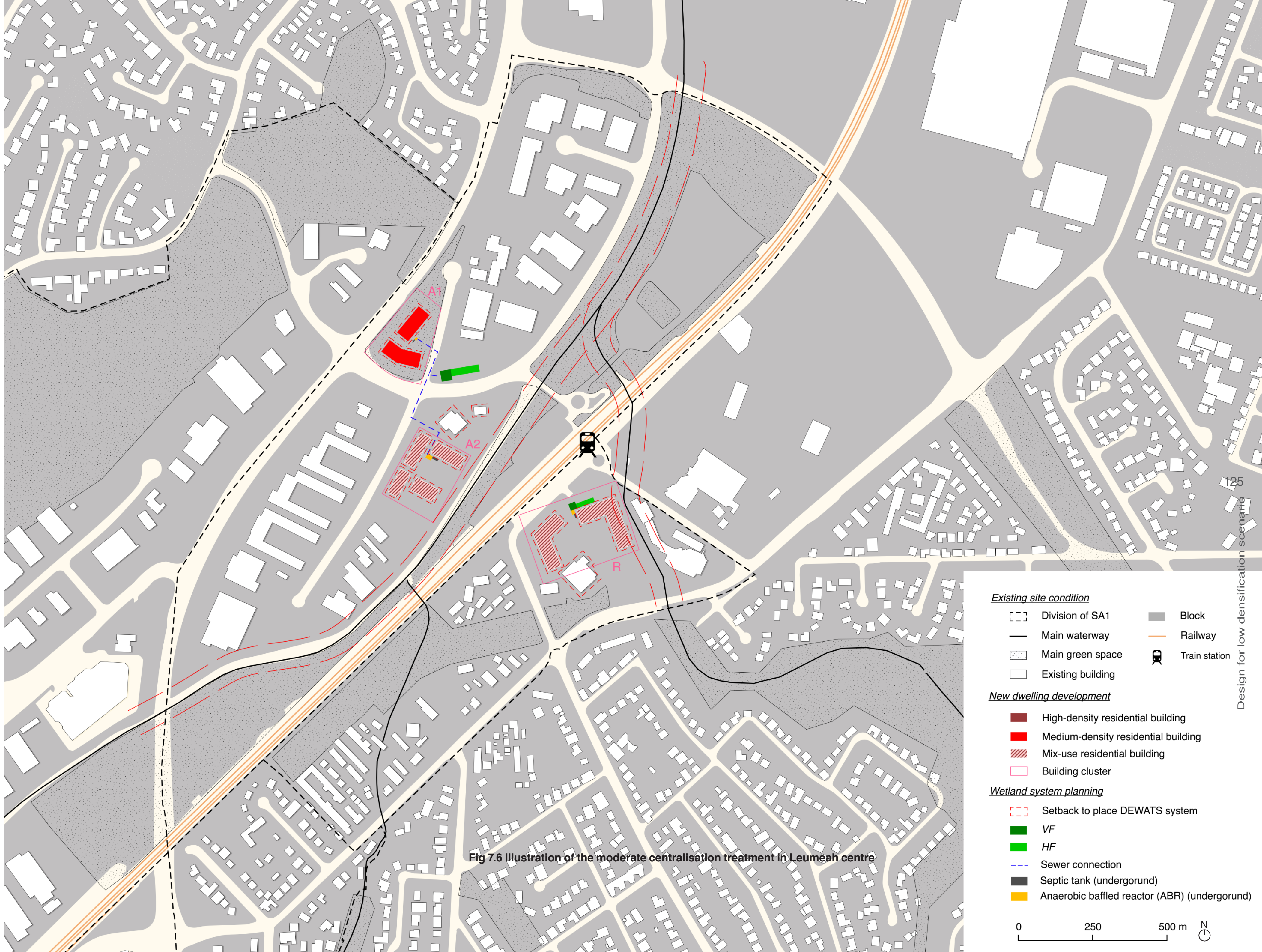


Fig 7.6 Illustration of the moderate centralisation treatment in Leumeah centre

High centralisation

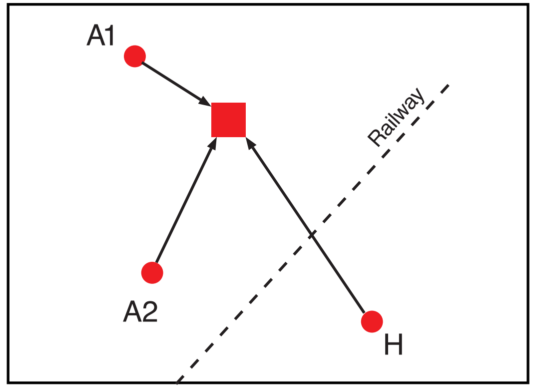


Fig 7.7 Pattern of the high centralisation treatment scheme

Clusters A1, A2, R all have one set of shared wetlands

In this case, there is only one treatment centre for all the new dwellings, which is the hardest scenario to achieve, because all of the clusters are connected collectively by the sewers, and the ones for cluster H have to run across the railway. Meanwhile, the concentrated wetlands for this case doesn't generate enough extra ecological and leisure value compared to the moderate centralisation scenario. Therefore, this case might be the least possible one to achieve.

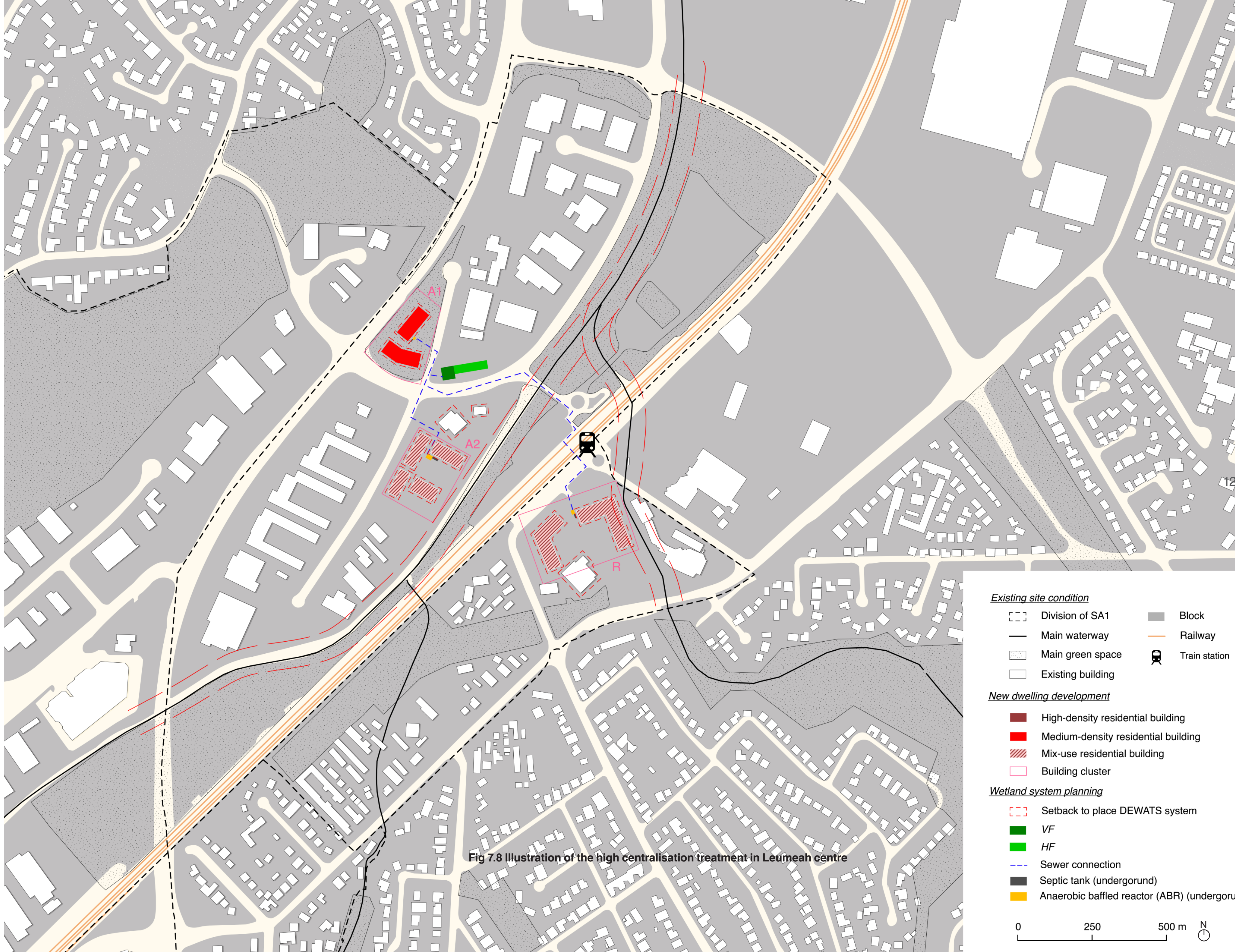


Fig 7.8 Illustration of the high centralisation treatment in Leumeah centre

7.2 Leumeah centre
Design stage 2: Post treatment

Basic pattern

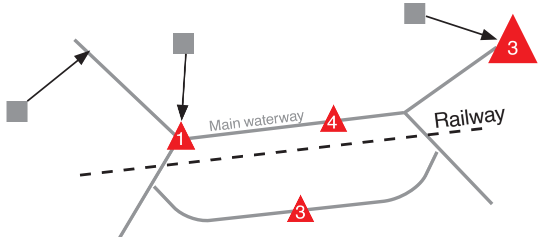


Fig 7.9 Basic pattern of the post treatment strategy in Leumeah centre

- 1 Joints / Key points of the existing surface water network
- 3 New constructed surface flow wetland
- 4 Revival and redesign of the surface water stream
- VF + HF with different levels of centralisation

Low centralisation of treatment

Moderate centralisation of treatment

Fig 7.10 Overview of the treatment schemes for Leumeah centre's low densification sceanrio

As the high centralisation scenario for the post treatment is similar to the moderate scenario, it is not illustrated separately.

Low centralisation

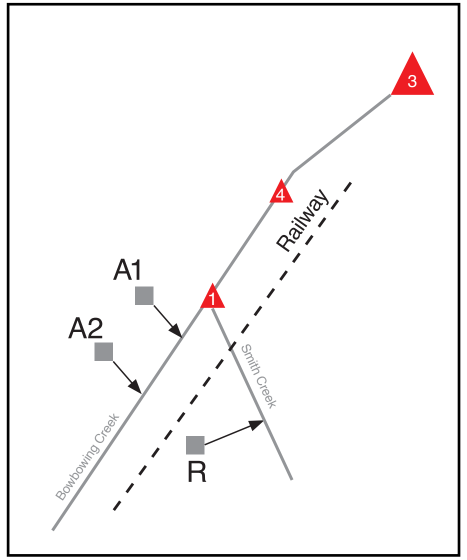


Fig 7.11 Pattern of the low centralisation treatment scheme

After treated by the subsurface flow wetlands (VF, HF), the water from A1 and A2 is discharged into Bowbowing Creek, while that from R is discharged into Smith Creek. The two branches meet at the joint with large open space next to the Leumeah Station, this area will be turned into a collective treatment area for short time retaining and pathogen removal. As it is close to the public transportation node, it will be an active place for leisure and strolling.

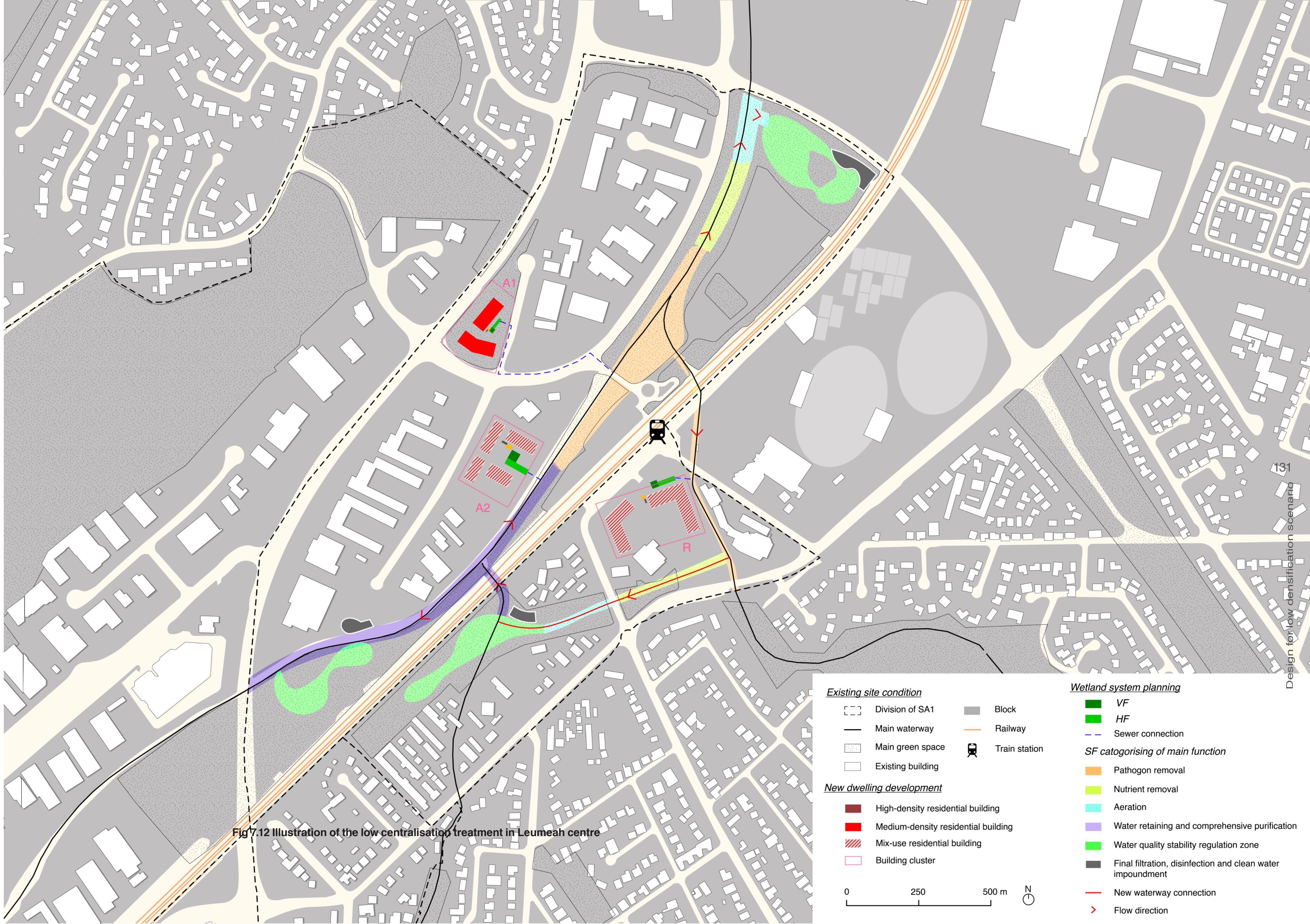


Fig 7.12 Illustration of the low centralisation treatment in Leumeah centre

Moderate centralisation

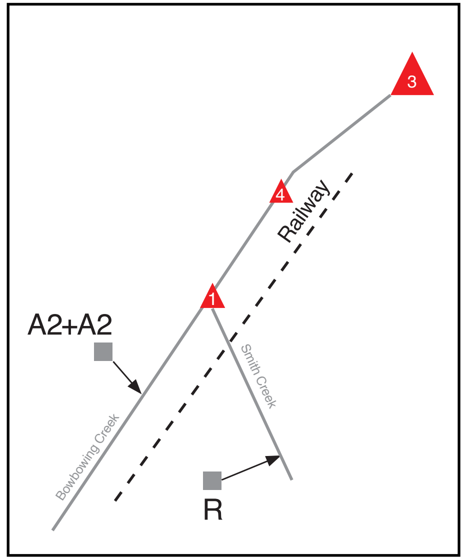


Fig 7.13 Pattern of the moderate centralisation treatment scheme

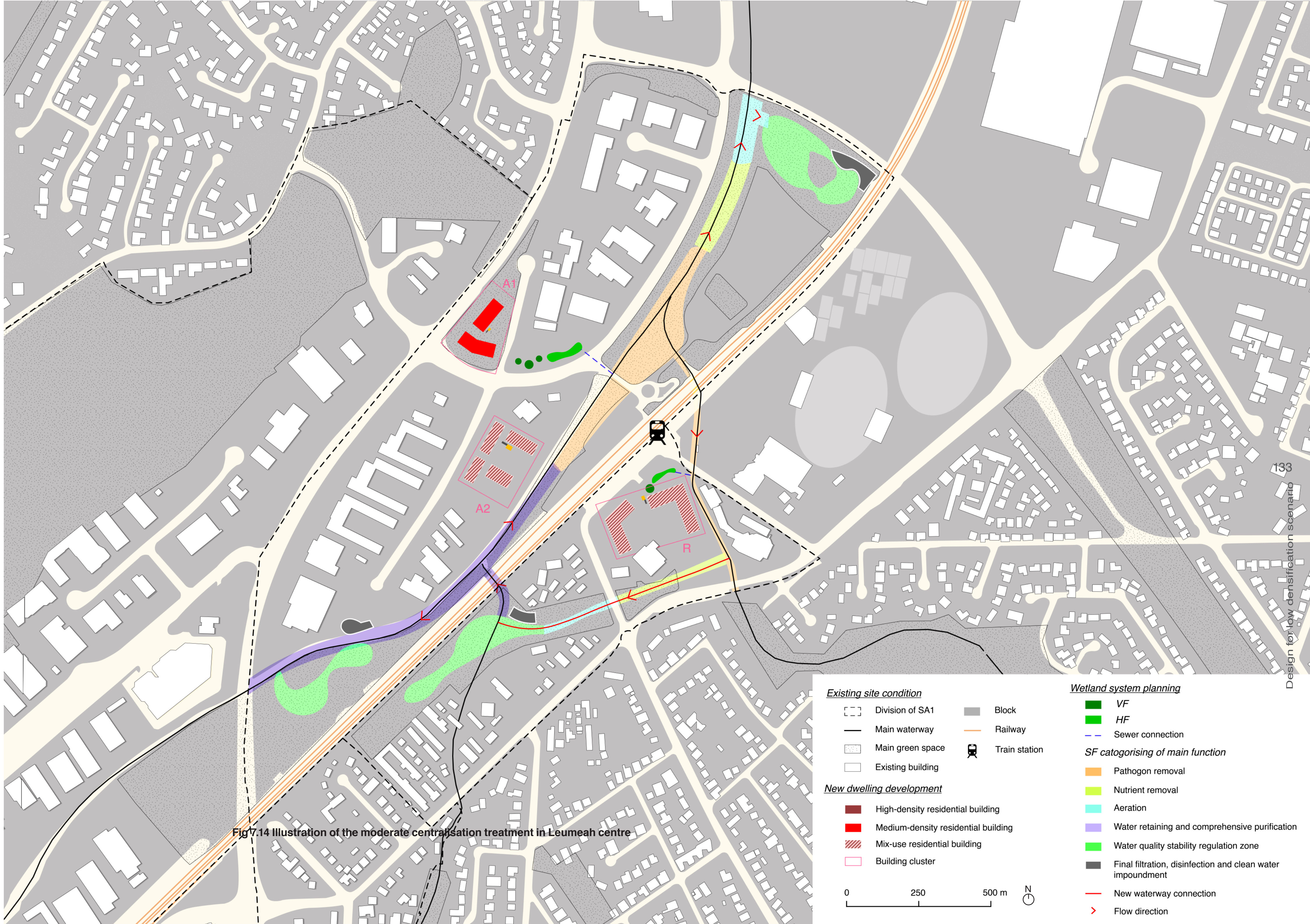


Fig 7.14 Illustration of the moderate centralisation treatment in Leumeah centre

7.3 Campbelltown centre
Design stage 1: Primary + Secondary + Tertiary treatment

Basic pattern

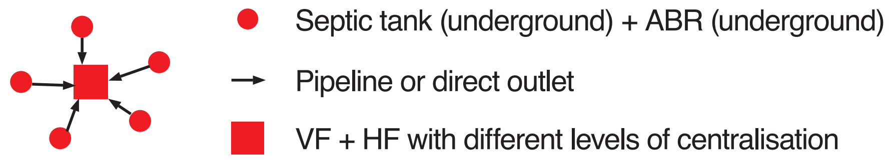
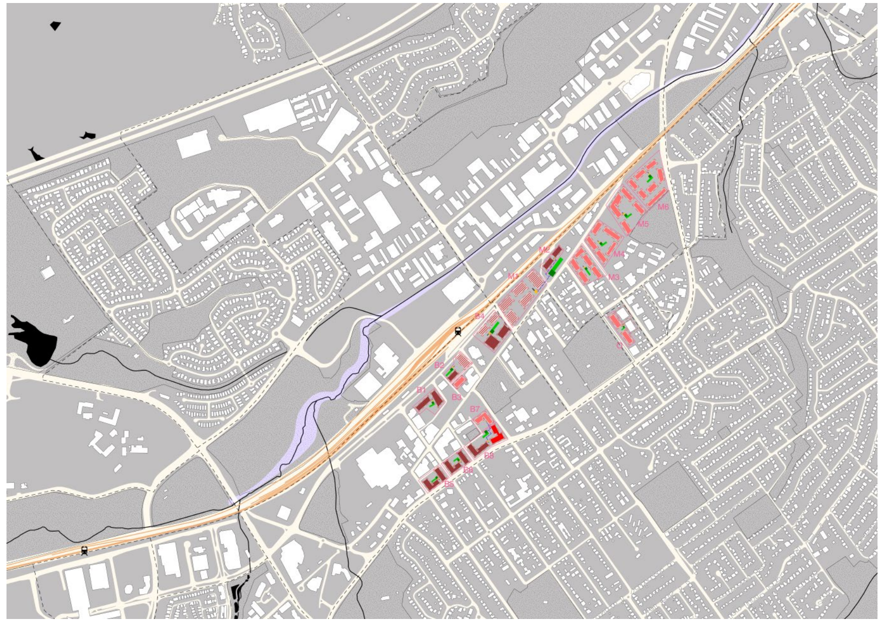
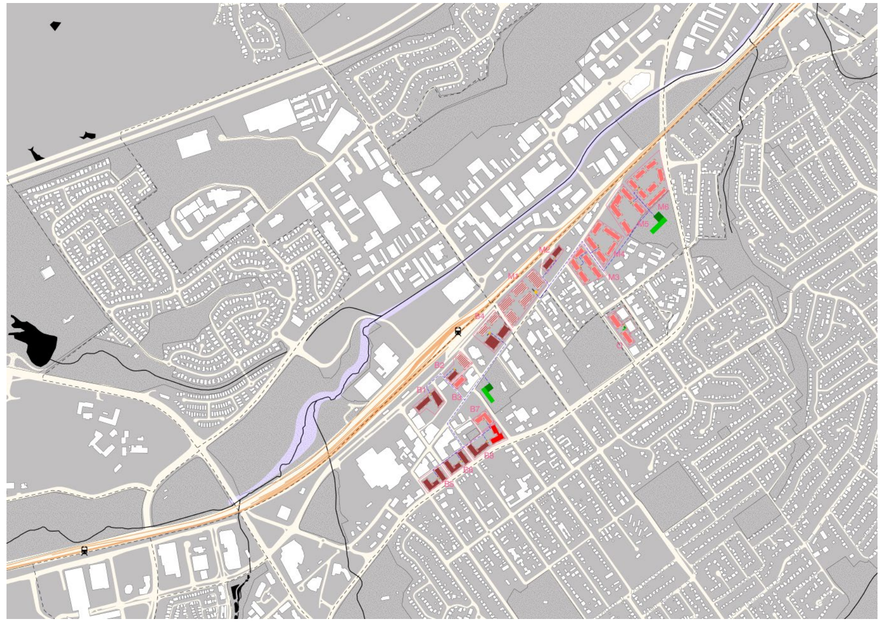


Fig 7.15 Basic pattern of the “Primary + Secondary + Tertiary treatment strategy” in Campbelltown centre

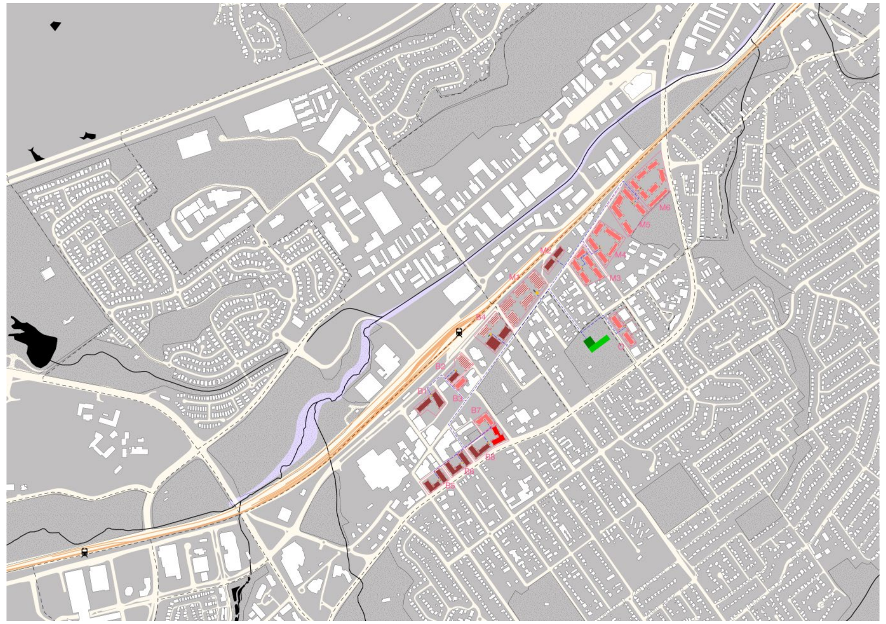
In the design of Campbelltown city centre with low densification scenario, only the southern part of the railway is densified (SA1: B, M, O). As there is hardly existing hydrological environment that can be developed as SF wetlands in the dedicated location, the SF weltlands are planned together with VF and HF as on-site and decentralised treatment.



Low centralisation of treatment



Moderate centralisation of treatment



High centralisation of treatment

Fig 7.16 Overview of the treatment schemes for Campbelltown centre’s low densification sceanrio

Low centralisation

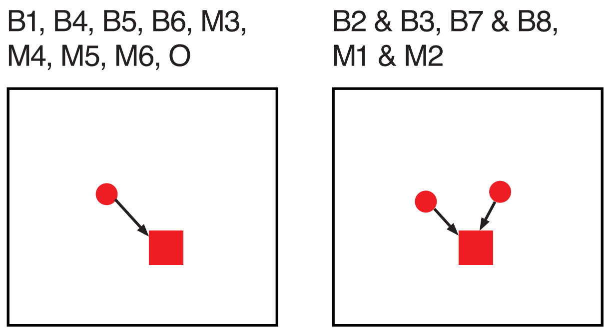


Fig 7.17 Pattern of the low centralisation treatment scheme

Clusters B2 & B3, B7 & B8, M1 & M2 have shared wetlands, the other clusters have seperate wetlands

In this case, the water is treated on-site within each cluster, the spatial configuration is mostly ideal for B1 and B5 to B7 as a community garden which is also visible for public from the street, while the ones for B2 & B3, M1 & M2 have the potential to become street-side garden that is public accssible.

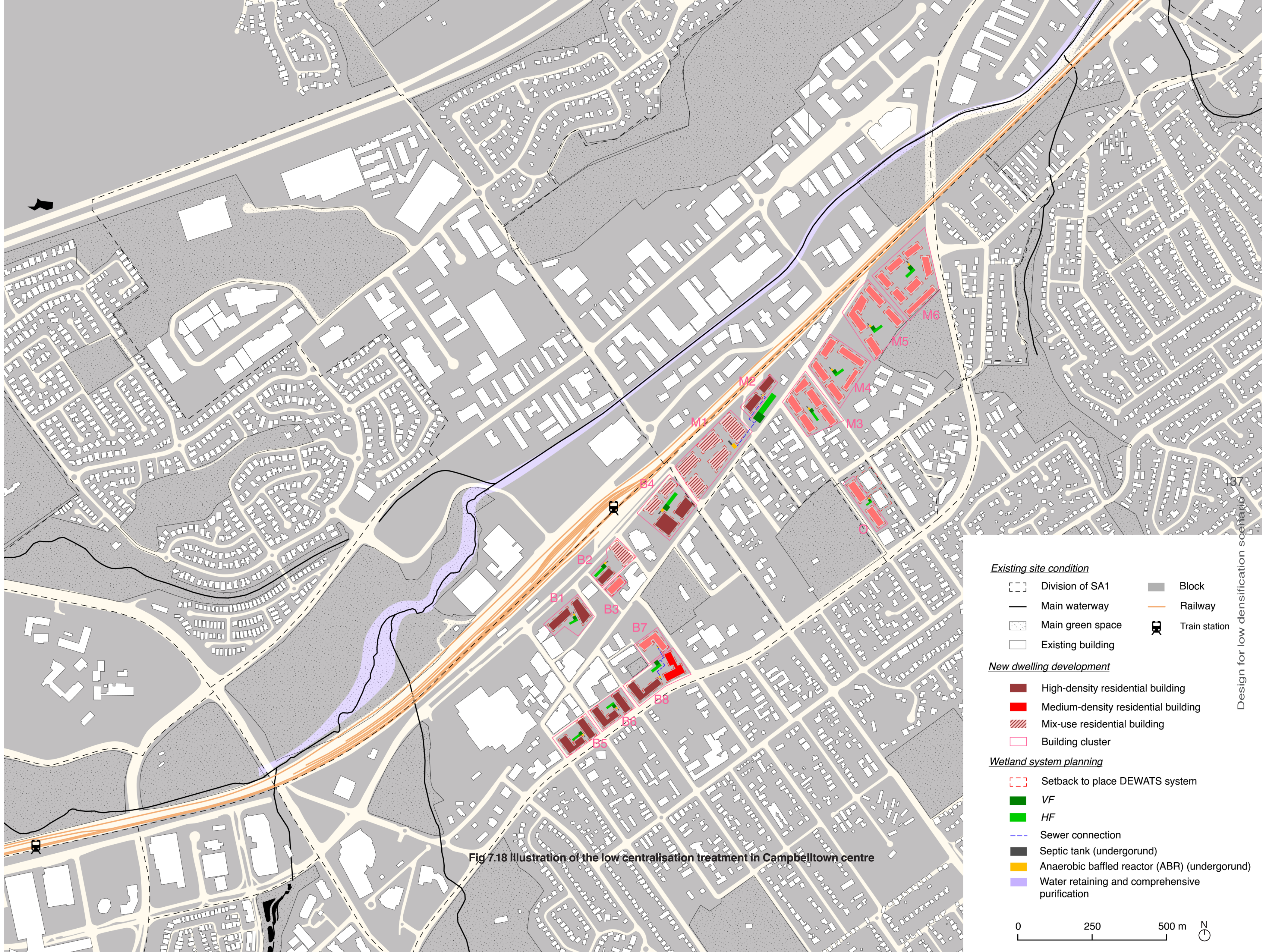


Fig 7.18 Illustration of the low centralisation treatment in Campbelltown centre

Moderate centralisation

Each SA1 has common wetlands

In this scenario, except the wetlands for cluster O, the other two sets of wetlands can be developed as add-ins in existing open space. Based on the spatial analysis (Open green space in Campbelltown Centre), the wetlands for B clusters are located in an existing park with developed layout. Therefore, the wetlands shall be designed as separate cells and weaved into the existing fabric. While the wetlands for M clusters, are placed in an undeveloped open space, which can become a wetland park with public leisure functions.

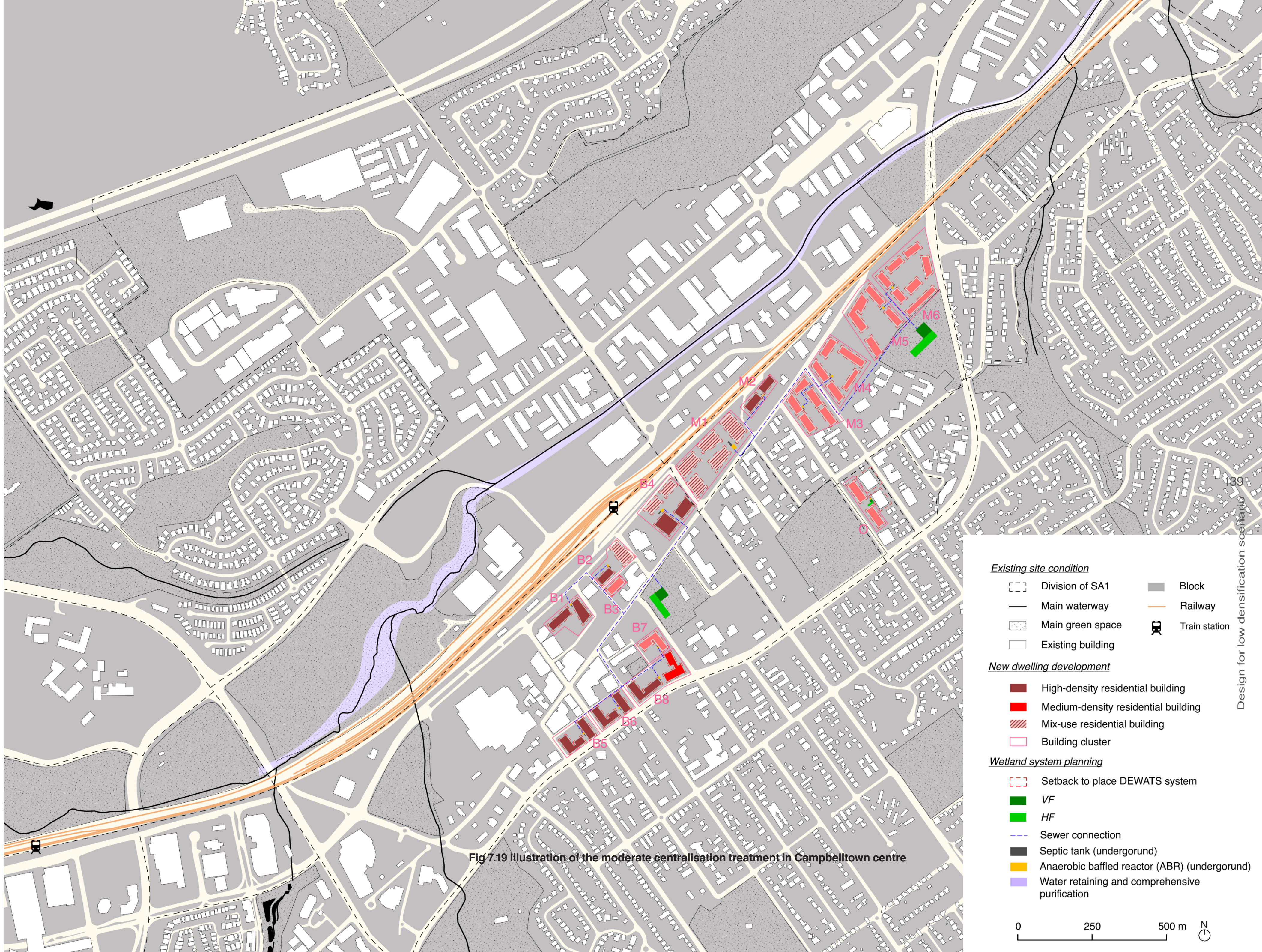


Fig 7.19 Illustration of the moderate centralisation treatment in Campbelltown centre

High centralisation

All clusters share one set of wetlands

In this scenario, the wetlands can only be placed where large open space is available with less preconfigured layout and the place is relatively close to all the clsuters. Under this circustance, only the Campbelltown Showground meets the quality. As this patch has enough large area, it can support more wastewater treatment if the southern part of Campbelltown centre is furtherly densified, and it can potentially accommodate a living machine treatment.

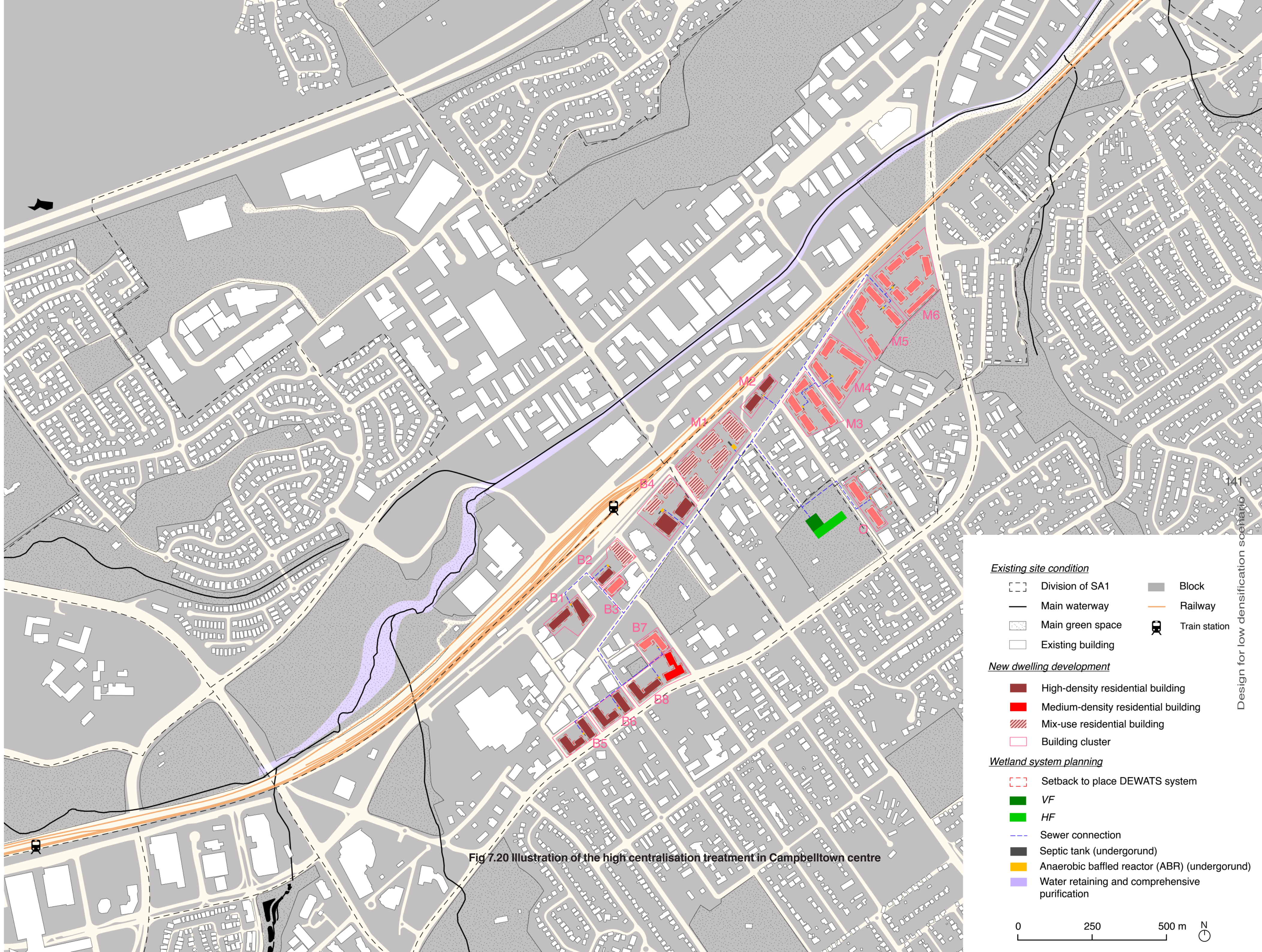


Fig 7.20 Illustration of the high centralisation treatment in Campbelltown centre

7.4 Campbelltown centre
Design stage 2: Post treatment

Basic pattern

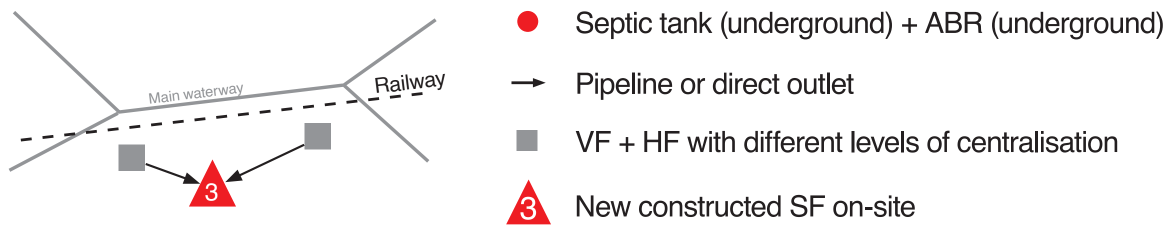
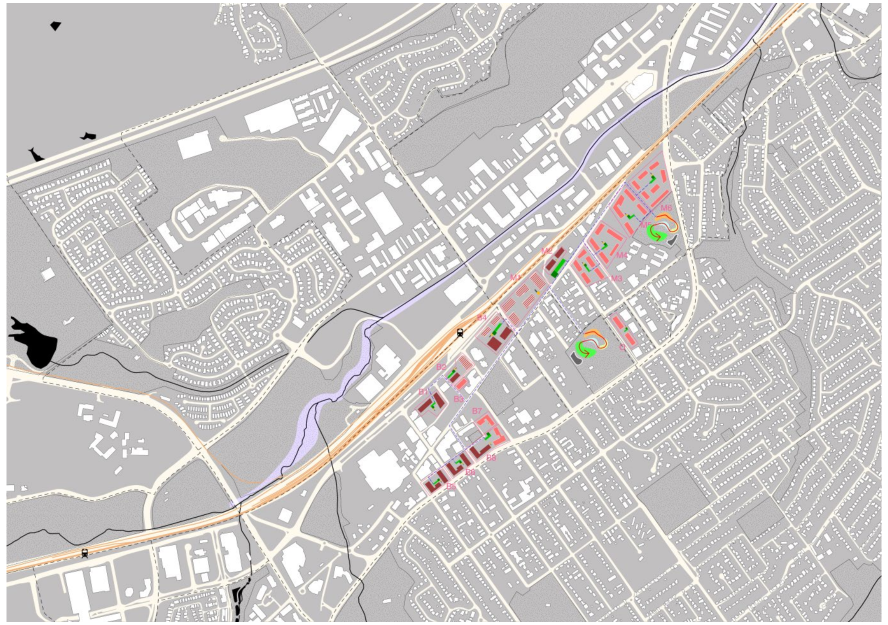
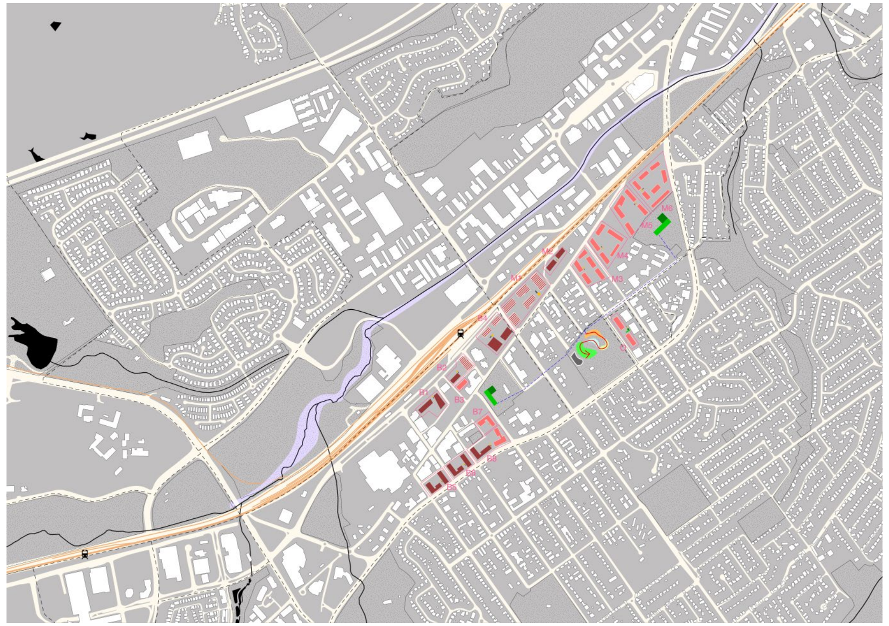


Fig 7.21 Basic pattern of the post treatment in Campbelltown centre

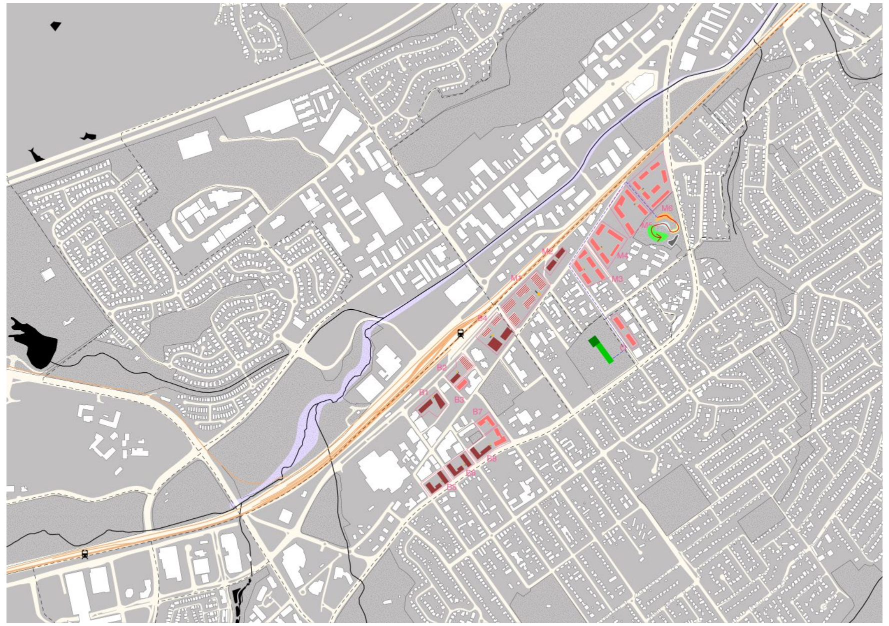
Compared to the other schemes, the post treatment of Campbelltown low densification scenario is limited in the area of surface flow wetlands although it exceeds the minimum requirement.



Low centralisation of treatment



Moderate centralisation of treatment



High centralisation of treatment

Fig 7.22 Overview of the treatment schemes for Campbelltown centre's low densification sceanrio

Low centralisation

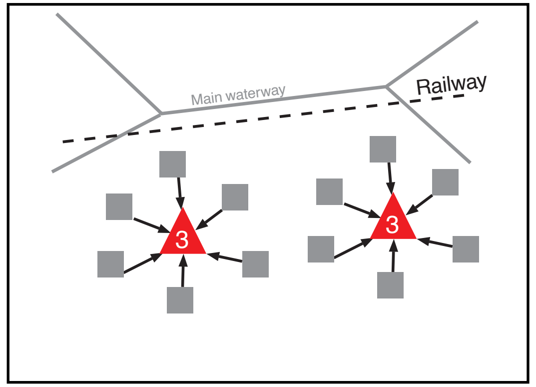


Fig 7.23 Pattern of the low centralisation treatment scheme

For the low centralisation scenario, there are two sets of surface flow wetlands numbered 1 and 2 in the graph. The set 1 treats water from the sbsurface wetlands for clusters B1-B8; the set 2 treats water from that of M1-M6 and O. This scheme requires the area from two collective open spaces where there is no existing design. More construction works are needed compared to the design for the other two levels of centralisation. However, it might brings about better treatment quality.

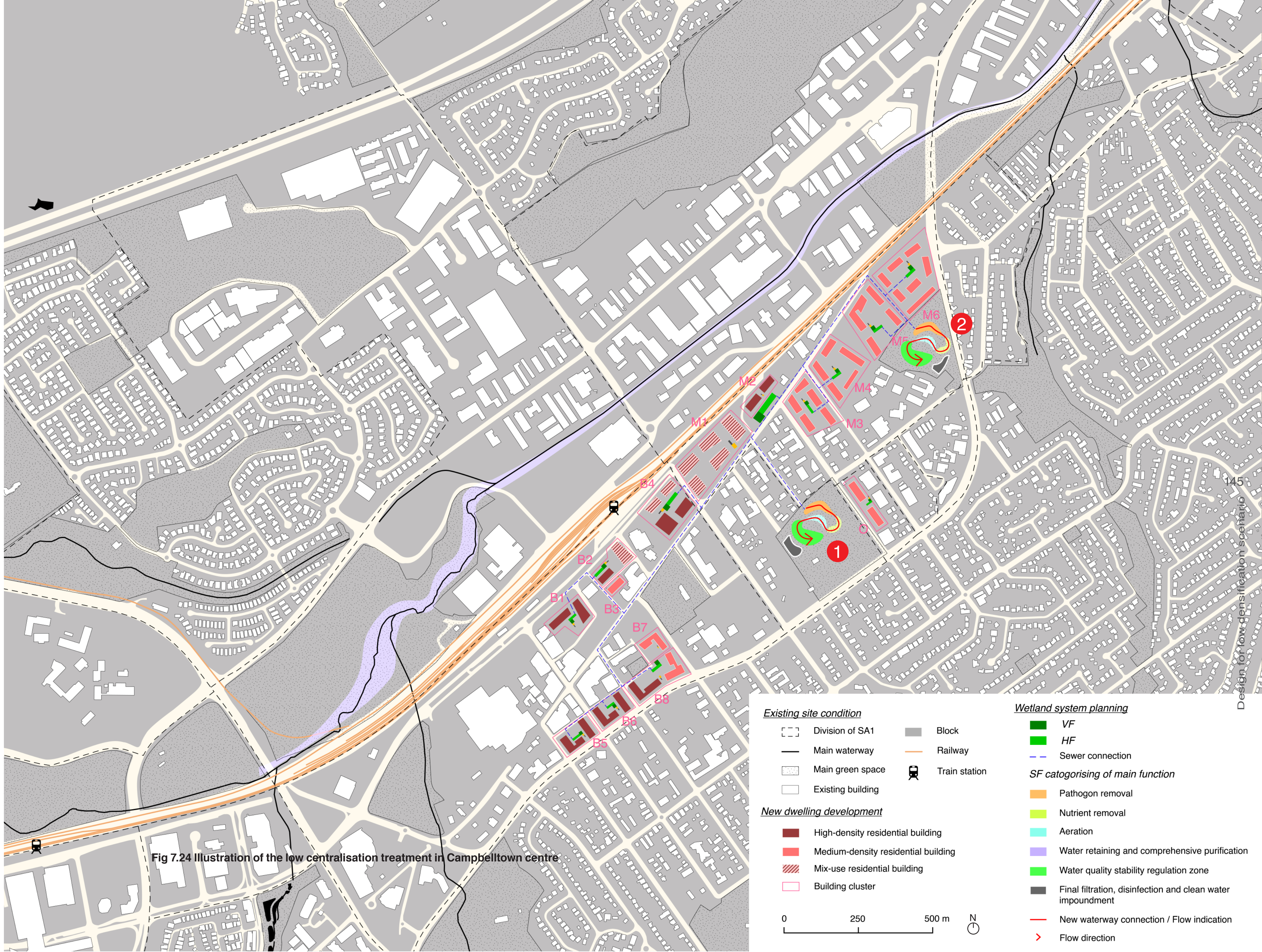


Fig 7.24 Illustration of the low centralisation treatment in Campbelltown centre

Moderate centralisation

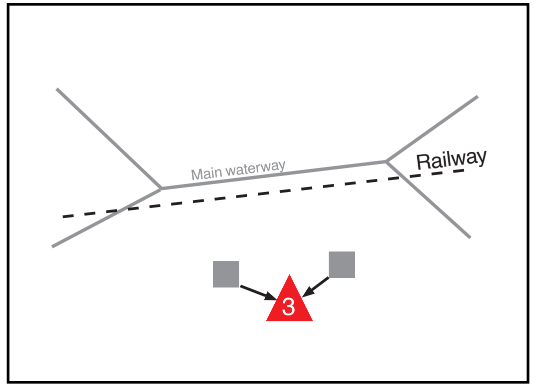


Fig 7.25 Pattern of the moderate centralisation treatment scheme

Different from the low centralisation scenario, there is one set of surface flow wetlands for the moderate centralisation scenario as the location for set 2 (as shown in the previous page) is now assigned for the subsurface wetlands and the total area for surface flow treatment is half of that for low centralisation scenario. In this case, the surface flow wetlands are monitored and administored collectively which reversely forms a relatively centralised way in post treatment and treated water distribution.

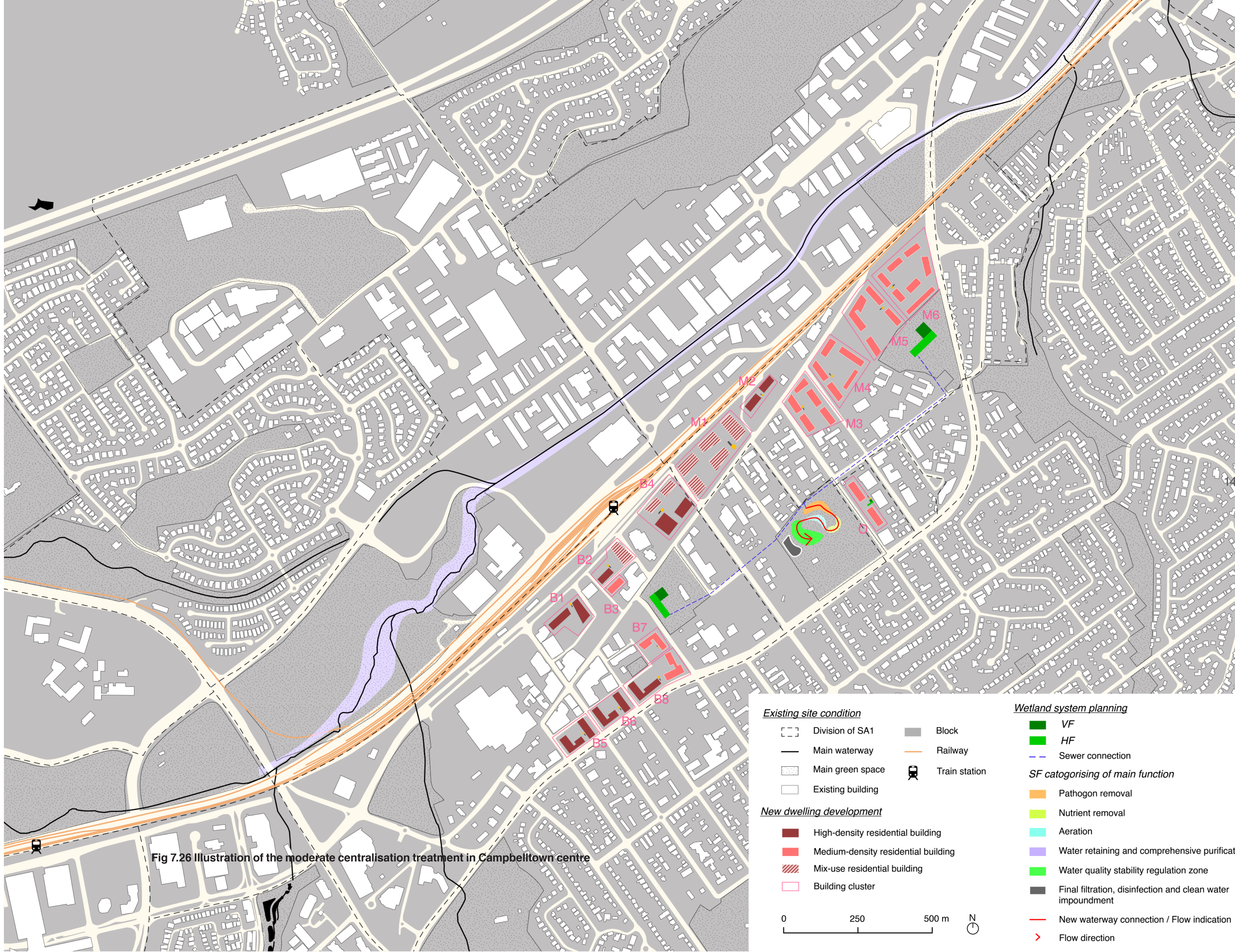


Fig 7.26 Illustration of the moderate centralisation treatment in Campbelltown centre

High centralisation

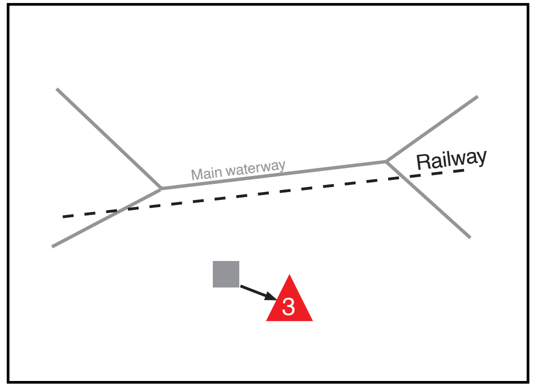


Fig 7.27 Pattern of the high centralisation treatment scheme

This is the scenario with most centralised treatment set-up in both sub-surface and surface wetlands treatments. Although the cost of the construction for this option tend to be the least and the process is easier to monitor, it is less flexible and adjustable autonomously (for example, once there is error in any treatment stage, the treatment for the whole area has to be stopped for checking).

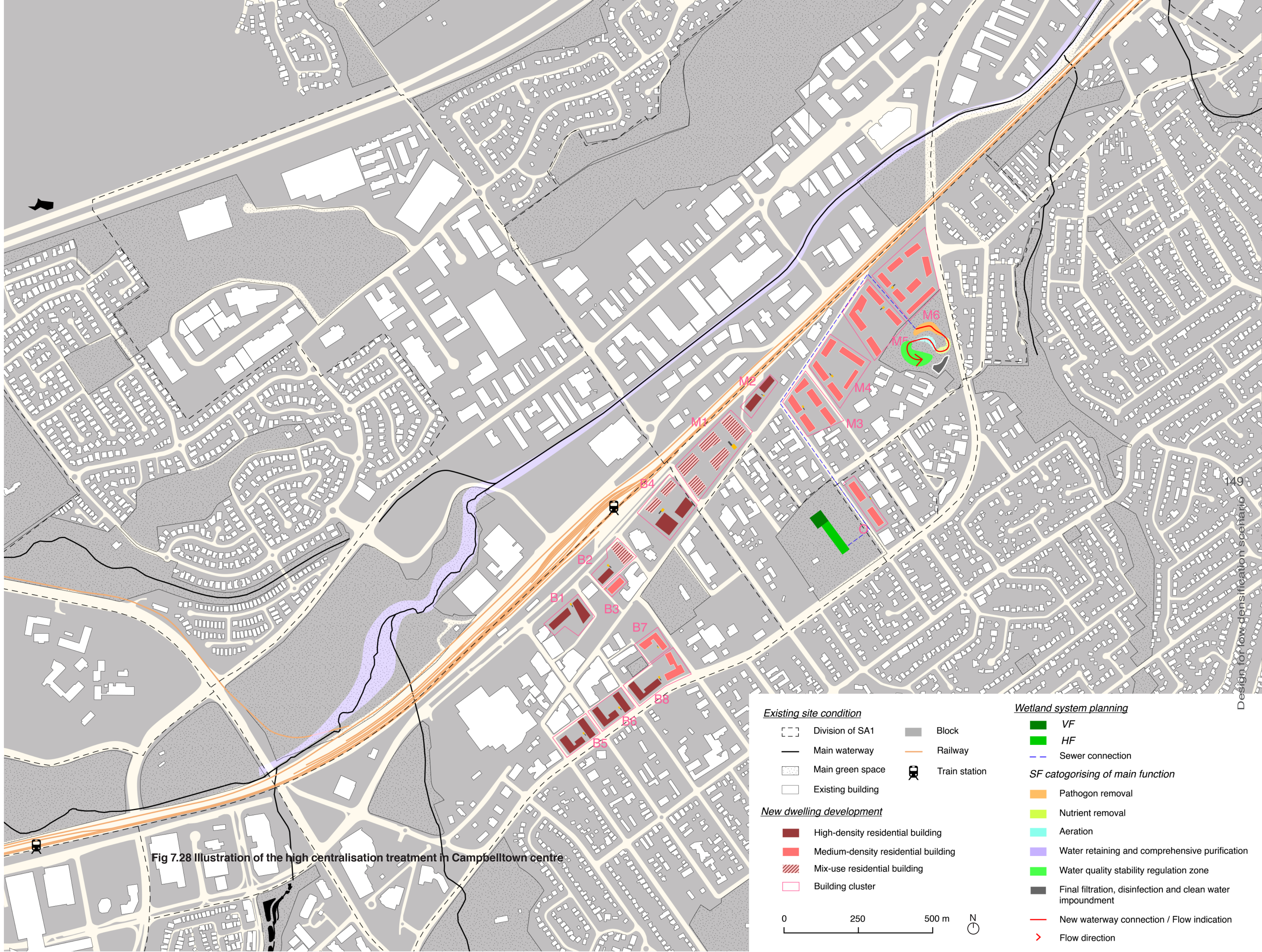
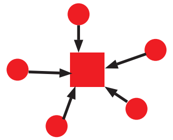


Fig 7.28 Illustration of the high centralisation treatment in Campbelltown centre

8. Design for high densification scenario

8.1 Leumeah centre
Design stage 1: Primary + Secondary + Tertiary treatment

Basic pattern



- Septic tank (underground) + ABR (underground)
- Pipeline or direct outlet
- VF + HF with different levels of centralisation

Fig 8.1 Basic pattern of the "Primary + Secondary + Tertiary treatment strategy" in Leumeah centre

In the high densification scenario, in addition to having new residential and mixed-use residential buildings on open areas, some of the low-medium density dwellings that are out-dated are also rennovated and densified to become medium-high density dwellings

Low centralisation of treatment

Moderate centralisation of treatment

High centralisation of treatment

Fig 8.2 Overview of the treatment schemes for Leumeah centre's high densification scenario

Low centralisation

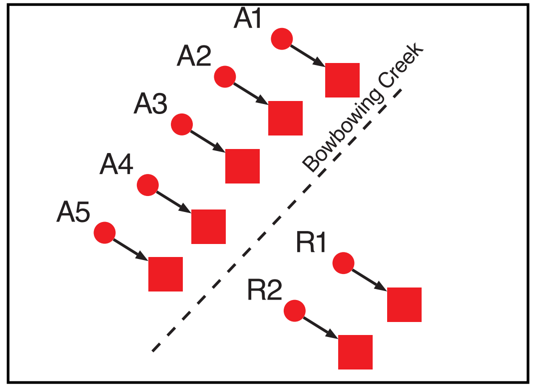


Fig 8.3 Pattern of the low centralisation treatment scheme

All the clusters have seperate wetlands

Compared to the same level of centralisation in low densification scenario, the area of individual wetlands are obviously larger, some of them (those for A2, A4 and A5) have close relation with the Bowbowing creek, which brings convenience to the connection between the first three treatment stages and the post treatment.

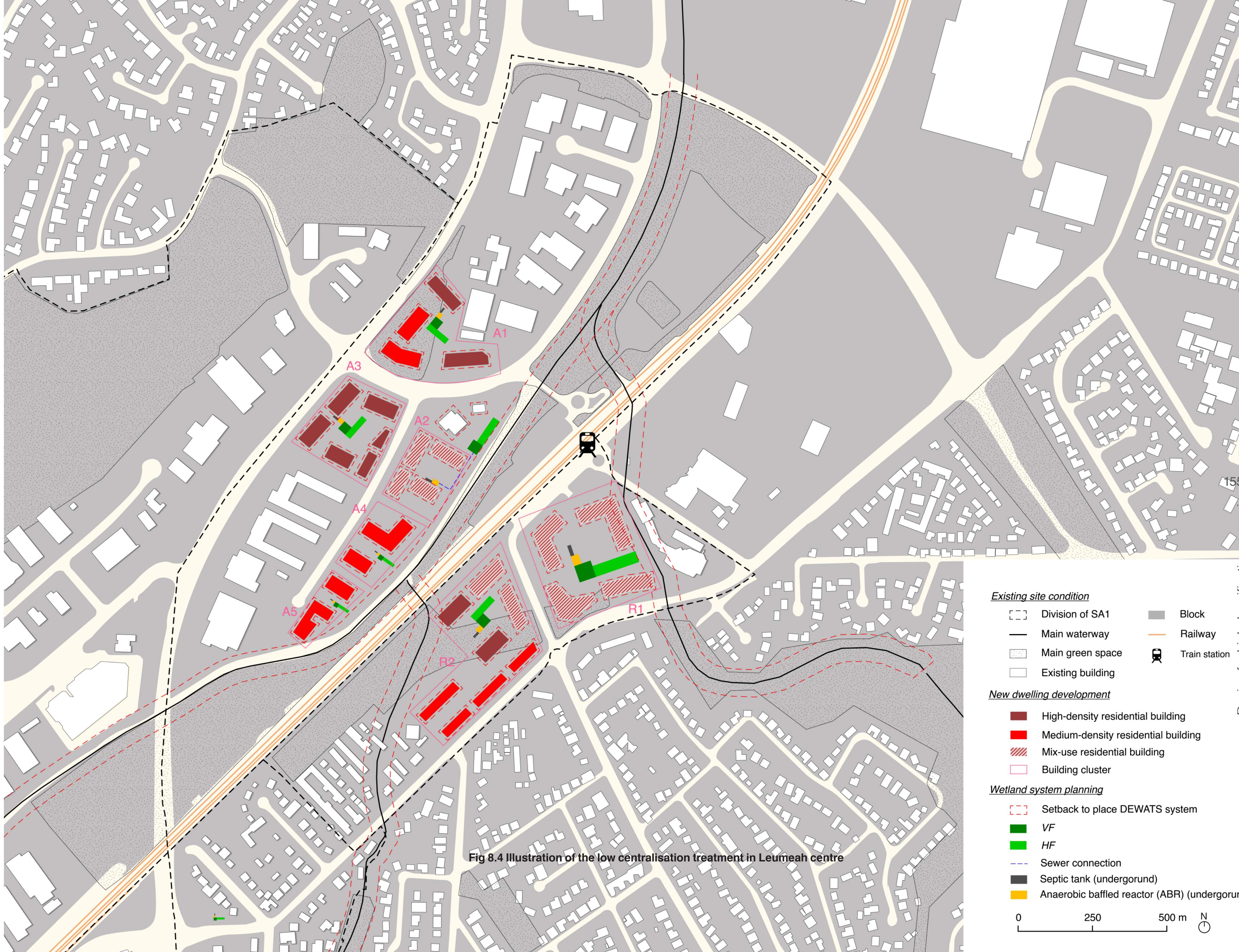


Fig 8.4 Illustration of the low centralisation treatment in Leumeah centre

Moderate centralisation

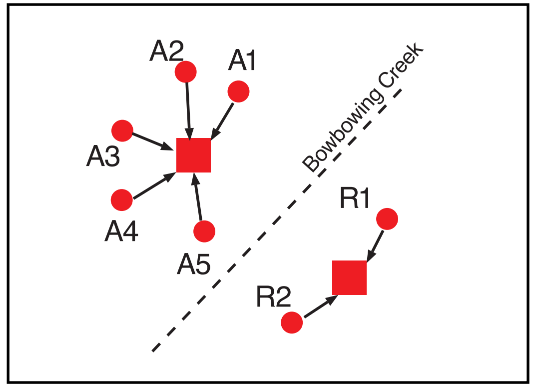


Fig 8.5 Pattern of the moderate centralisation treatment scheme

Clusters in the same SA1 share single set of wetlands

In this scenaro, the open area that is capable to support the wetlands area is limited, which indicates that the upper limit of densification to be equipped with a moderate centralisation of DEWATS is almost here.

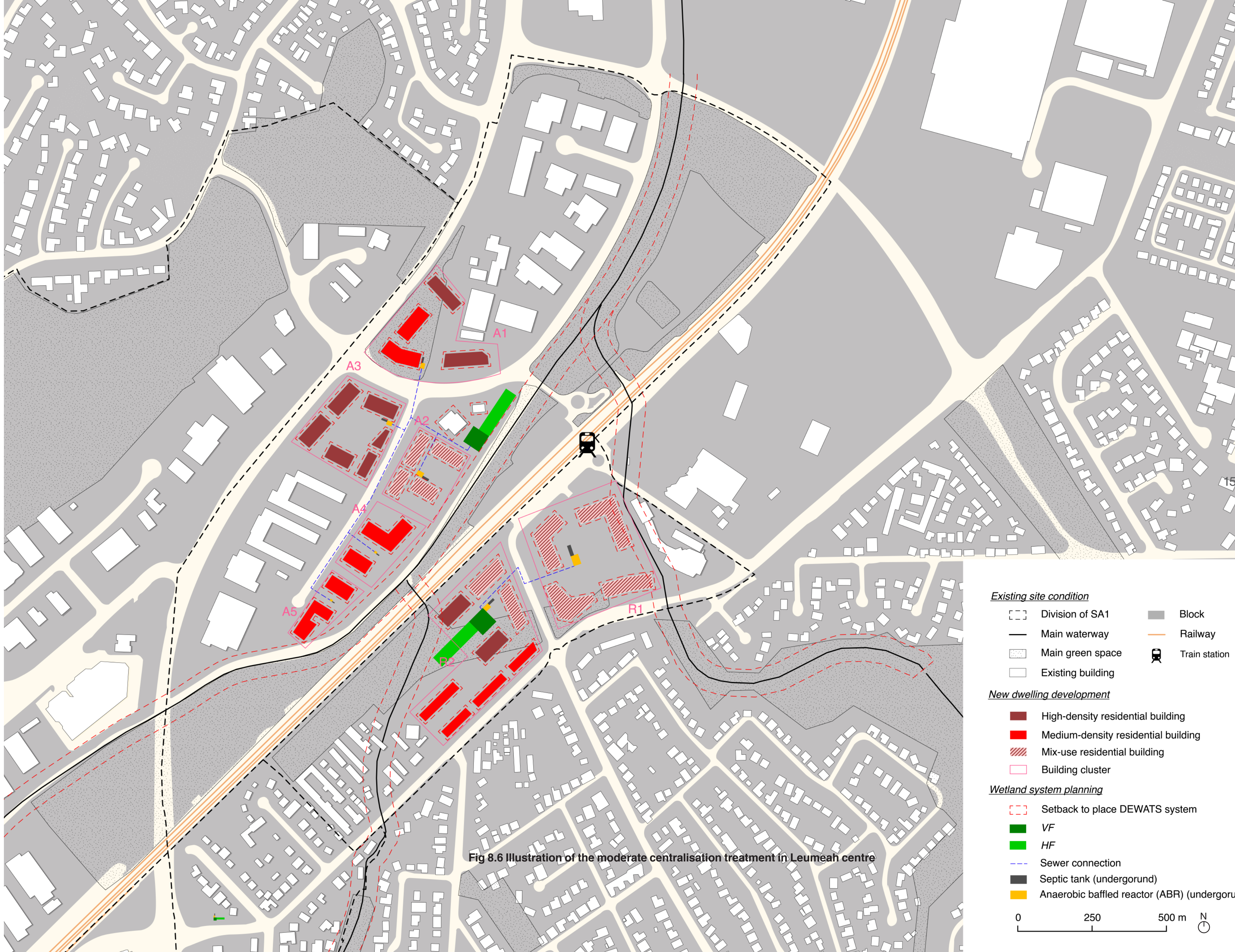


Fig 8.6 Illustration of the moderate centralisation treatment in Leumeah centre

High centralisation

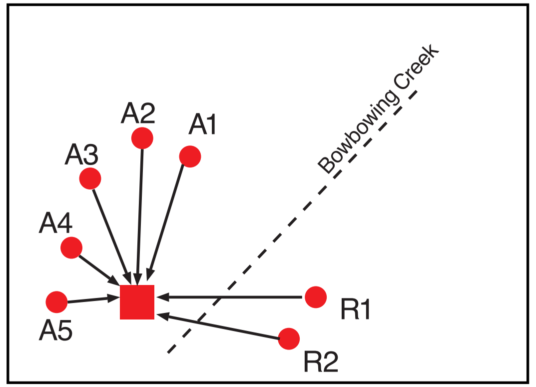


Fig 8.7 Pattern of the high centralisation treatment scheme

All the clusters share single set of wet-lands

This scenario is difficult to achieve, be-causelong distance of sewers have to be constructed that across the railway and the Bowbowing creek. It is nonesense to realise this high centralisation treatment when the other two options are easier to achieve and have lower error rate.

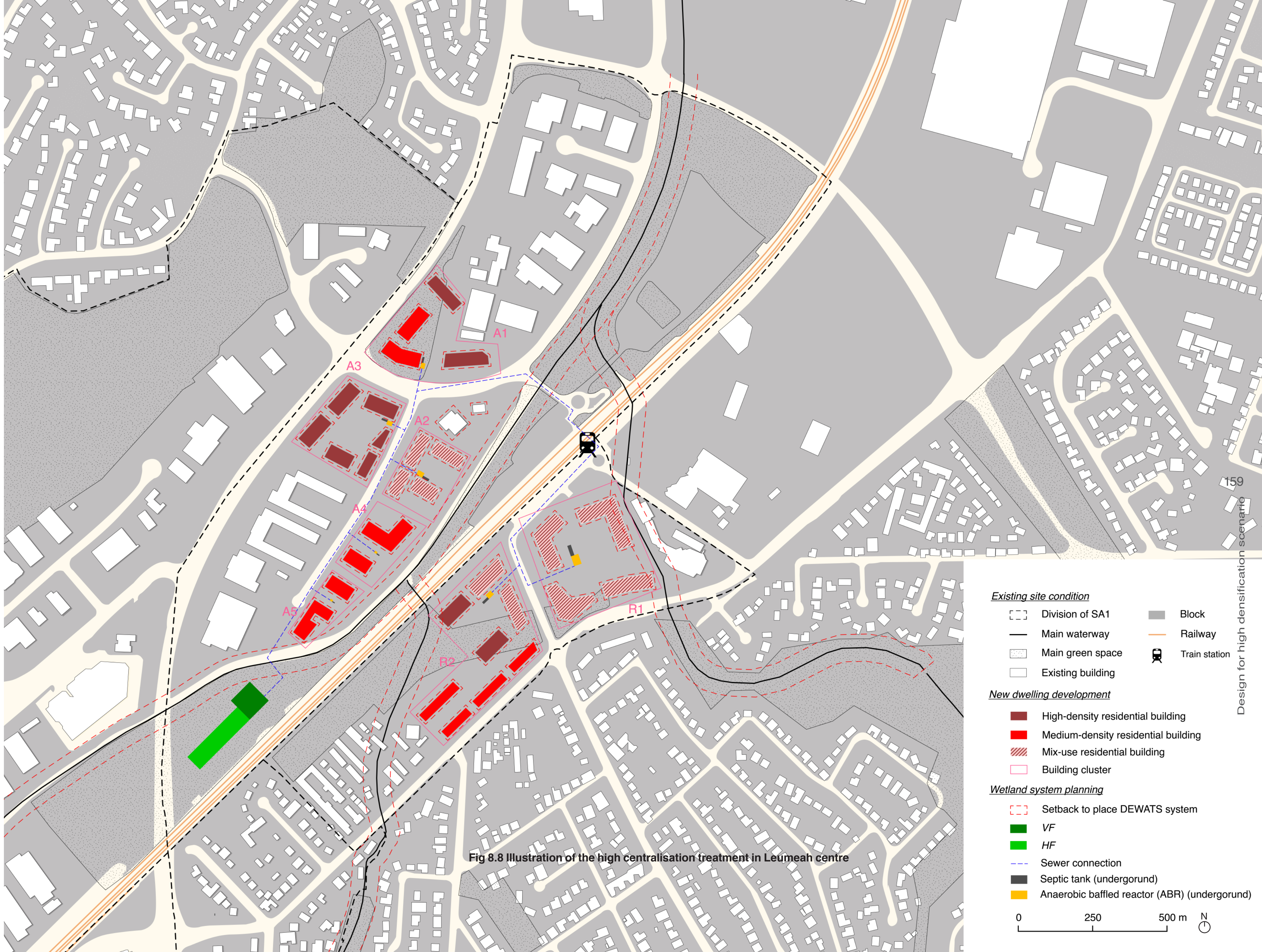
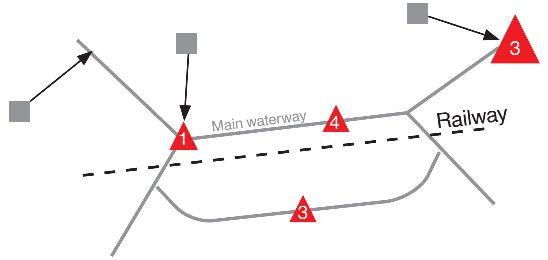


Fig 8.8 Illustration of the high centralisation treatment in Leumeah centre

8.2 Leumeah centre
Design stage 2: Post treatment

Basic pattern



- 1 Joints / Key points of the existing surface water network
- 3 New constructed surface flow wetland
- 4 Revival and redesign of the surface water stream
- VF + HF with different levels of centralisation

Fig 8.9 Basic pattern of the post treatment in Leumeah centre

The design of post treatment for high densified Leumeah centre applies the similar strategy with the low densification case, where a new water flow (set of surface flow wetlands) is introduced to form a new treatment loop outside the main water bone (the Bowbowing creek) but still join the treatment by the Bowbowing creek at some points.

Low centralisation of treatment

Moderate centralisation of treatment

High centralisation of treatment

Fig 8.10 Overview of the treatment schemes for Leumeah centre's high densification sceanrio

Low centralisation

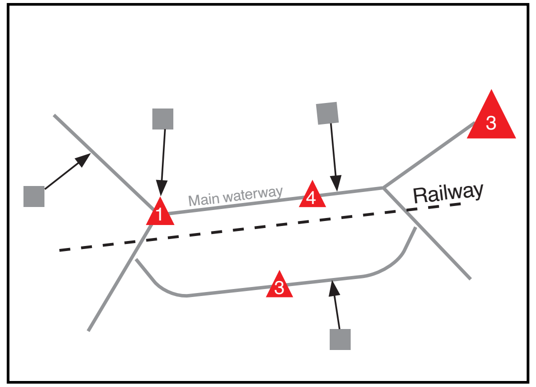


Fig 8.11 Pattern of the low centralisation treatment scheme

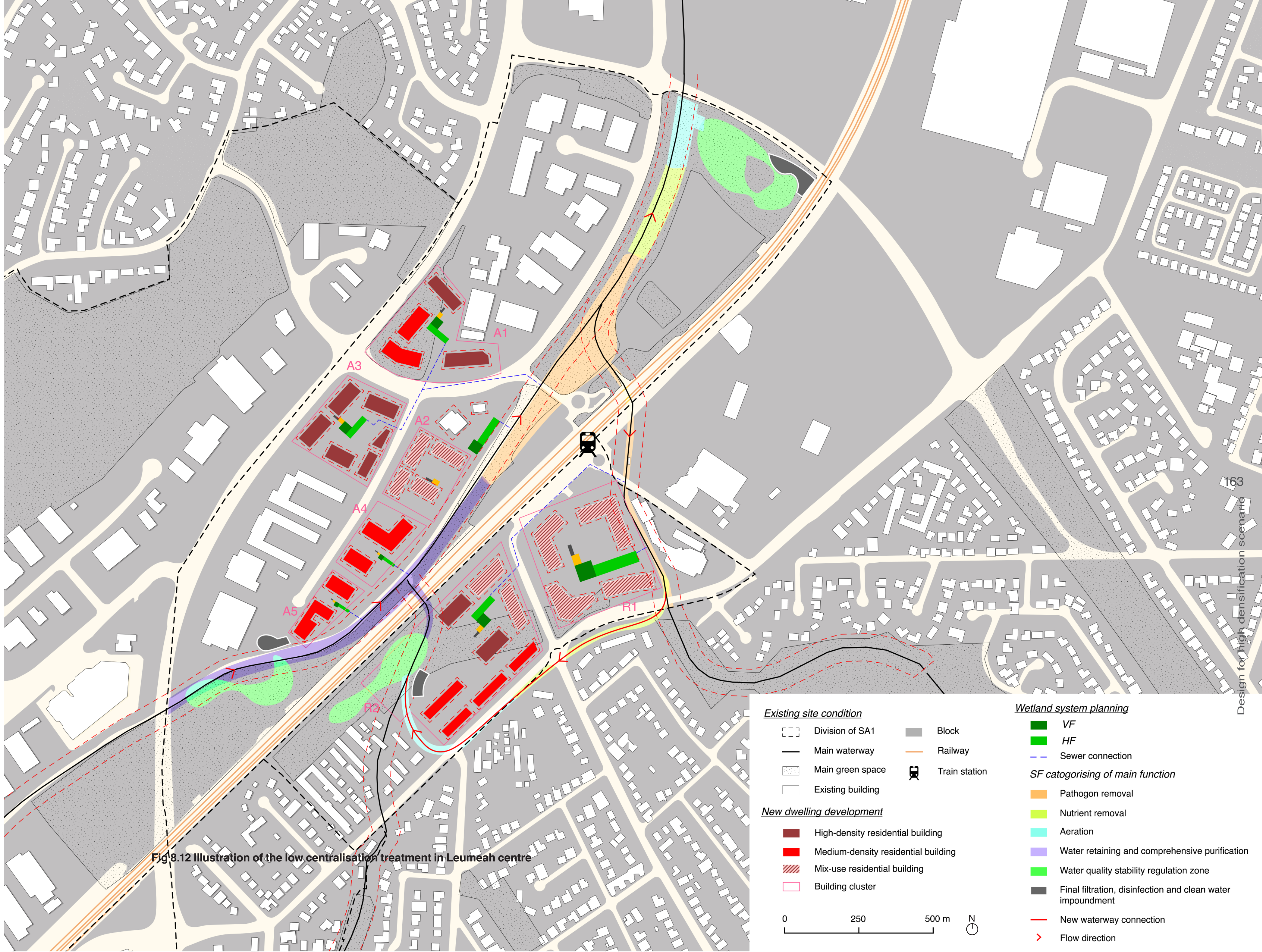


Fig 8.12 Illustration of the low centralisation treatment in Leumeah centre

Moderate centralisation

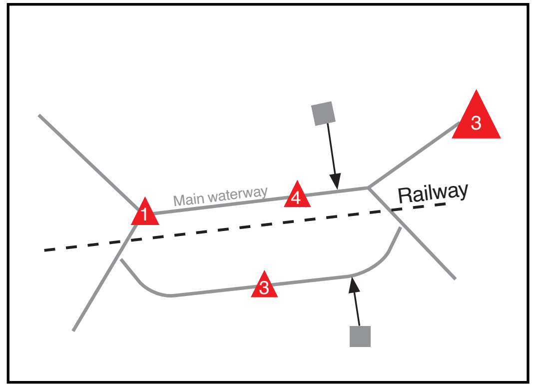


Fig 8.13 Pattern of the moderate centralisation treatment scheme

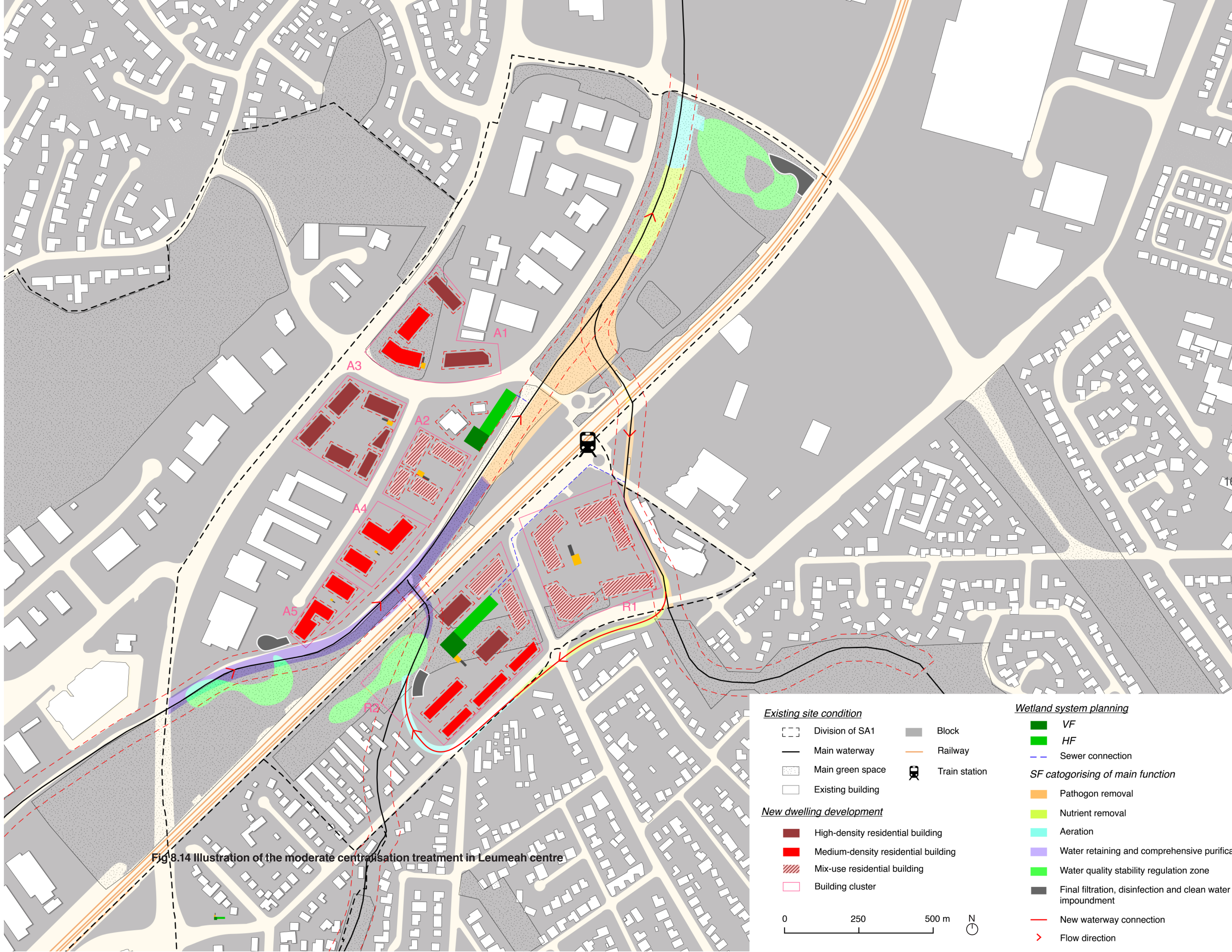


Fig 8.14 Illustration of the moderate centralisation treatment in Leumeah centre

High centralisation

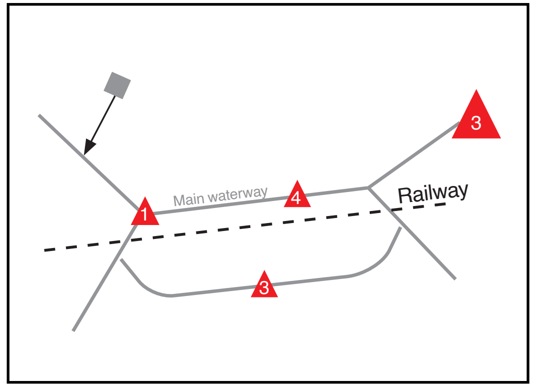


Fig 8.15 Pattern of the high centralisation treatment scheme

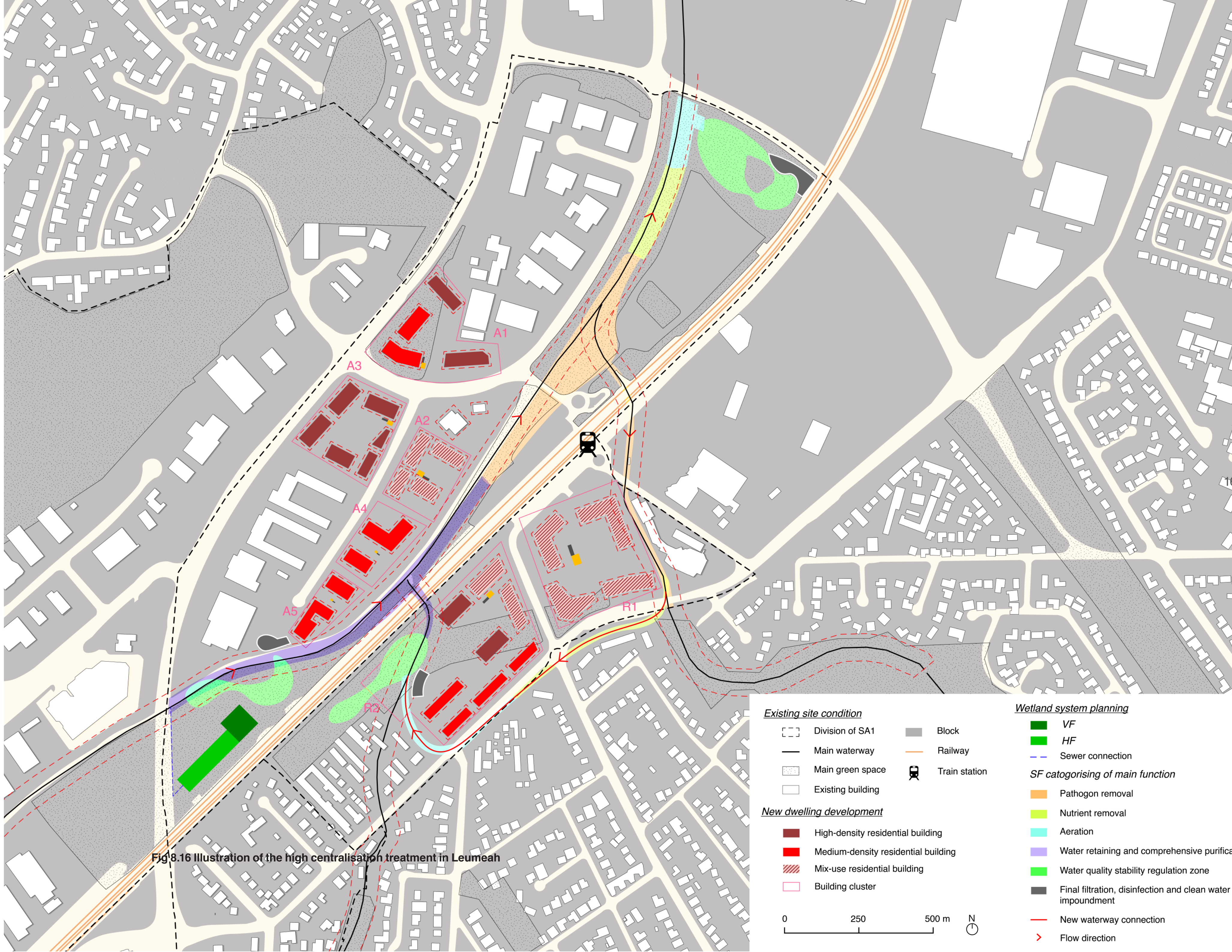


Fig 8.16 Illustration of the high centralisation treatment in Leumeah

8.3 Campbelltown centre
Design stage 1: Primary + Secondary + Tertiary treatment

Basic pattern

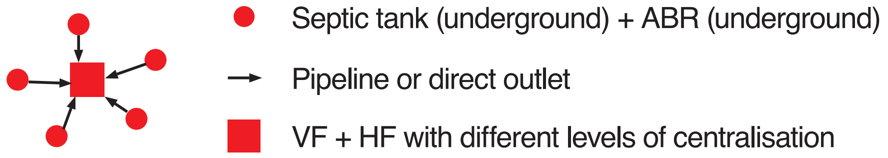


Fig 8.17 Basic pattern of the "Primary + Secondary + Tertiary treatment strategy" in Campbelltown centre

In the high densification scenario, both sides of the railway in Campbelltown centre are densified. In the southern part (of the railway), the design is the same as in the low densification scenario that all the treatment stages are on-site treatments. While in the northern part, the design concept is similar to that for the Leumeah centre, only VF and HF remain decentralised.

Campbelltown centre

Low centralisation of treatment

Moderate centralisation of treatment

High centralisation of treatment

Fig 8.18 Overview of the treatment schemes for Campbelltown centre's high densification sceanrio

Low centralisation

Illustrating the northern part to the railway

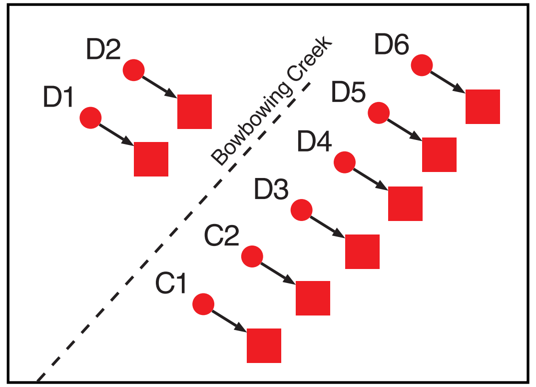


Fig 8.19 Pattern of the low centralisation treatment scheme

All the clusters have seperate wetlands (Northern part to the railway)

In the northern part, all the clusters have separate wetlands. For the wetlands of clusters D1-4, there can be expected an integrated landscape development with the VF, HF, and the redevelopment of Bowbowing Creek together.

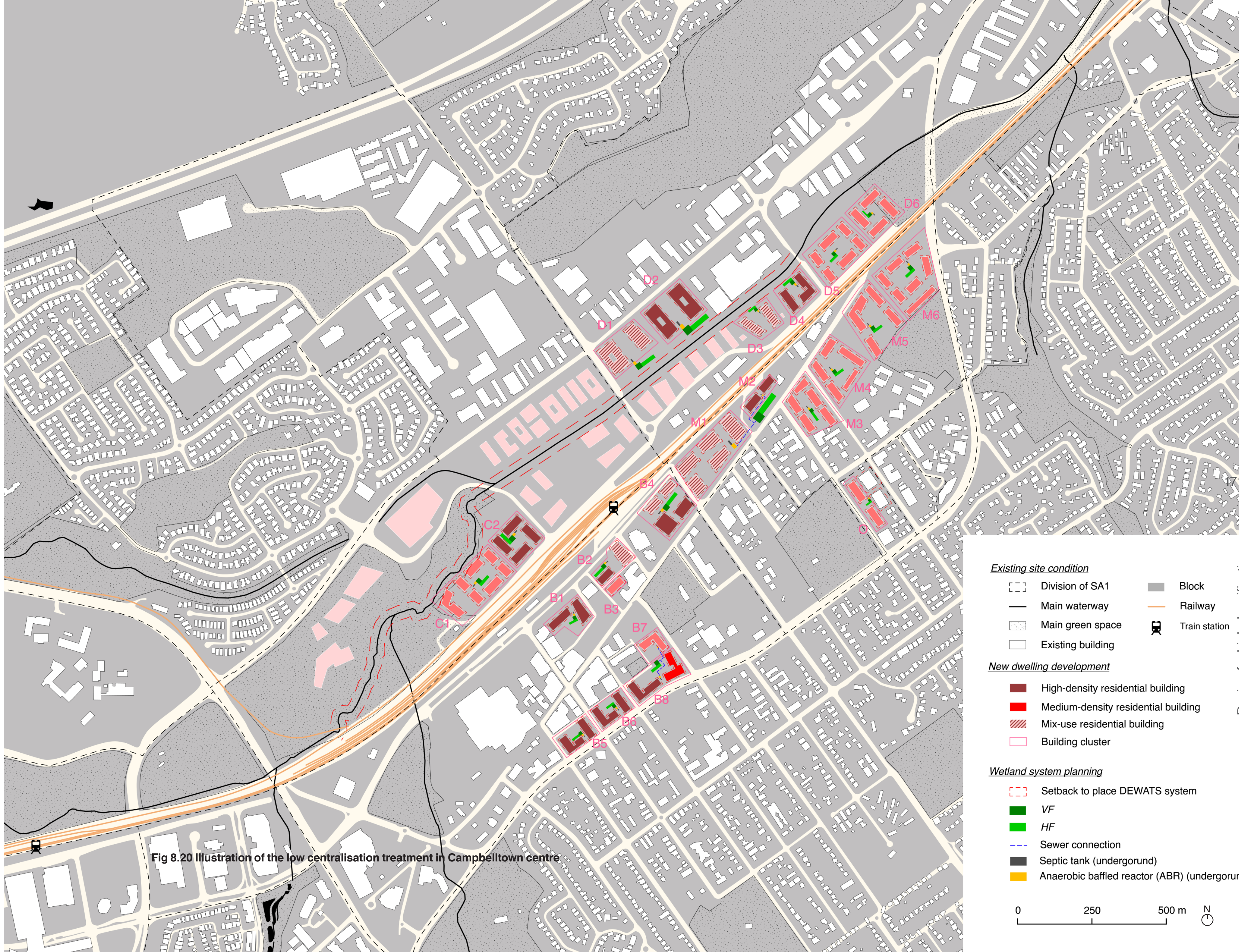


Fig 8.20 Illustration of the low centralisation treatment in Campbelltown centre

Moderate centralisation

Illustrating the northern part to the railway

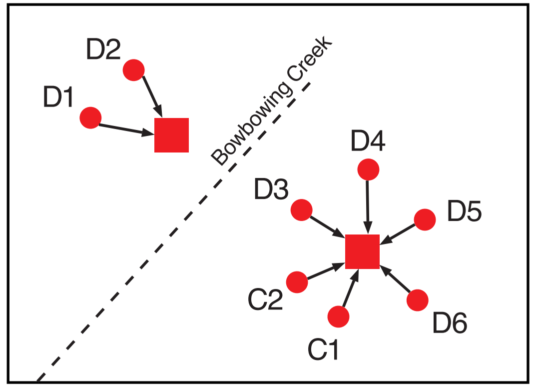


Fig 8.21 Pattern of the moderate centralisation treatment scheme

D1 & D2, C1-C2 & D3-D6 share common wetlands

Divided by the Bowbowing Creek, the wetlands cannot be located and managed with the division of SA1. In this case, the clusters to the same side of the creek share one set of wetlands. For the clusters to the southern side of the creek (C1-C2 & D3-D6), long distance of sewers are required to collect the water and deliver it to the treatment place, which is an ideal place for living machine treatment as it is close to the technology hub.

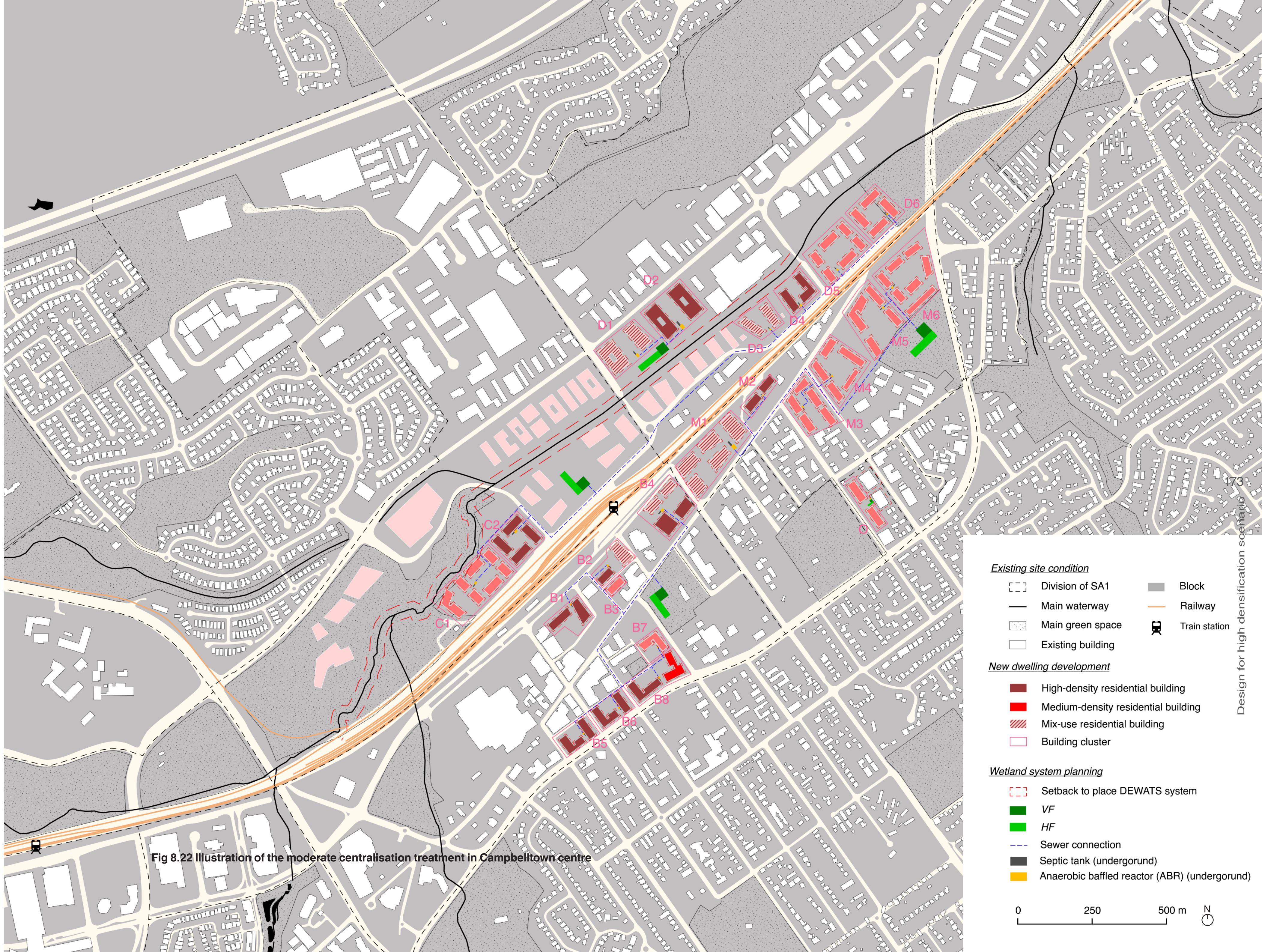


Fig 8.22 Illustration of the moderate centralisation treatment in Campbelltown centre

High centralisation

Illustrating the northern part to the railway

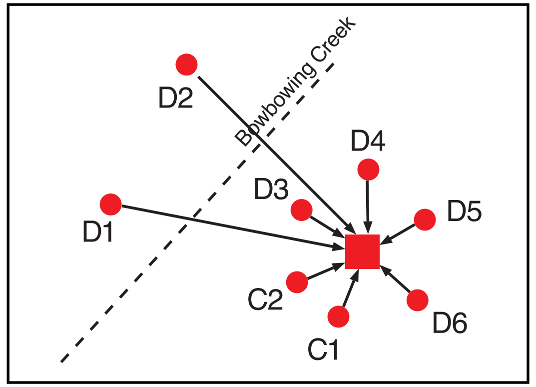


Fig 8.23 Pattern of the high centralisation treatment scheme

All clusters in northern part share one set of wetlands

This scenario is the least feasible one, as the sewers for clusters D1 and D2 have to go across the creek to deliver the waste-water. It is difficult for the construction and also generates higher risk of leakage and pollution when it is operated.

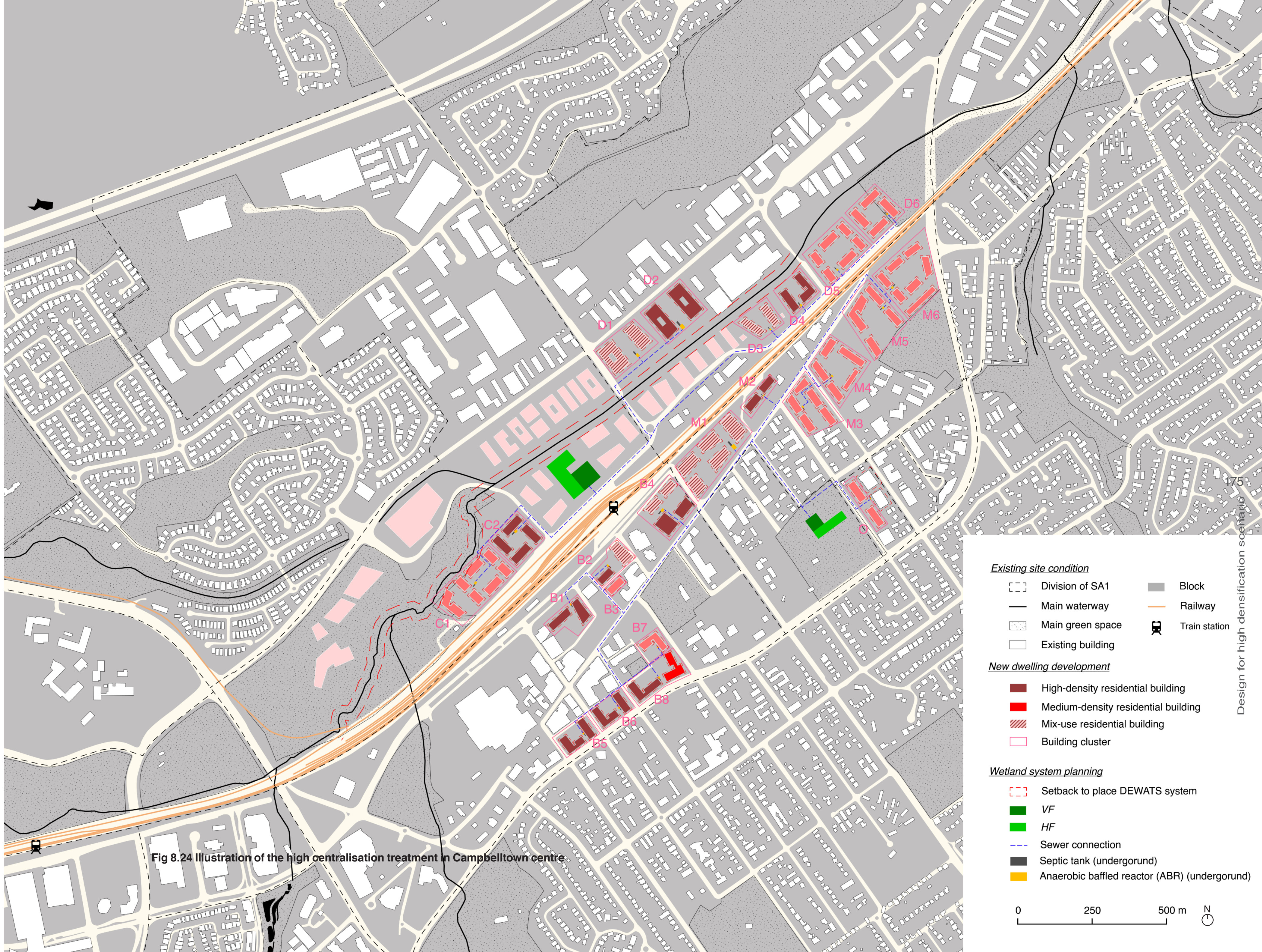
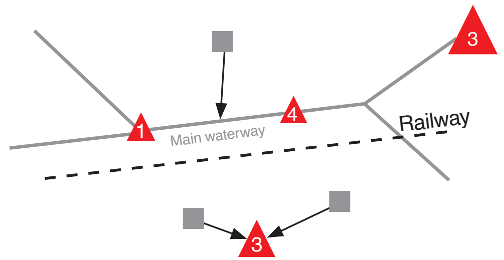


Fig 8.24 Illustration of the high centralisation treatment in Campbelltown centre

8.4 Campbelltown centre
Design stage 2: Post treatment

Basic pattern



- 1 Joints / Key points of the existing surface water network
- 3 New constructed SF on-site
- 4 Revival and redesign of the surface water stream
- VF + HF with different levels of centralisation

Fig 8.25 Basic pattern of the post treatment in Campbelltown centre

For the southern part (to the railway) of the Campbelltown centre, the design is the same as that of the low densification scenario. While for the northern part, the Bowbowing creek can still become part of the post treatment with small redevelopment and serve treated water to the dwellings located in the northern part.

Low centralisation of treatment

Moderate centralisation of treatment

Fig 8.26 Overview of the treatment schemes for Campbelltown centre's high densification sceanrio

As the high centralisation scenario for the post treatment is similar to the moderate scenario, it is not illustrated separately.

Low centralisation

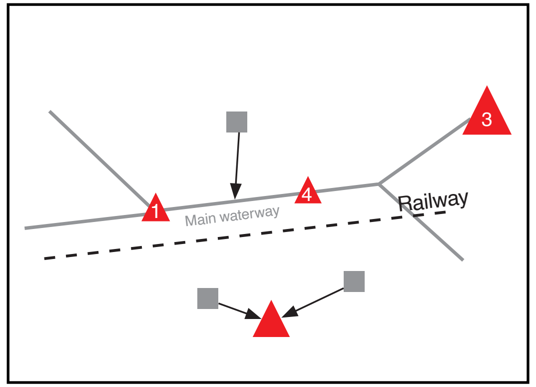


Fig 8.27 Pattern of the low centralisation treatment scheme

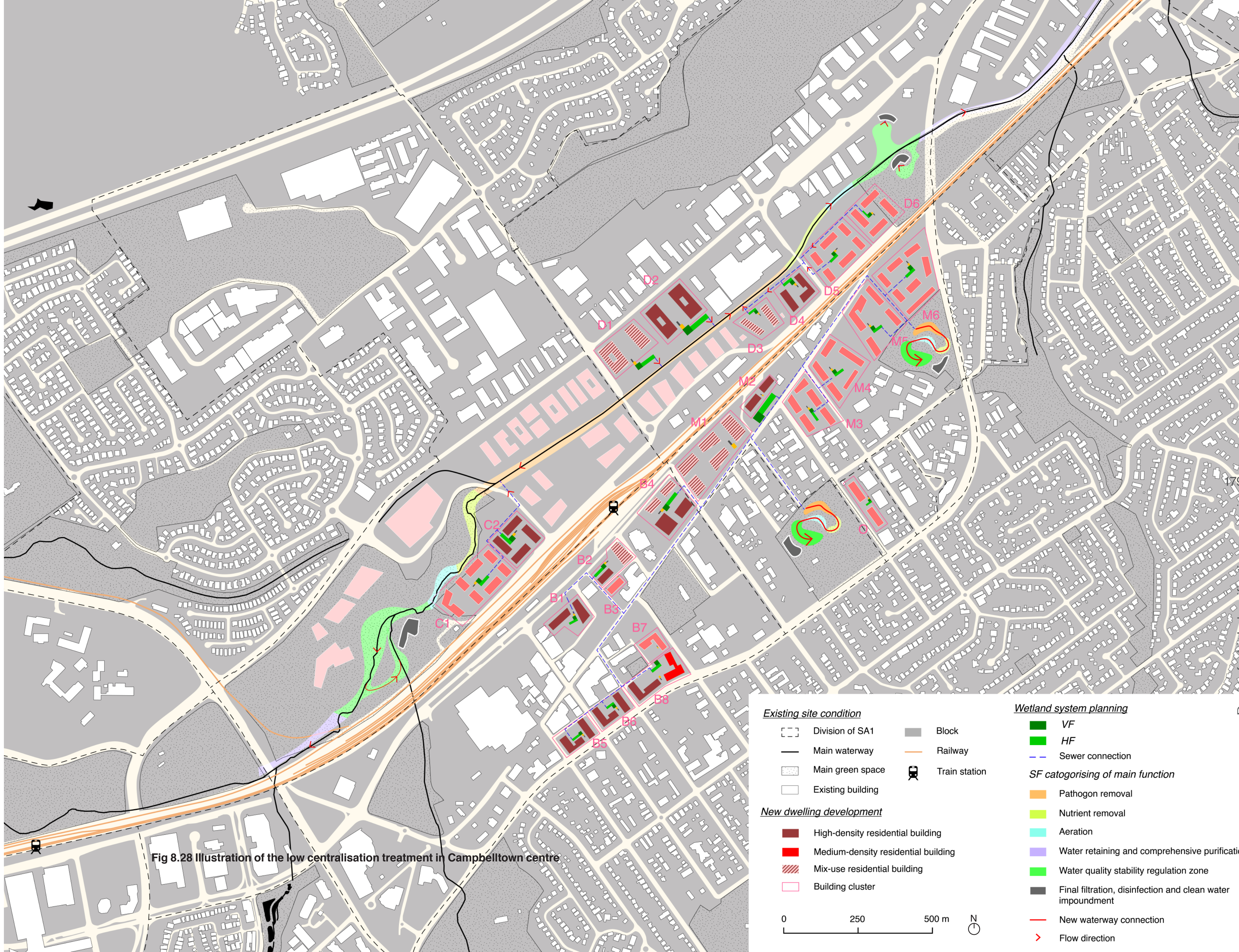


Fig 8.28 Illustration of the low centralisation treatment in Campbelltown centre

Moderate centralisation

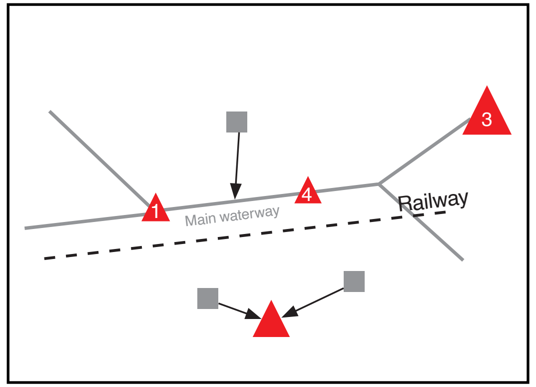


Fig 8.29 Pattern of the moderate centralisation treatment scheme

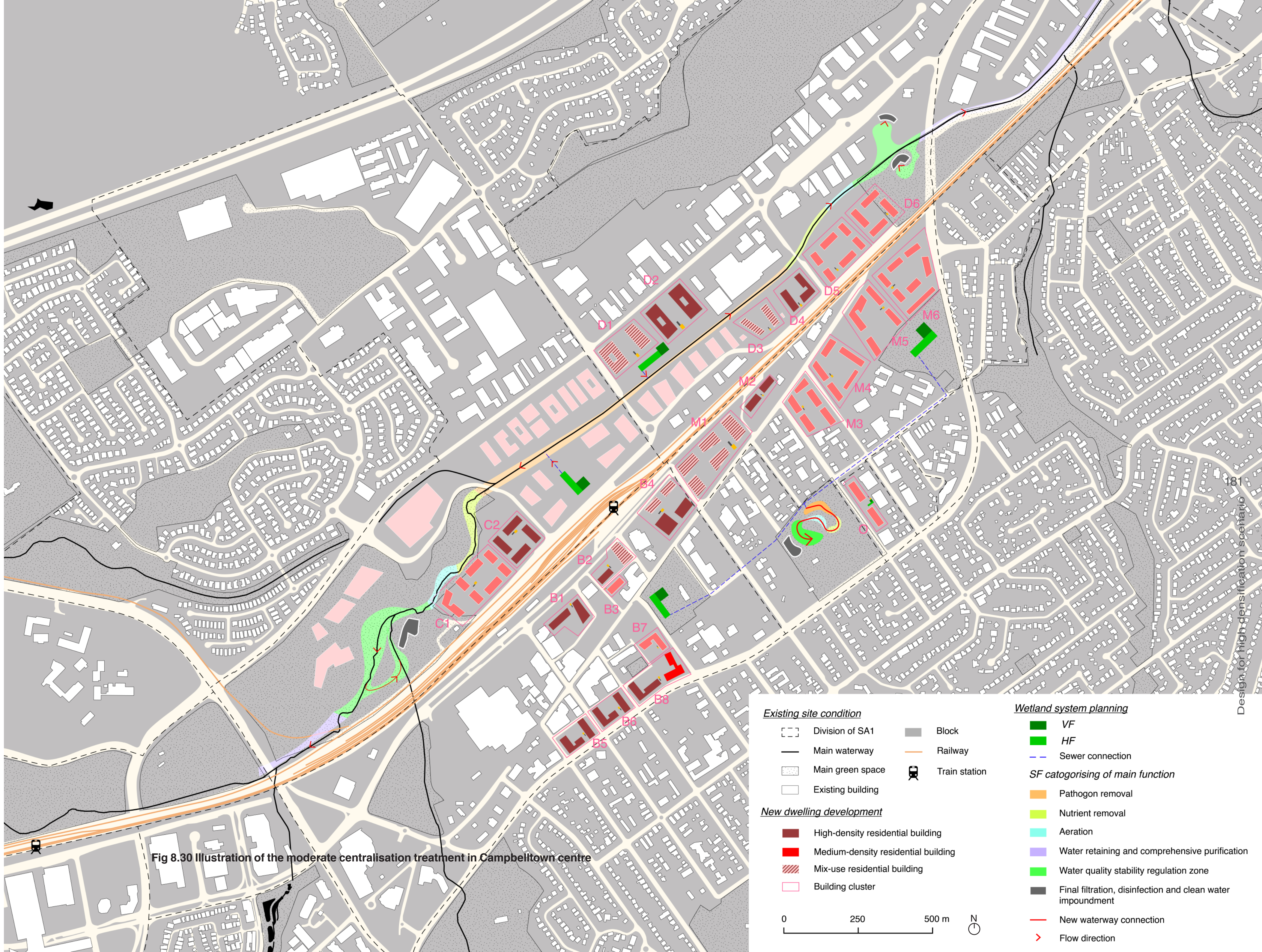


Fig 8.30 Illustration of the moderate centralisation treatment in Campbelltown centre

9. Connection for treated water re-use

9.1 Leumeah centre: low densification
9.2 Leumeah centre: high densification
9.3 Campbelltown centre: high densification

9.1 Leumeah centre: low densification

1. The treated water can be directly re-used by irrigating the sportsfield nearby.
2. After the irrigation, water is drained and is promising to be treated and re-used again, they can be released to the creek and join a second cycle of treatment.
3. In order to make the treated water available for household use in new dwellings, a new surface flow connection has to be created, which innitiate the second treatment cycle with the same sub-stages of SF treatment.
4. In the end, the water can be collected and monitored by the plants and be supplied to the new residential buildings.

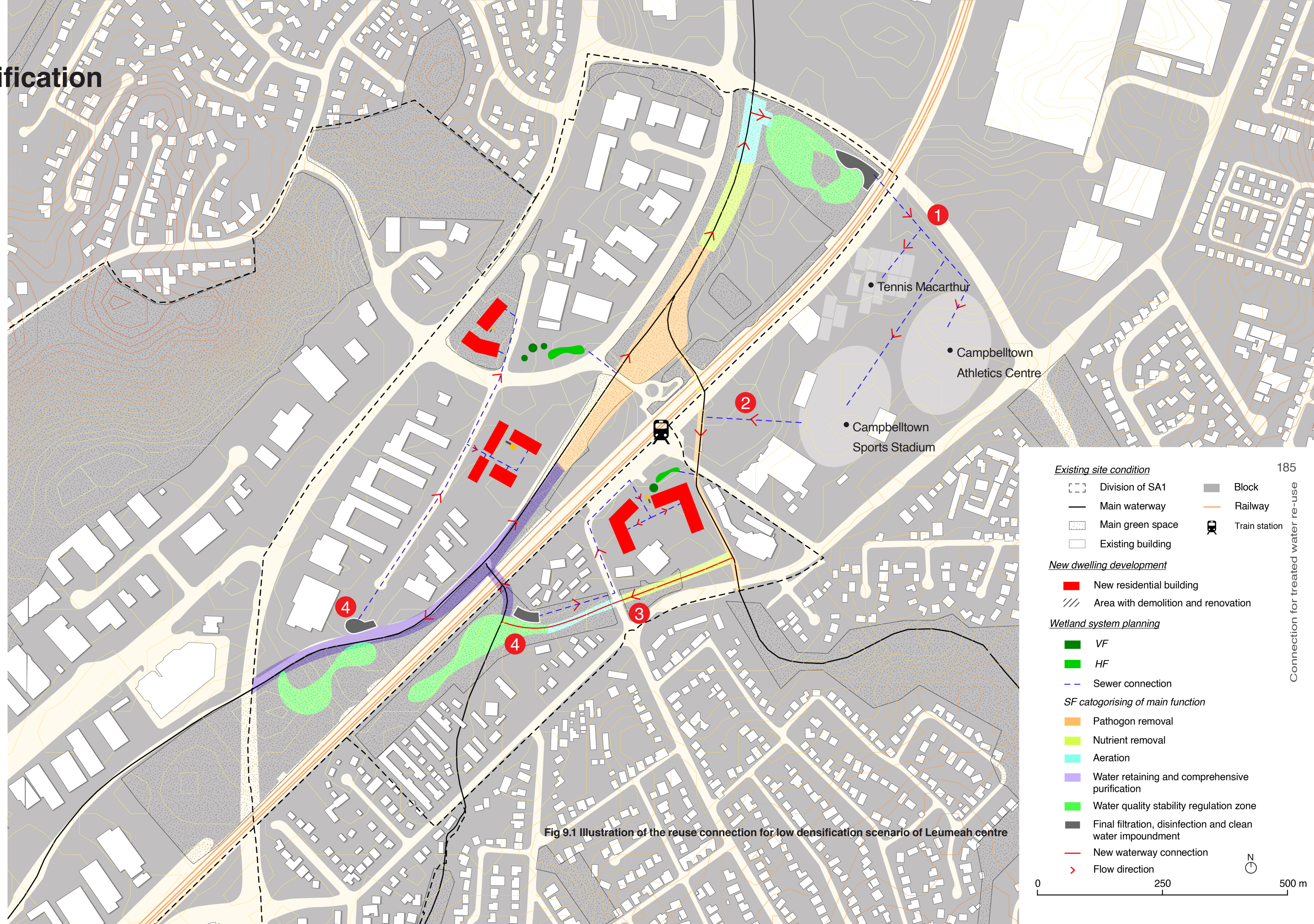


Fig 9.1 Illustration of the reuse connection for low densification scenario of Leumeah centre

9.2 Leumeah centre: high densification

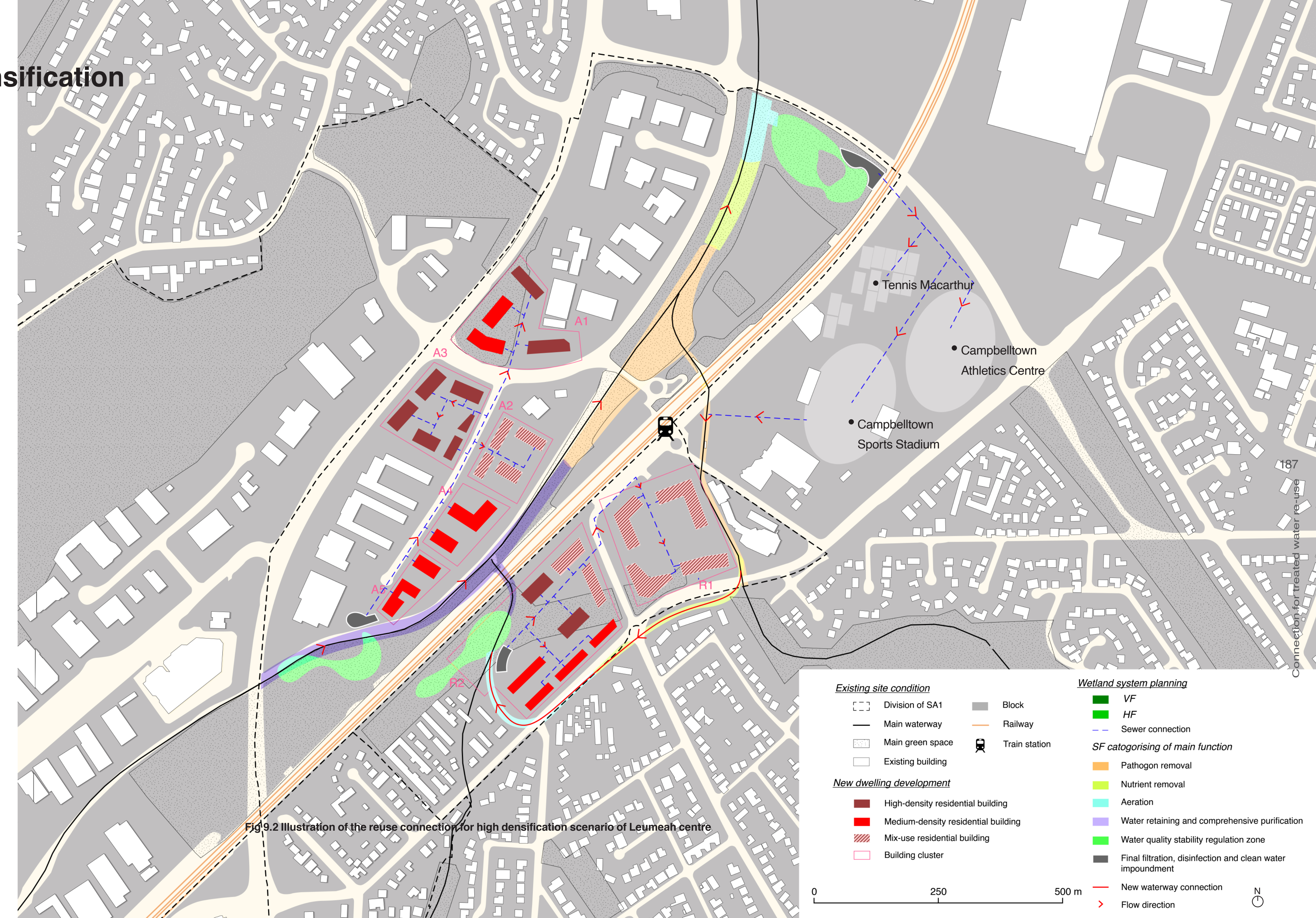


Fig 9.2 Illustration of the reuse connection for high densification scenario of Leumeah centre

9.3 Campbelltown centre: high densification

As there is no significant sports field in Campbelltown that requires frequent and large scale irrigation, all the treated water are re-used by the added local households

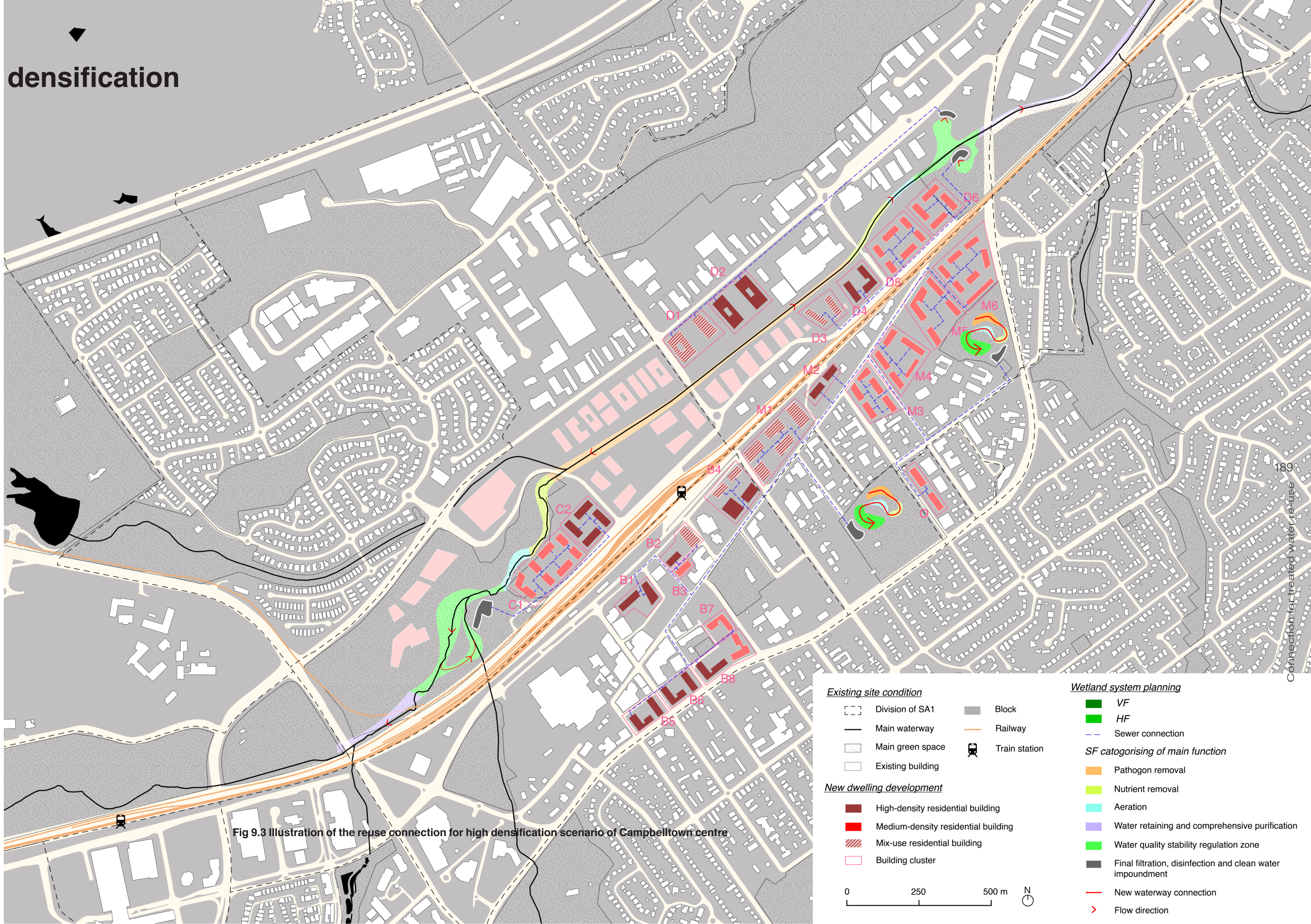


Fig 9.3 Illustration of the reuse connection for high densification scenario of Campbelltown centre

10. Spatial design

10.1 Categorisation of the wetlands

This section discusses how the designed constructed wetlands in the project add value to the spatial quallity in different scales and relations with the surroundings.

Building
Road / Street
Block
VF + HF with different levels of centralisation

Street-side garden (Fig 10.1)

With a relative smaller scale compared to the other types, the garden can be an add-in of an exisitng flowerbed or grass area as a less obvious element but still contributes to a better greenview or streetscape (Fig 10.3).

Fig 10.1 Typical location of a streetside garden

- Treatment level: Secondary - tertiary
- Applied scenarios: Low-moderate centralisation of treatment scenarios in Leumeah centre, low centralisation of treatment in Campbelltown centre
- Location: Along the streets and roads
- Typical area requirement per set (combination of vertical and horizontal subsurface wetlands): 300 - 2000 m^2
- Public accessibility: Completely accessible on site for surrounding blocks and roads; vision accessibility depends on its scale and location.

On-site community garden (Fig 10.2)

This type of setting is ideal to become an adornment for a public courtyard, which can fit with pavements and be accompanied by public furnitures, contributing to a vibrant neighborhood social and living environment (Fig 10.4, Fig 10.5).

Fig 10.2 Typical location of a community garden

- Treatment level: Secondary - tertiary
- Applied scenarios: Low-moderate centralisation of treatment scenarios in Leumeah centre, low centralisation of treatment in Campbelltown centre
- Location: Within each building cluster
- Typical area requirement per set (combination of vertical and horizontal subsurface wetlands): 100 - 1,800 m^2
- Public accessibility: Completely accessible on site for the residents of corresponding building clusters but might not be accessible for others, depending on the location; vision accessibility is limited: people outside the cluster can hardly see the wetlands.

Fig 10.4 "Urban Decentralised Treatment Garden" (Ulrich, n.d.), as an example of on-site community garden

Fig 10.3 "Phyto-purification of greywater" (Chez Yves Damoiseau, 2010), as an example of street-side garden

Fig 10.5 "On-site sewage treatment in Sidwell Friends School" (American Society of Landscape Architects, 2017), as an example of on-site community garden

Building
Territory
Surface flow wetland
Road / Street
VF + HF with different levels of centralisation

Functional pond and water routes (Fig 10.6)

This feature is aimed at treating the domestic wastewater and stormwater at the same time, meanwhile improving the riverfront landscape. The redevelopment is drectly worked on the existing surface water area, and will be equipped with promenades that provide unique aesthetic experience while satisfying ecological and display functions (Fig 10.8).

- Treatment level: Tertiary - Post
- Applied scenarios: Engaged in all scenarios
- Location: Existing waterways including Bowbowing Creek, Smith Creek, Leumeah Creek, and new connections
- Total area: Around 125,000 m^2
- Public accessibility: Completely accessible to public as a place for leisure and strolling around; vision accessible to the whole city centre

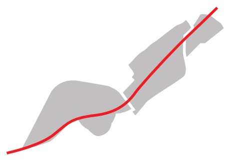


Fig 10.6 Illustration of the functional water route

Cells in the park (Fig 10.9)

For designing the wetlands in the parks that have exisitng clear layout, the wetlands (or redesigning the existing applicable planting terraces) can be formed as seperate cells between the pathways and ornaments in the park, connecting the cells with visible water networks to weave the new wetlands into the existing park fabric.

- Treatment level: Secondary - tertiary - (post)
- Applied scenarios: Moderate-high centralisation of treatment scenarios in Campbelltown centre
- Location: existing public park area, undeveloped open area
- Typical area: 2,000 - 7,300 m^2
- Public accessibility: Completely accessible to public as the added fabric of the existing or future park area

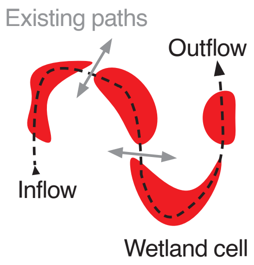


Fig 10.7 Illustration of the wetland cells in park

Fig 10.8 "Shanghai Houtan Park: Landscape as a living system" (Landscape China, 2018), as an example of functional waterway

Fig 10.9 Example of wetland in parks (Russell et al., 2021)

Living machine showroom (Fig 10.10)

This feature can be expected in the open space that is located to the northern side of the Campbelltown train station (SA1: C). The constructed wetlands are organised in an in-door environment (Fig 10.11) that displays the sturcture and principle of the DEWATS transparently. It provides opportunity for public education of the knowledge in DEWATS and the functions of plants in water treatment.

- Treatment level: Secondary - tertiary - (post)
- Applied scenarios: Moderate-high centralisation of treatment scenarios in highly densified Campbelltown centre
- Location: Campbelltown city centre where the place is proposed to be technical and education centre
- Typical area: 2,000 - 5,000 m^2
- Public accessibility: Completely accessible to public as an in-door exhibition and education centre that shows the treatment process transparently

Fig 10.10 Illustration of the living machine showroom

Fig 10.11 "Sechelt Water Resource Centre " (PUBLIC Architecture + Communication, 2018), as an example of treatment show-room

10.2 Demonstrative wetland design

Design for Mawson Park (for moderate centralisation of treatment)

Mawson Park shares the same age as Campbelltown, it was established when Governor Macquarie bestowed the town's name upon it in 1820, which was referred to as "The Green" or "The Recreation Reserve,". The park underwent a renaming in 1938 to commemorate Dr. William Mawson, a respected physician who served the community for 28 years before retiring.

Nowadays, the park is also playing an important role in commemorating the history of Campbelltown and Anzac (Australian and New Zealand Army Corps) spirits by symbolic sculptures and monuments in park (Fig 10.12-14). Mawson Park serves as the venue for significant ceremonial events like Anzac Day and Remembrance Day. These occasions allow the younger and future generations to honor and acknowledge Australia's military history, as well as the bravery presented by those who fought in wars.

Surrounding the park are different services that help create vibrant life together with the park (Fig 10.16-19).

Fig 10.12 The War Memorial sandstone obelisk (Kontos, 2021)

Fig 10.13 A Naval memorial, Air Force Memorial and Army Memorial (Campbelltown City Council, n.d.-b)

Fig 10.14 A sculpture / fountain that commemorates Mrs Elizabeth Macquarie, whose maiden name was Campbell (Campbelltown City Council, n.d.-b)

Fig 10.15 A small children's playground (Campbelltown City Council, n.d.-b)

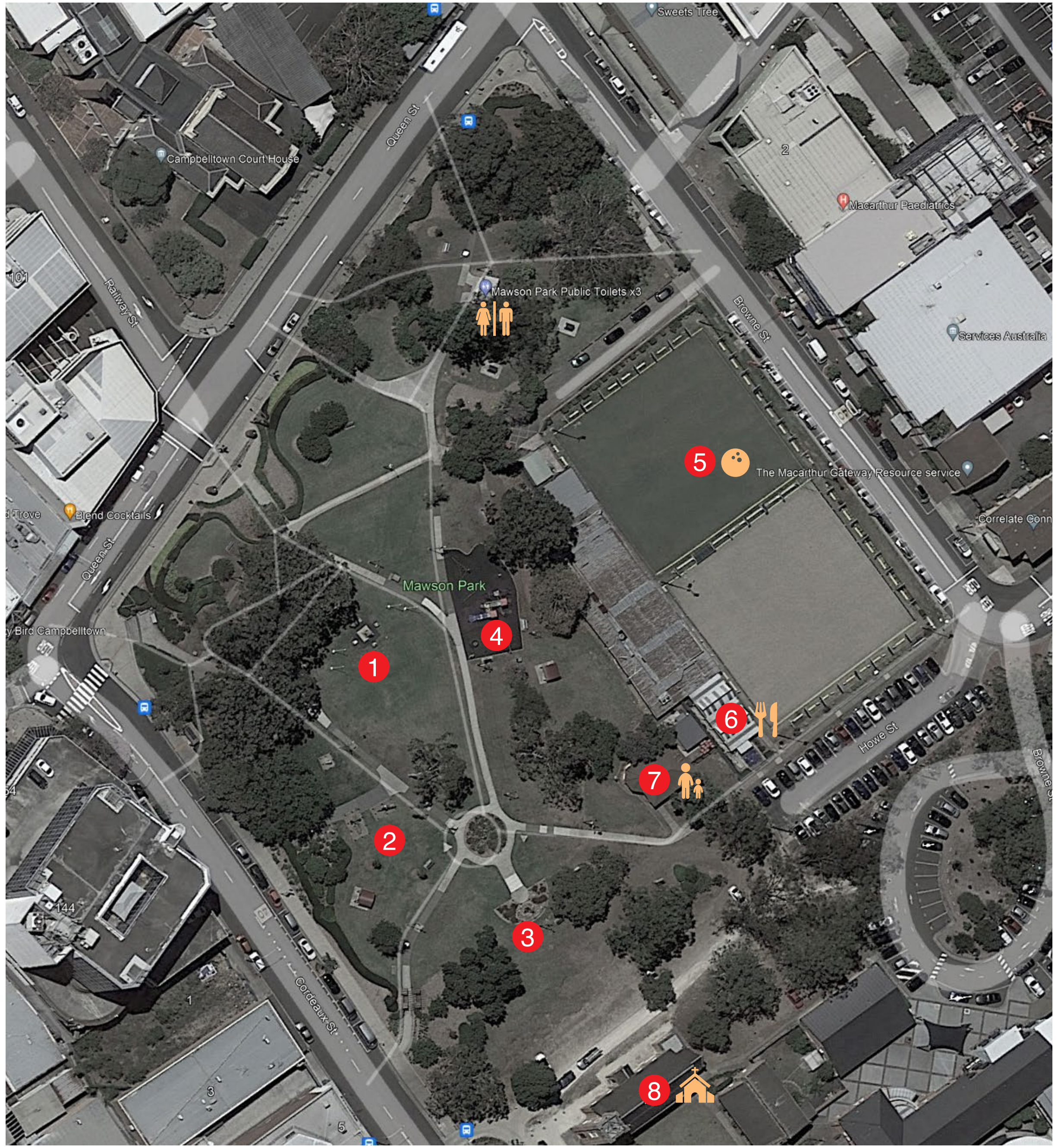


Fig 10.16 Campbelltown City Bowling Club (Macarthur, n.d.)

Fig 10.17 Chilli Joe Thai Cuisine Restaurant (Google, 2023)

Fig 10.18 Mawson Park Early Childhood Health Service (Monument Australia, 2019)

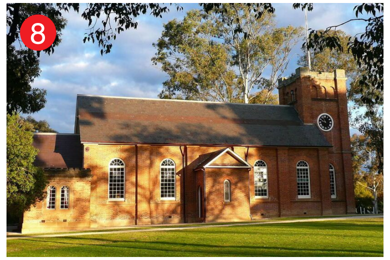
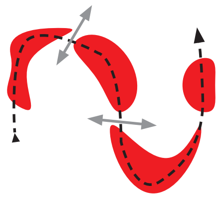


Fig 10.19 Campbelltown Anglican Church (Design, 2021)

Design consideration

The design reserves the original layout of the park to the largest degree, and ensures that all the historically significant objects are unintervene. The wetland features are weaved in the existing texture as “cells in the park” (page 194)



1. The vertical flow subsurface wetland is designed with an observation deck (bridge) above, which enables the visitors to have a good visiting and observing experience from different angles. Meanwhile, it separates the visitor routes from the playground area, for the sake of ideal experience of both functions.

2. The pavillion provides necessary shading and meeting place, which also makes the landscapes visually connected.

3. The two branches of the water routes are also a part of the horizontal subsurface flow wetland. One of the branch (western) passes through the place with multiple millitary sculptures as a way guidance, the other (eastern) goes across an area with dense trees and bushes where visitors can have immersive landscape experience both at ground and eye level.

4. As one of the most important feature in the park, the role of the fountain is enhanced by being an island embraced by a small undulating hill where people can sit freely and enjoy the scenery around. The horizontal flow wetland goes around the hill and provides treated water for the fountain. The site is an ideal place for the church community and the Bowling club nearby.

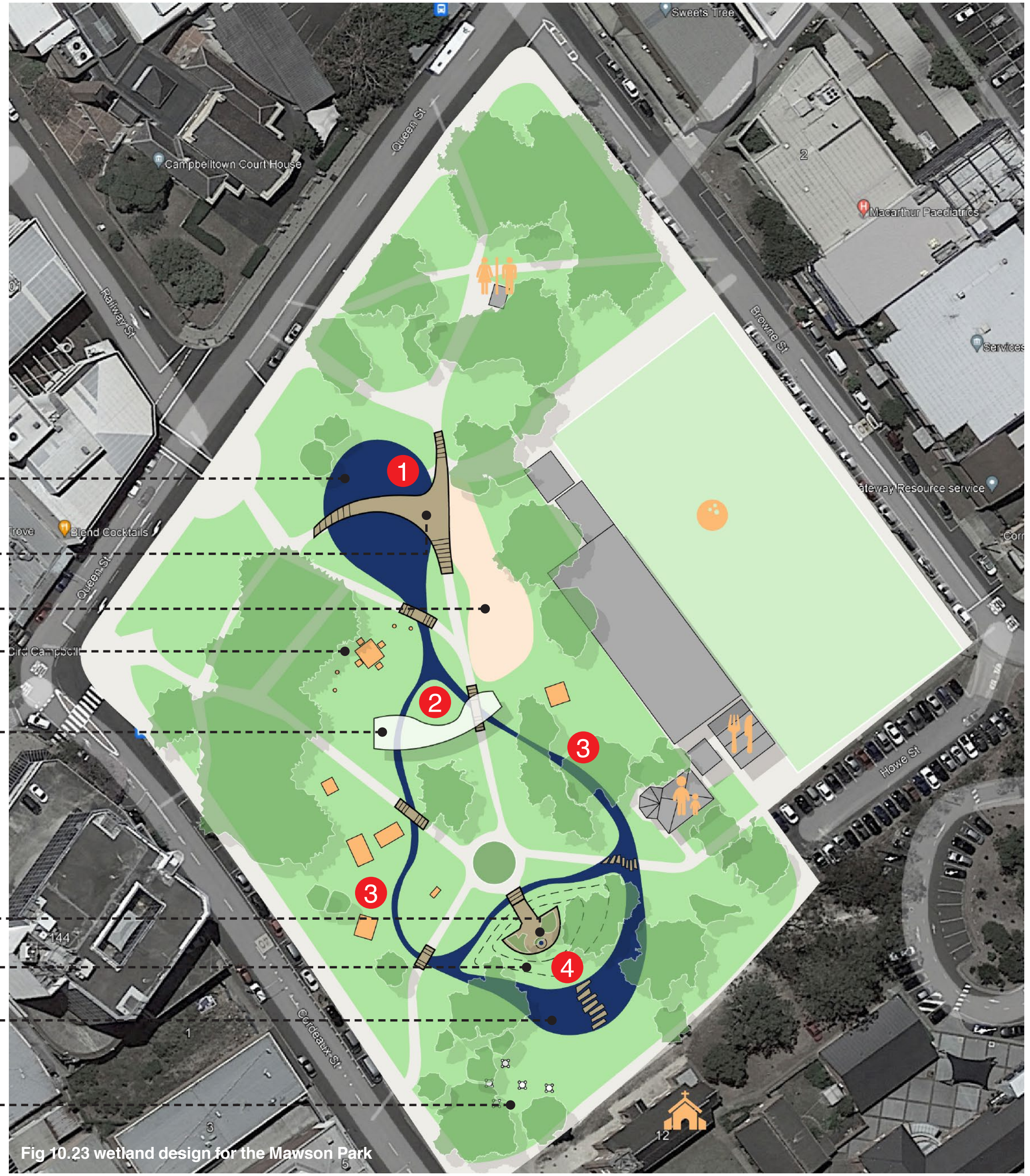


Fig 10.23 wetland design for the Mawson Park

Fig 10.21 Example of the observation deck (The Wild Deck Company, 2018)

Fig 10.22 Example of the pavilion (Landscape China, 2018)

Fig 10.24 Mawson Park before design

Fig 10.25 Mawson Park after design

Design for Campbelltown Showground (for high centralisation of treatment)

Campbelltown Showground is an open field that caters to a wide range of events. It serves as a central hub for agricultural shows, exhibitions, trade shows, concerts, and sporting events.

Arround the showground, there are diverse educational services such as bicycle education (Fig 10.26), preschool (Fig 10.27), and rugby club (Fig 10.28). A new high-rise residential building “the Emerald” (Fig 10.29) was just built up and in use. There is a car park next to the showground, which will be potentially demolished and replaced by the integrated wetland design.

Fig 10.26 Campbelltown’s Bicycle Education Centre
(Campbelltown City Council, n.d.-b)

Fig 10.30 Satellite map of the Campbelltown showground (Google map, 2021)

Fig 10.27 Campbelltown Community Preschool
(Campbelltown Community Preschool, n.d.)

Fig 10.28 Campbelltown Harlequins Rugby Club
(Campbelltown Harlequin Rugby Club - Juniors, 2020)

Fig 10.29 New properties in 38/48-52 warby Street
(Totten, 2023)

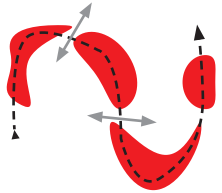
Design consideration

In the design, the showground's mian function of events and performance holding is kept and strengthened. Meanwhile, the space will also be designed with special features for bicycle practicing and children playing, considering the surrounding services and the extra spatial needs they may have.

1. The vertical flow subsurface wetland is integrated with an open air theatre. The audience can sit either on the auditorium or the adjacent small hill designed for free seating. Facing the main entrance of the showgroung, this feature is an eye-catching element when there is performance held.

2. The bike park is the other main activity that is underlined in the design, which is mainly a fun topography with variations of biking routes to explore. The horizontal subsurface flow runs across the and underneath the biking park where the space forms a cave and the pedestrians can also pass through. The biking park is separated from the pedestrian's routes to ensure the safety and the experience for both functions, while people can also watch the bicycle activities from their paths. The biking park can be straightly accessed through the entrance opening to the south, close to the Campbelltown's Bicycle Education Centre.

3. A new playground is prepared for the children in Campbelltown Community Preschool and Campbelltown City Outside School Hours Care which are located around the park. A cafe and some meeting points are located next to the playground for the parents to spend their time while watching children playing.



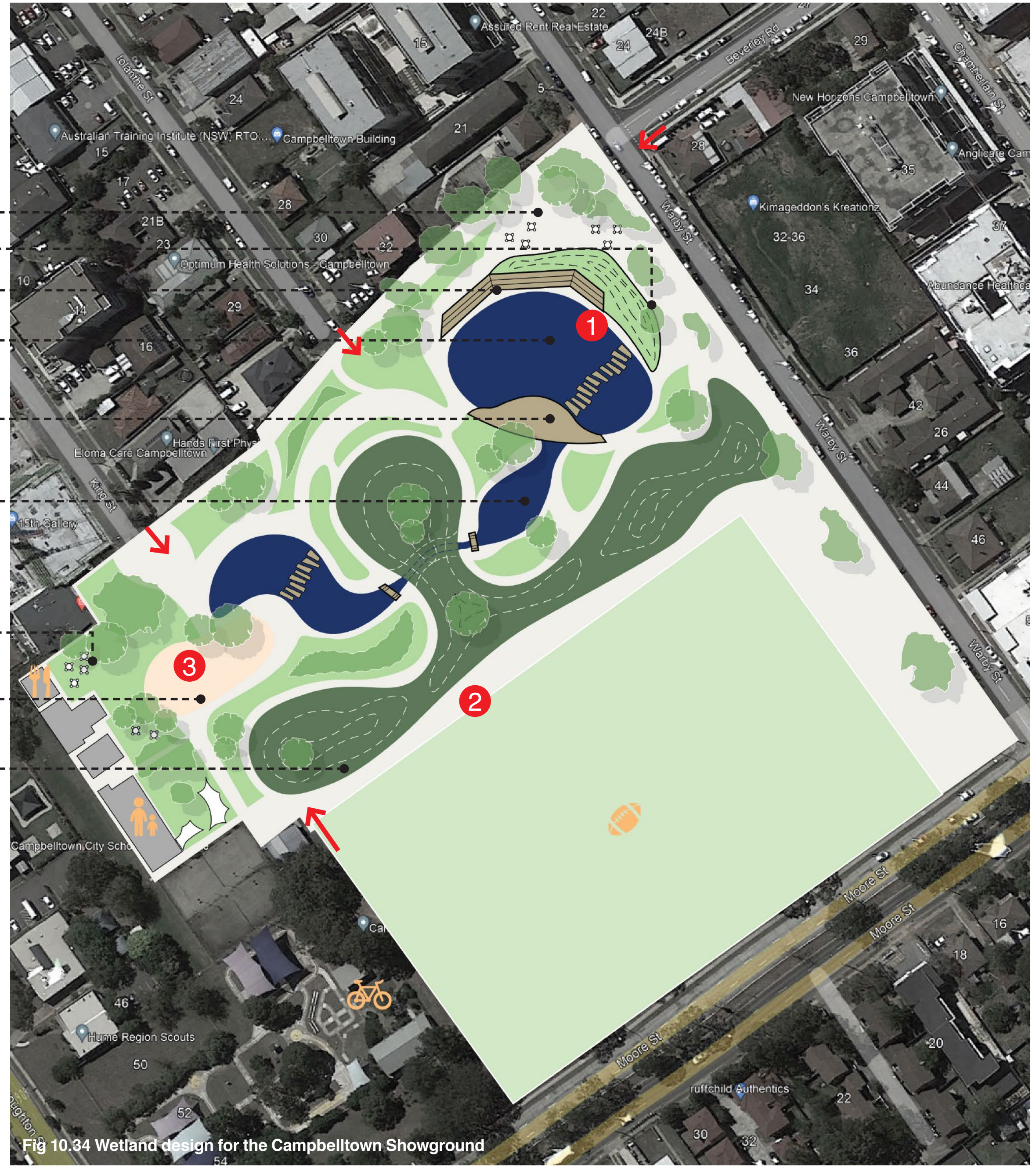


Fig 10.34 Wetland design for the Campbelltown Showground

Fig 10.31 Example of the theatre (WWT, 2023)

Fig 10.32 Example of the bike park (BERN, n.d.)

Fig 10.33 Example of the playground (Arcady, 2011)

Fig 10.35 Campbelltown Showground before design

Fig 10.36 Campbelltown Showground after design

Design for the community garden (for low centralisation of treatment)

The site to be demonstrated with design is currently occupied by a large warehouse that sells construction equipments and area for car parking. With the redevelopment to be expected, the warehouse is supposed to be moved to an outer area of the local government area, so this piece of land can be available for residential development.

At present, there is a drainage way going across the site. As the DEWATS is introduced to this area, the existing drainage is no longer needed and will be replaced by the new design.

Fig 10.37 Location of the site for community garden design

Fig 10.39 View on Farrow Rd (Google streetview, 2021)

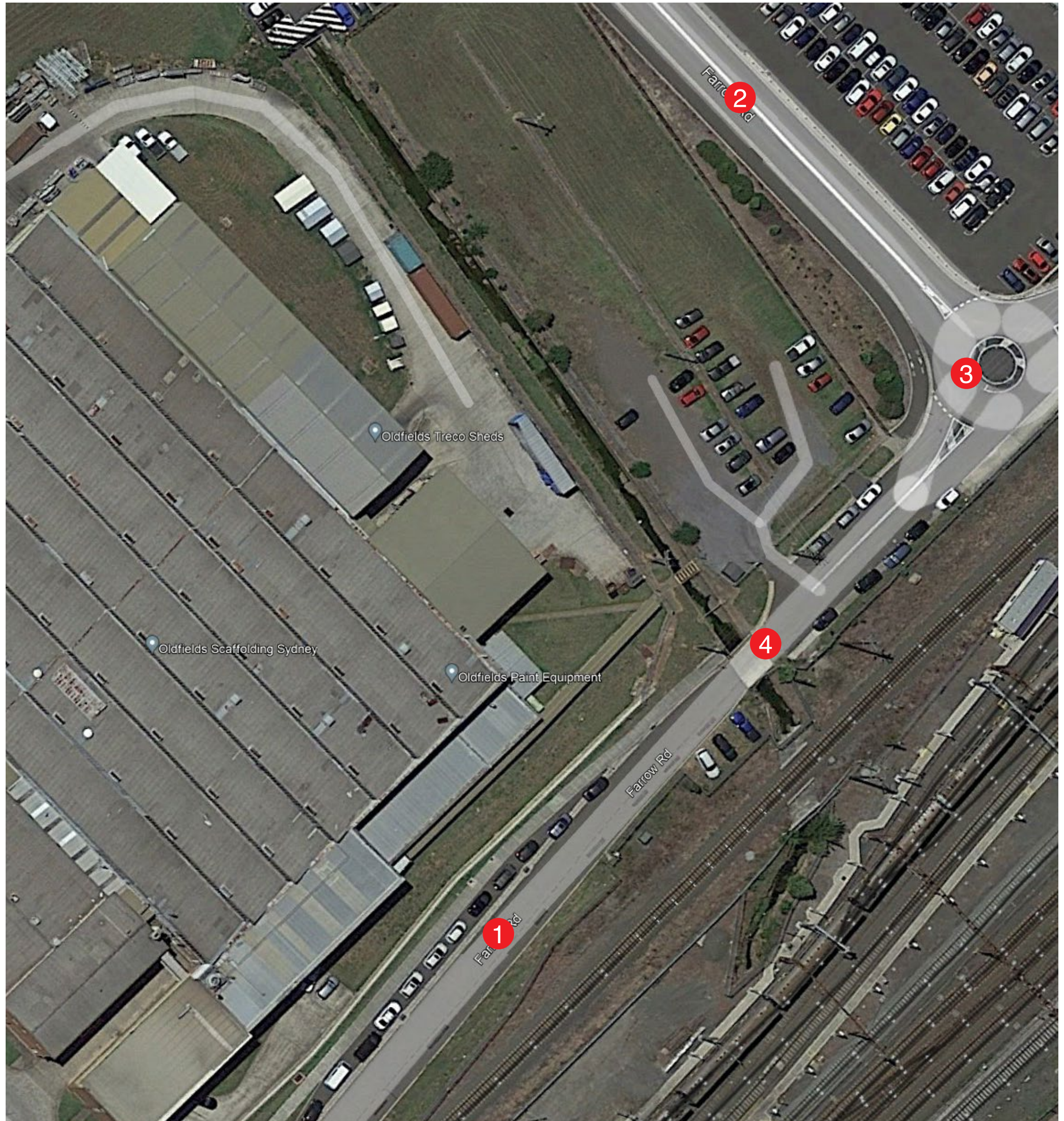


Fig 10.38 Satellite map of the site for community garden design (Google map, 2021)

Fig 10.40 View on Farrow Rd (Google streetview, 2021)

Fig 10.41 View on Farrow Rd (Google streetview, 2021)

Fig 10.42 View on Farrow Rd (Google streetview, 2021)

Design consideration

The desgin for the community garden is more focused on creating an exclusive and relaxing environment that satisfies the desire for both small-scale socialisation and privacy. Different from the other two design scenarios, the challenge for low centralisation treatment designing also includes how to allocate the facilities of the first two treatment stages (septic tanks and ABR).

1. The ABR and septic tanks are hidden by the bushes around to ensure an empty space above and prevent them from being unintentionally damaged. The side of the ABR that is connected to the vertical flow wetland is attached and decorated with a multi-layer observation deck, where people can sit and enjoy the scenery.
2. There are several meeting and observing points that serve different needs: landscape watching, group meeting, being alone. The points have different distances from the wetland body.
3. A pavillion will stand at the centre of the wetland body, where people can sit still and enjoy the overview of the wetland

As the detailed design of a community garden and its surrounding landscape depends a lot on the layout and circulation of the surrounding buildings, this design can only point out the possibility and direction to develop the design on site. More collaboration and communication should be conducted to ensure it a better fit for the built environment.

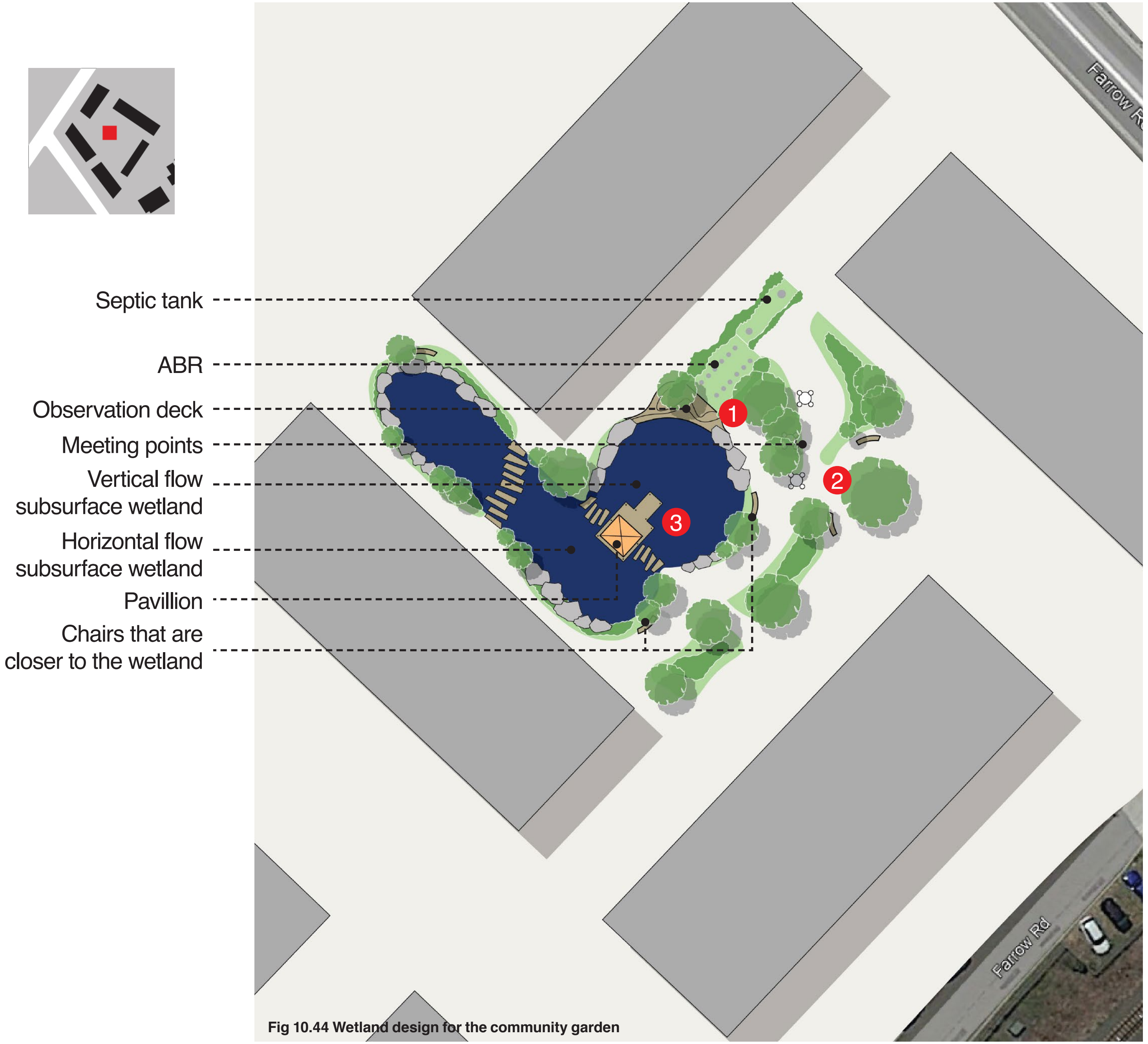


Fig 10.44 Wetland design for the community garden


Fig 10.43 Example of the community garden (Waterscapes Australia, n.d.)

10.3 Other design experiment

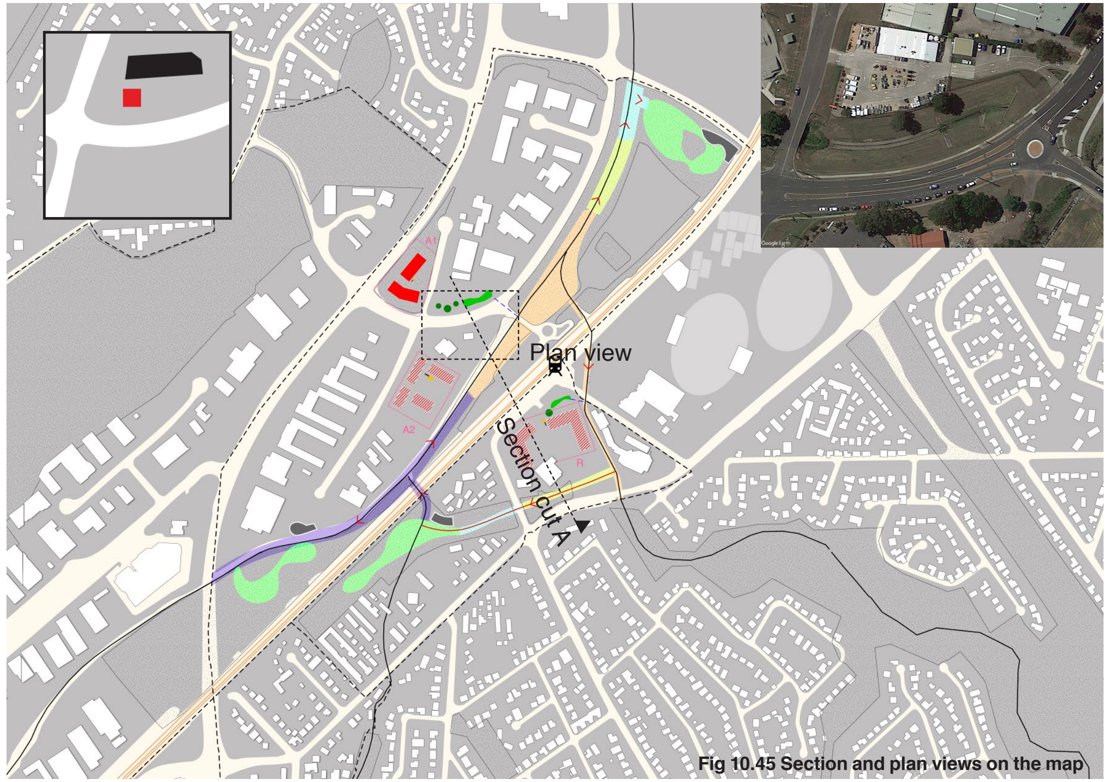


Fig 10.45 Section and plan views on the map

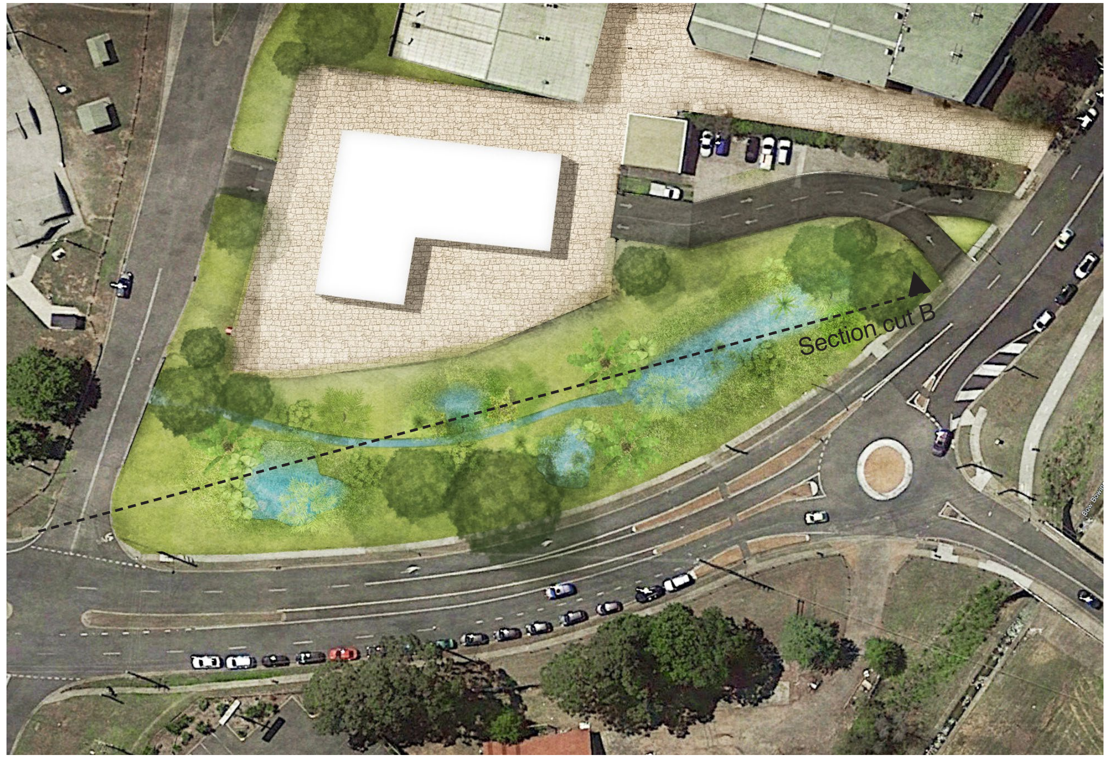


Fig 10.46 Plan view of the street-side garden

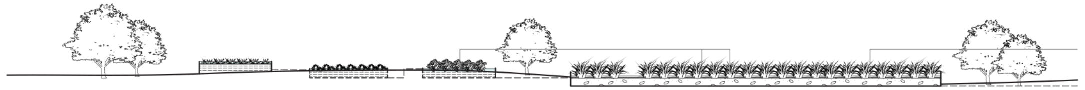


Fig 10.47 Section B

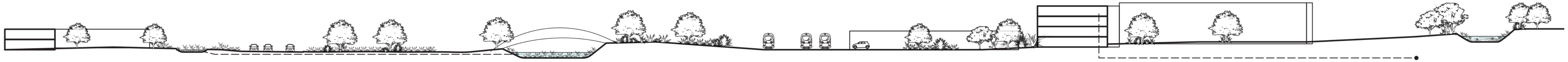


Fig 10.48 Section A

View range: area with VF+HF in Leumeah centre

Fig 10.49 Current view of the green space between building cluster A1 and A2

Fig 10.50 Designed view of the green space between building cluster A1 and A2

Bowbowing Creek in Campbelltown centre

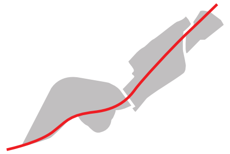


Fig 10.51 Current view of the Bowbowing creek

Fig 10.52 Designed view of the Bowbowing creek

11 . Evaluation

11.1 Parameters

Cost for the DEWATS construction

This evaluation covers the investment cost, annual capital cost, operation cost, and income from biogas with rough calculations based on the template provided by Gutterer et al. (2009). The treatment components including septic tanks, ABR, subsurface flow wetlands are designed with a life expectancy of 20 years (expected to be replaced or rennovated after being used for 20 years), and that for the sewers are designed as 50 years. The biogas is produced by Anaerobic Baffled Reactor (ABR) in the secondary treatment stage, through anaerobic digestion with different groups of organisms. Although the biogas is not a central topic of the thesis, it is one of the main sources of the income. As the production of biogas is only related to the wastewater data (flow amount, strength of COD, COD/BOD ratio), the amount only varies with the dencification levels and non-related to levels of treatment centralisation.

According to the results (Fig 11.10), the costs are not necessarily reduced with the level of centralisation increasing, as higher amount of sewers and excavation works will be required, which can be especially found in the scenarios of Campbelltown centre, where the densification is more intensive and less local water routes are applied as treatment channels. For some scenarios, the difference between the costs are quite few, such as the difference between low and moderate centralisation, low densification scecnario of Leumeah centre, and between moderate and high centralisation, low densification scecnario of Campbelltown centre. Then the cost becomes less of a promoter for decision-making, and the other parameters should be considered in priority.

For more in-depth evaluation, the results should be compared to the cost of the treatment in traditional way to assess whether the DEWATS solution is more economic (in the case of Campbelltown, that should be the cost of treatment in Malabar Treatment Plant). However, as the data of wastewater treatment inflow volume and related expenditures are not accessible, this step cannot be achieved at the moment.

Treatment quality

(refer to page 44-45 for more information about wastewater quality assessment)

Although the treatment quality is flexible depending on the weather, temperature, usage patterns etc. The theoretical and expected water quality after treatment can be briefly assumed based on the functional area/distance of constructed wetlands with various target of treatment (pathogen, BOD removal, etc.) and the possible retention time. Assuming that all the scenarios and treatment points of the same stage adopt the same quality of infiltration strategy and media, the scenarios are comparable theoretically.

The typical water greywater and balckwater constituents are summarised in Figure 11.2, according to Oteng-Peprah et al. (2018), typical household wastewater is composed of 75% of greywater and 25% of blackwater, which is taken into account as the basic quantity of constituents in the calculation. As all of the treatment components in the proejct is designed to be larger than the minimum requirement, the standard treatment quality summarised by the DEWATS guideline (Harvey et al, 2017) can be referred to for calculating the assumed water quality after final treatment. Additionally, the performance of DEWATS components discussed by Gutterer et al. (2009) also provides the typical ratios of constituents removal that each step performs.

Comparing the expected treatment quality of the design and typical effluent quality from standard central treatment, it is clear that for the quantity of BOD_5, although the highest value exceeds the standard criteria by around 1% in the effluent after primary treatment, and that exceeds the criteria by 33% after secondary treatment, most range of the designed treatment quality conforms to the standard quality. For the TSS removal, the performance of the designed system completely meets the standard for each treatment stage. This outcome indicates that the DEWATS scheme is a feasible solution to treat the wastewater into effluent with similar qualilty as that from the centralised treatment systems. However, the DEWATS scheme also requires more frequent sampling and monitoring as the process is affected by more natural-based and uncontrolled factors that can make a big difference in treated water quality.

Different from subsurface flow wetlands, the surface flow treatment is less functional in the removal of BOD, COD and TSS, but this stage has longer detention time which is crucial for stablisation and oxidation (Moore, 2023). Therefore, although the performance of the surface flow wetlands in the design is difficult to quantify, the area of it is also considered as a factor that affects the water quality in a less precise way.

Parameter	Greywater range from greywater fixtures	Greywater typical	Blackwater typical
BOD_5 (g/m^3)	250 to 550	360	267
COD (g/m^3)	400 to 700	535	533
TSS (g/m^3)	30 to 180	40	200
TN (g/m^3)	10 to 17	13	67
TP (g/m^3)	3 to 8	5.4	15
Total coliform (CFU/100 mL)	10^2 to 10^6	10^5	10^4 to 10^7
E.coli (CFU/100 mL)	10^2 to 10^6	10^4	10^4 to 10^7

Fig 11.1 Typical domestic wastewater composition (Department of Health, 2020)

	After primary treatment (septic tank)	After secondary treatment (ABR)	After tertiary treatment (subsurface wetlands)
BOD_5 (g/m^3)	168-253		1-15
COD (g/m^3)	267-401	53-187	3-56
TSS (g/m^3)	36-40	23-30	19-27
TN (g/m^3)	19-24	6-15	2-9
TP (g/m^3)	3-7	2-7	1-4
Total coliform (CFU/100 mL)	32,500-195,000	6,500-117,000	65-23,400
E.coli (CFU/100 mL)	25,750-128,750	2,575-64,375	26-12,875

Fig 11.2 General treatment results of the project

Treatment	BOD mg/l	Total Suspended Solids mg/l	Total Nitrogen mg/l	Total Phosphorus mg/l	*E coli* org/100 ml	Anionic Surfactants mg/l	Oil and Grease mg/l
Raw Wastewater	150-500	150-450	35-60	6-16	10^7-10^8	5-10	50-100
A	140-350	140-350					
B	120-250	80-200	30-55	6-14	10^6-10^7		30-70
C	20-30	25-40	20-50	6-12	10^5-10^6	< 5	< 10
D	5-20	5-20	10-20	< 2			< 5
E					$< 10^3$		
F	2-5	2-5	< 10	< 1	$< 10^2$		< 5

Table 7: Typical effluent quality for various levels of treatment

NOTES: PLANT TYPE - TYPICAL TREATMENT PROCESSES

	Treatment Process Category	Parameters to be removed	Examples of Treatment Processes
A	Pre Treatment	Gross solids, some of the readily settleable solids	Screening
B	Primary Treatment	Gross solids plus readily settleable solids	Primary sedimentation
C	Secondary Treatment	Most solids and BOD	Biological treatment, chemically assisted treatment, lagoons
D	Nutrient removal	Nutrients after removal of solids	Biological, chemical precipitation.
E	Disinfection	Bacteria and viruses	Lagooning, ultraviolet, chlorination.
F	Advanced wastewater treatment	Treatment to further reduce selected parameters	Sand filtration, microfiltration.

ABBREVIATIONS **BOD** = Biochemical Oxygen Demand

Fig 11.3 Typical effluent quality after each treatment stage (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 1997)

The feasibility of reuse for the different functions can be evaluated with the "Guidelines for water quality evaluation and re-use" (page 45), the level of BOD can satisfy the requirement of urban, recreational, and environmental reuse, the level of TSS also conforms the criteria for environmental reuse. As the publications regarding the assessment of coliforms in DEWATS is insufficient, the range of result is large which is based on generalised removal rate from 50% to 90% for first and secondary treatment, and 80% to 99% for tertiary treatment, more researches are needed in this field in order to perform effective evaluation.

Public accessibility and visibility of the wetlands

In addition to the functional values, wetlands naturally contributes to the increase of green view and a comforting environment with water flow sound. However, the level of publlic accessibility and visibility determines the range of people that can enjoy this benefit: a community garden within a purely residential block is less public visible than a street-side garden. This difference is obvious in the planning of subsurface (vertical flow and horizontal flow) wetlands which is the main component to evaluate for this aspect.

1	2	3	4	5
Most (more than half of) wetlands are accessible and visible only within the building cluster (all sides occupied).	Most wetlands are accessible and visible to one minor street surrounding.	Most wetlands are accessible and visible at least to one minor street surrounding, some of which are faced to a main street or junction.	Most wetlands are accessible and visible to main streets or junction surrounding.	Most wetlands are accessible and visible to junctions and is located in a public open area.

Fig 11.4 Evaluation scale of public accessibility and visibility

Adaptation to population increase

For the low densification scenarios, this parameter is evaluated based on their similarities in the locations of wetlands with correspondent high densification scenarios of the same centralisation degree. This evaluation reflects that whether higher amount of domestic wastewater can be treated with as little adjustment (such as area expansion) as possible for the wetlands in low densification scenario. For the high densification scenarios, it is presumed whether there is enough area left for more wetland area to treat extra wastewater, if the population is even higher than the high scenario in the design.

1	2	3	4	5
All the wetlands have to be re-located to a large degree (to a different block etc.) in order to fit a higher densi-fication level.	Most wetlands have to be re-located to a large degree (to a different block etc.) in order to fit a higher densi-fication level.	Most wetlands are adaptable to a higher densi-fication level by adjustments of position within the block.	Most wetlands are highly adaptable by simply changing the area, while small proportion of the remaining wetlands require adjustments of position within the block.	All wetlands are highly adaptable by simply enlarg-ing the area.

Fig 11.5 Evaluation scale of adaptation to population increase

INPUT - collecting water for treatment and reuse

Wastewater production

The wastewater production rate in this thesis depends on the population calculated as 80% of the total water consumption rate (detailed information in page 68-69: Area requirement for DEWATS in Campbelltown), therefore it stays the same in the scenarios that have the same densification level. The wastewater production is a relative stable input compared to the stormwater harvesting, although the consumption pattern differs in seasons or involuntarily.

Stormwater harvesting

In addition to the household wastewater that is collected from the septic tanks, the wetlands, surface water flows and some specific sports fields (in Leumeah centre) also harvest stormwater that can be treated together with wastewater. According to Fig 11.6, there is great difference between the rainfall in summer (Dec-Feb) and in winter (Jun-Aug), indicating that in summer, there can be more rainwater harvested ideally with surpluss for storage.

OUTPUT - consumption of water during or after treatment

Evaporation

According to the annual average pan evaporation statistics (Bureau of Meteorology, 2006), 1500 milimetres per year of evaporation rate can be expected for Campbelltown (extra information in page 20: “High evaporation rate”), which will be calculated together with the area of water surface in the target sites to determine the rough amount of water lost in evaporation for each scenario, which is not reused by any functions.

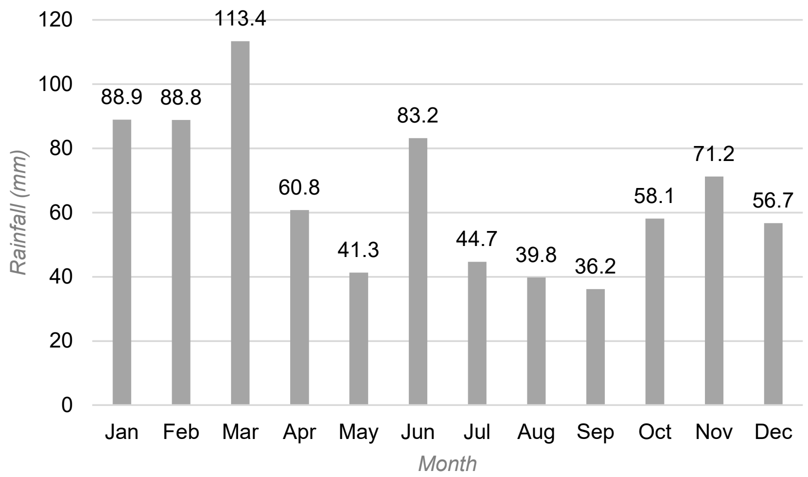


Fig 11.6 Mean data of monthly rainfall in Campbelltown (Mount Annan) from year 2006 to 2023, addapted from Bureau of Meteorology (2023)

Irrigation for open sports field

Leumeah centre is designed to be an energetic precinct that encourages sports and is fully prepared as a much-anticipated sports destination in Greater Sydney (Campbelltown City Council, 2020b). The site accommodates two sports stadiums "Campbelltown Sports Stadium" and "Campbelltown Athletics Centre" which are needed to be irrigated and equipped with drainage standardly to maintain their quality as is suggested by Football NSW (2015). Meanwhile they can also become sources of rainwater harvesting with well-designed drainage system as is proposed.

"Campbelltown Sports Stadium" accommodates a standard football pitch that requires the irrigation of a minimum of 50,000 litres of water per application. Approximately 3 applications are expected per week (150,000 litres per week) to keep a pitch in a healthy and safe condition (Football NSW, 2015). Considering the rainfall, the irrigation is not necessary for all weeks throughout the year. When there is heavy rainfall in wet seasons (Jan-Mar & Jun, as Fig 11.6), the field is naturally watered and the overflow can be collected through the drainage system for irrigation when it is needed at the other time, in dry seasons (May, Jul-Sep, as Fig 11.6), or further treated to be used for other purposes (household mainly).

Consumption in household

In general, the water is consumed in household for showers, gardening, toilets flushing, washing clothes, inside taps, bath tubs, and dishwasher (Fig 11.9). To meet the need of the area development for Leumeah centre and Campbelltown centre, the new housing types are mainly medium and high density, private gardens can be hardly expected for that and the outdoor irrigation is not considered as one of the main household consumption purposes. Considering the treated water quality, at least toilet flushing and washing clothes can be served with the treated water, which equals to around 42% of the total household water consumption.

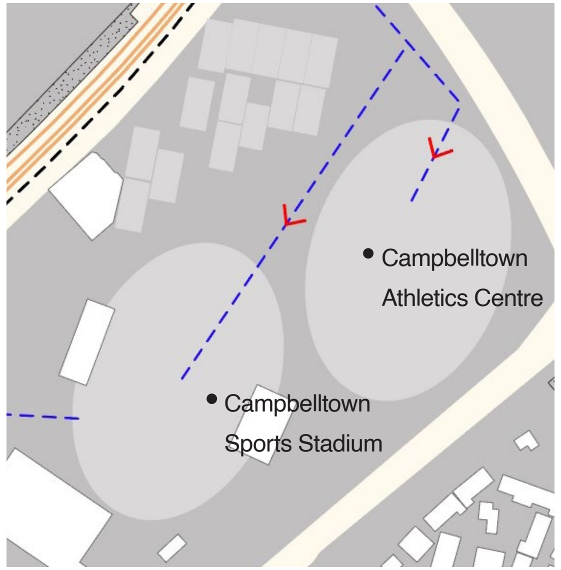


Fig 11.7 The sports field in Leumeah centre

The irrigation can ideally serve Campbelltown Sports stadium and Campbelltown Athletic Centre at least

Fig 11.8 The sports field in Leumeah centre in satellite view, adapted from Google Map (2023)

As there is no public data that indicates the area of the football pitch in the stadiums which is still under construction, the dimensions of the grass fields are referred to be 105 m in length and 68 m in width (total area of 7,140 m²) based on FIFA recommendation (Football NSW, 2018).

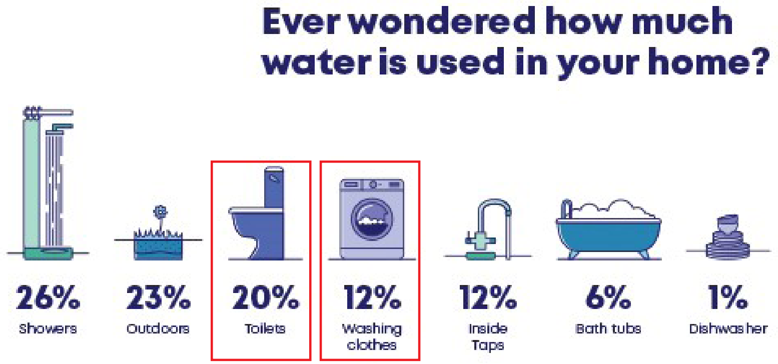


Fig 11.9 Proportion of domestic water consumption (Sydney Water, 2022)

Weekly use per person:

Flushing toilet: 4 L/flush x 5 flush x 7 d = 140 L/w

Washing machine: 65 L/load x 1 load/w = 65 L/w

11.2 Leumeah centre

Level of densification	Low densification: additional 1,171 population			High densification: additional 5,142 population		
Level of treatment centralisation	 Low centralisation	 Moderate centralisation	 High centralisation	 Low centralisation	 Moderate centralisation	 High centralisation
Annual cost (A$)	133,602 - 222,670	133,146 - 221,910	157,794 - 262,990	180,416 - 305,439	173,243 - 295,082	171,872 - 293,404
Treatment quality	Capable to meet the standard of tertiary treatment and hopefully post treatment as well.			Capable to meet the standard of tertiary treatment and hopefully post treatment as well.		
Public accessibility and visibility of the wetlands	3	4	4	1	3	4
Adaptation to population increase	2	1	1	4	1	5
Performance for water reuse: Wastewater generation (m^3/year)	34,185			150,138		
Performance for water reuse: Stormwater harvesting by wetlands (m^3/year)	756	760	758	3,575	3,383	3,311
Performance for water reuse: Stormwater harvesting by sportsfields (m^3/year)	5,591			5,591		
Performance for water reuse: Evaporation (m^3/year)	1,449	1,455	1,453	6,848	6,481	6,342
Performance for water reuse: Irrigation for sports field (m^3/year)	2,400			2,400		
Performance for water reuse: Household consumption (m^3/year)	11,520			50,594		
Performance for water reuse: Reuse efficiency (input / treated water that is re-used)	96.3%	96.5%	96.4%	95.7%	95.9%	96.0%

Fig 11.10 Comprehensive evaluation for Leumeah centre

11.3 Campbelltown centre

Level of densification		Low densification: additional 6,322 population			High densification: additional 11,429 population		
Level of treatment centralisation		 Low centralisation	 Moderate centralisation	 High centralisation	 Low centralisation	 Moderate centralisation	 High centralisation
Annual cost (A$)		168,327 - 289,955	164,587 - 284,283	164,142 - 283,608	395,961 - 680,624	401,881 - 691,218	421,800 - 724,542
Treatment quality		Capable to meet the standard of tertiary treatment and hopefully post treatment as well.			Capable to meet the standard of tertiary treatment and hopefully post treatment as well.		
Public accessibility and visibility of the wetlands		3	5	5	2	5	5
Adaptation to population increase		5			3	4	4
Performance for water reuse	Wastewater generation (m^3/year)	184,602			333,724		
	Stormwater harvesting (m^3/year)	4,144	4,077	4,069	7,459	7,371	7,356
	Evaporation (m^3/year)	7,938	7,809	7,794	14,287	14,120	14,091
	Household consump-tion (m^3/year)	62,209			112,460		
	Reuse efficiency (input / treated water that is re-used)	95.8%	95.9%	95.9%	95.8%	95.9%	95.9 %

Fig 11.11 Comprehen-sive evaluation for Campbelltown centre

11.4 Discussion of common risks

Risk of system failure during operation

System failure can be categorised into two types: “insufficient treatment of wastewater” and “reduced flow at the outlet of the facility” (Gutterer et al., 2009), each of which can be caused by multiple factors, this chaptor will only discuss those that the possibility of happening is comparable between different scenarios and are non-related to personal assets.

Factors may cause **insufficient treatment of wastewater** (Gutterer et al., 2009):
- Excessive quantity of in-flow - might happen to the place prone to localised flooding, when the constructed wetlands are also holding and treating stormwater. This risk can happen to both of the scenarios, becasue the area along Bowbowing creek is prone to flooding according to flood risk analysis (page 78-79). However, as the whole scheme also contributes to the treatment and re-use of stormwater, there is also extra surface flow wetlands area that can hold stormwater, the risk of flooding is already reduced.
- Excessive in-flow contamination - caused by non-domestic wastewater sources accidentally, which may happen to the area with industrial sites and companies surrounding. This risk can happen to the sites because there are currently car repair shops and construction retail places in the southern part of the two sites. Although these sites are not allowed to release polluted water to the surface water stream or any surface area, there is still small chance that leakage from these sites may happen unexpectedly and the contaminations run into the surface water flow.

Factors may cause **reduced flow at the outlet of the facility** (Gutterer et al., 2009):
- Pump malfunction - lack of power to facilitate the water flow. The malfunction may happen to the scenarios that require more pumps to direct the flows, especially in Leumeah centre as the elevation for the designed new water routes are around 2 m higher than the Bowbowing creek.
- Pipes cloggging - most likely to happen where the constructed wetlands are integrated with other plants (significant native or planted for green view) that are not supposed to be part of the treatment media, the roots of the plants grow into the system unexpectedly. This may happen to the scenarios with street-side gardens and the constructed wetland area that is designed to be integrated with an existing artificial/natural landscape.
- Pipes leaking - same problem as stated in “Pipes clogging”; can also happen to the place with railways or other load-bearing, vibrating infrastructures above. Therefore, the scenarios with sewers underneath are not reccommended if this risk is attached importance, such as the high treatment centralisation scenarios for Leumeah centre.

11.5 Contribution to spatial use

Generalising the outcome from "Demonstrative wetland design" (page 198-219), all the wetlands-centred design attribute value to people's activities and cater to their space usage tendency in different aspects.

The "Community garden" type of design as the main role in all the low centralisation scenarios can be perceived as an exclusive environment that creates an exquisite and intimate vibe for small range of users within the target building cluster. Compared to the other two demonstrative designs, the community garden, as part of the domestic living environment, caters to more daily interactions between neighbors with relatively static and noiseless states of activities, such as landscape watching and family chating. The design outcome should be less user-specified, but be able to support a comfortable public space that brings the neighbourhood together.

The designs for moderate and high centralisation treatment have more capacity for different active activities to happen, such as biking and events holding in Campbelltown Showground, or being as a thematic park with educational significance. These designs consider the surrounding contexts, services and functions that may have additional expectations for using this venue. Therefore, these two scenarios focus more on constructing a social environment for the whole precinct, by providing spatial opportunities for specific activities and target users to bring them together. In this aspect, the wetland features weaved in-between the activity venues function as embellishments, companion, and facilitators.

Considering above, it is difficult to conclude which scenario is the optimal public space contributor, because they all satisfy the social environment that they are related to. In order to promote more ideal designs regarding wetland-centred public space for the precinct and city centre area, the three levels of centralisation should be combined based on a more developed built and social context, which deserves more research and design experiments. To be further explored, the design and management approaches should be aimed at promoting harmonious engagement in activities, minimizing conflicts, and fostering a sense of connection and value.

11.6 Monitoring

Monitoring for wastewater and reclaimed water

According to Gutterer et al. (2009), a regular assessments every 6 to 12 months at least for the wastewater-treatment system's performance is recommended. The assessment includes analyzing the quality of the inflow and outflow of the wastewater to ensure compliance with legal standards. The results can then be compared to the desired performance (page 224 and Appendix: Guidelines for water quality evaluation and re-use) outlined during the planning phase, enabling improvements in the design of future treatment plants.

As is suggested by U.S. Environmental Protection Agency (2004), in order to ensure that the parameters in the reclaimed water complies to the standard requirement for different re-use purposes, the sampling frequency should be on regular basis of different intervals, mostly on a daily or weekly basis (more information in Appendix: Guidelines for water quality evaluation and re-use, column "Reclaimed water monitoring")

Responsibility for monitoring and maintainence

To facilitate evaluation, the operator and operating body should maintain daily records of the wastewater treatment process. The key data to be recorded are the number of users, specific issues encountered, and details of operational and maintenance activities carried out. In cases where the system is poorly operated or the number of users declines over time, it is the responsibility of the local authority to investigate the causes and take appropriate actions accordingly.

In Sydney's centralised wastewater treatment system, the responsibility for monitoring mainly lies in the specific treatment plant that conducts the process, the results of which are collectively assessed by Sydney Water authority. However, for the decentralised treatment system, the power and responsibility are also decentralised to different authorities and executive bodies. Referring to cases and guidelines from other areas, the monitoring can be undertaken in different aspects by local government and municipality bodies, non-governmental organisations, and private sectors (Gutterer et al., 2009). For Campbelltown Local Government Area, the responsible roles can be the followings:

- Campbelltown City Council: The council is responsible for developing and implementing policies, guidelines, and regulations related to decentralised wastewater treatment systems in Campbelltown. They issue permits, conduct inspections, and ensure compliance with relevant standards and regulations.

- Environmental Health Department: The Environmental Health Department within Campbelltown City Council can be the primary division responsible for monitoring and regulating decentralised wastewater treatment systems. They oversee the implementation of wastewater management plans, conduct inspections, and enforce compliance.

- NSW Department of Planning, Industry, and Environment: The department provides guidance and support to local councils and authorities in NSW for environmental management, including wastewater treatment. They may play a role in setting standards and regulations that apply to decentralised systems and provide technical expertise when needed.

- Technology and infrastructure providers for the treatment: Depending on the services that are provided, the technical providing coorporations are supposed to give instructions in monitoring the infrastructures' operation and treatment process. On site investigation and guidance can be expected for special situations as well.

- Local communities in Campbelltown: The residents' active participation in reporting visible unexpected system malfunctions to the city council contributes to the effectiveness of the system. The problems that can be monitored by the community include pollutants in constructed wetlands that are distinctly not from the semi-treated wastewater after secondary treatment, leakage that can be spotted, over-flow of any treatment stage, exceptional plant growth states, etc. The city council and health department take the responsibility to educate the residents about the knowledge mentioned and trigger their willingness to help monitoring and maintaining the wetland system's sustainability.

Additionally, the experimented DEWATS in Campbelltown is an important part of the integrated water system proposal for the Greater Sydney area (page 88-91: 6.1 Conceptual framework), the Sydney Water authority should be informed of the DEWATS' operation status and monitoring reports.

11.7 Impact on the other area in the Greater Sydney

Reducing the pressure of Macarthur Filtration Plant and Cataract Dam

According to the analysis in "Water filtration of the Greater Sydney area and Campbelltown" (page 80), without an efficient water recycle and re-use scheme, the new residents in the targeted area will still totally rely on the potable water supply from Macarthur Filtration Plant and Cataract Dam for all of the household consumption. With the DEWATS scheme that serves re-usable water, it reduces the dependence of 42% of the potable water from the dam (page 228: "*Consumption in household")* and the working load of the filtration plant.

Rewriting the traditional pattern of consumption-treatment-discharge

For most part of the urban area in Sydney, the domestic wastewater are treated in central treatment plant and discharged to environmental flows or deep ocean (page 82-83: "Wastewater treatment of the Greater Sydney area and Campbelltown"), although the treatment quality can be better in this way, it's less efficient as more process (re-harvesting from surface water or desalination) are undertaken before the water is served again. If a DEWATS scheme can achieve the same performance (in the future) as the traditional way, the water can be treated on-site and served to households directly. The pattern will become consumption-treatment-reuse, being hopefully an example for the rest of the potential or developing urban area to follow.

Contributing to a better surface water quality overall

The Bowbowing Creek is well connected to the waterways that go through surrounding area, not only urban environment, but also wild reserves, such as Leumeah Creek in Leumeah Creek Reserve and Smith Creek that goes through Helen Stewardson Reserve, Abercrombie Reserve and several other reserves. The improvement in the water quality of Bowbowing Creek by surface flow treatment from the DEWATS scheme can simultaneously benefit the reserves by allowing the treated water into the environmental flows naturally.

12. Reflection

Relation between this project, master track (Ur), master programme (MSc AUBS)

This project is aimed at experimenting a new solution for wastewater treatment in an developing urban area, which addresses the topics of urban technology, urban sprawl, housing, sustainability and public spaces with different levels of elaboration, the topics are important in urbanism concept and are applied with the skills/knowledge that are provided by the master track of Urbanism and the program. For example, when I was drafting the densification scenarios, the vision from the government, expected land-use, streetscape with building heights, and the relations between housing typologies and their distance to the city centre are all considered comprehensively; when the wetlands are placed, they are also characterised and assigned with different roles ("Categorisation of the wetlands") based on their scale and relations with the surroundings. All the design outcomes come from comprehensive and multidisciplinary understanding of urban issues and needs, meanwhile, they contribute to a place-making language that serves urbanism.

How did my research influence design/recommendations and how did the design/recommendations influence research?

This project is generally research-oriented, because it is initiated with the motivation to test the performance of decentralised wastewater treatment. While the design parts are more inclined to systemic experiment in which several variants (densification, centralisation of wetlands) are manipulated to achieve a relative balance between the population and potentials for constructed wetlands in public space, the purpose of the design is not to achieve a concrete result, but simulate different possibilities to satisfy different needs. During the process, the research serves as guideline that ensures the feasibility of design and build up theoretical base for each design step. For example, by researching on the area requirement of DEWATS components, the design of the wetland unit can be more grounded on functional feasibility. Meanwhile, designing also informs the need for research in order to evaluate. With natural-based design approach, for each scenario, there are uncertainties in the design performance that can be more tangible and evaluable by researching further on the climate and local conditions, following that, the scenarios become more comparable in quality and quantity parameters.

Social relevance

Social relevance in this thesis is mainly reflected in the growing population (density), the contradiction between the growing demand and stormwater shortage, and social concerns about the quality and re-usability of treated water. Through the research, design, and evaluation, this project simulates the densification scenarios and possibilities to reduce the dependence on stormwater shortage by water-reuse, and explores the ways to meet the qualities for different re-use purpose. The final result might support or discourage the densification scenarios, while it creates an overview for the society of how the urban environment will be like if we base the urbanisation on water saving and water re-use with DEWATS and how to achieve the balance between social development and sustainable water supply. In addition, the design of the integrated wetland-centred public space is an experiment of how the different scales of the constructed wetlands related to centralisation levels contribute to the spatial use that support social activities without judgment. On the other hand, the wetlands' sustainable operation also requires social efforts in monitoring, protecting, and respecting, which also brings educational and interactive opportunities for the government to get closer to the masses, establishing a bridge for communication.

Professional relevance

The thesis addresses possibilities and challenges in professional goals of urbanists. In most cases, designing urban environment can be easily based on and target at achieving well outward functions and appearance of the space, but it is difficult for urbanists to tailor a certain technical intervention in place that is required to achieve those targets, thus resulting in obstacles to developing more advanced urban functions. The thesis might point out the way to understand the relations between the technical requirement of DEWATS and the layout of built environment, which can be inferred to other technical-centred innovations to be built in urbanisation, and helps the urbanists have easier communication with technical engineers.

Additionally, revitalising the neglected and mismanaged water bodies and participating them as a functional role to achieve new urban visions is an important part of the thesis. It might becoming an inspiring part for other projects focused on improving water quality of rivers.

Scientific relevance

The thesis focuses on the development of DEWATS, which is a new way of wastewater treatment compared to traditional centralised treatment plants. This technology is still imperfect and there is a lot to be improved. The thesis will reveal and summarise the problems, providing suggestions for the future development of this technology from the perspective of applying it in an growing district, which might be valuable for other experts in scientific field to develop DEWATS with better performance.

As the thesis only explores a specific DEWATS composition (septic tank + ABR + VF + HF + SF), it is still arbitrary to claim that this is the optimal DEWATS solution for Campbelltown and Greater Sydney, considering that there are already more effective but expensive solutions of DEWATS, which can also be tested for the area. Meanwhile, emerging technologies are constantly developing, there are endless possibilities for this field to be tested and verified of its effectiveness with more developed scientific methods.

Ethical relevance

Dealing with water related problems depends on both production and consumption sides. Especially when the water treatment and reproduction is managed in a decentralised and natural-based way, extra public attention is supposed to be paid to care for and maintain the system's daily operation, by avoiding artificially polluting the waterway and wetlands and proactively reporting the abnormal status (leakage, overfill, etc.) of any stages in the treatment that can be observed. Meanwhile, correct and efficient use of the water resource is an all-time practice to keep no matter how many ways there are to solve the water scarcity, which is an important role in sustainable development and is still a keynote to strengthen in the public consciousness.

Limitation and uncertainty

Because of the lack of data availability, some of the information (such as the water account and different densification scenarios) comes from assumption. Some sources give different estimation or counting outcomes, which reduces the accuracy of the calculation results.

The topic of DEWATS is seldom discussed together with densification and large-scale distribution, therefore precedents can hardly be found. Multiple practices are available with different scales without design processes, which can only consulted for their layout and technical set-up. In order to get more inspired in design, some natural-based stormwater treatment schemes are referenced.

As a multi-disciplinary project that involves not only urban design related skills, but also water management, demographics, landscape, and biology, there are plenty uncertainties existing in each of the field with the lack of knowledge while finishing the thesis individually in one year. Meanwhile, each field that is presented in the project deserves more efforts and exploration to be fully integrated in the design and fullfill the completeness of it. Especially for the technical parts, the understanding and expression might be incomplete and abridged with also the intention to make it more understandable for the public. Therefore, more collaboration with the experts in other related fields will be required to get the project more developed and unimpeded.

Transferability

The project results are closely related to the local context, including climate data, housing typology, direction of development, etc. with a combination of qualitative and quantitative analysis engaging. Meanwhile, the project focuses more on experimenting instead of the certainty of results. Therefore, the results can only be referred for projects with similar intention of implementing DEWATS and are located in similar climate (southern hemisphere, subtropical) and environment (accommodating waterways, enough open space, etc) context. However, the methods used in this project is highly transferrable for other projects that have demand on densification and planting constructed wetlands in urban area, for example, calculating the potential population and dwelling number and symbolising different levels of treatment centralisation with basic patterns to communicate the idea. However, it is always recommended to base the methodology and analysis on the needs of the subject and the local situation of the target sites.

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14. Appendix

Guidelines for water quality evaluation and re-use (attached to page 44, page 223)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Urban Reuse All types of landscape irrigation, (e.g., golf courses, parks, cemeteries) – also vehicle washing, toilet flushing, use in fire protection systems and commercial air conditioners, and other uses with similar access or exposure to the water	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6-9 • ≤ 10 mg/l BOD [7] • ≤ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See Table 2-7 for other recommended limits. • At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve < 14 fecal coli/100 ml, may be appropriate. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • Reclaimed water should be clear and odorless. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • A chlorine residual of 0.5 mg/l or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. • See Section 3.4.3. for recommended treatment reliability.
Restricted Access Area Irrigation Sod farms, silviculture sites, and other areas where public access is prohibited, restricted or infrequent	• Secondary [4] • Disinfection [6]	• pH = 6-9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• See Table 2-7 for other recommended limits. • If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Food Crops Not Commercially Processed [15] Surface or spray irrigation of any food crop, including crops eaten raw.	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6-9 • ≤ 10 mg/l BOD [7] • ≤ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• See Table 2-7 for other recommended limits. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • High nutrient levels may adversely affect some crops during certain growth stages. • See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Food Crops Commercially Processed [15] Surface Irrigation of Orchards and Vineyards	• Secondary [4] • Disinfection [6]	• pH = 6-9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • < 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• See Table 2-7 for other recommended limits. • If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • See Section 3.4.3 for recommended treatment reliability.
Agricultural Reuse – Non-food Crops Pasture for milking animals; fodder, fiber, and seed crops	• Secondary [4] • Disinfection [6]	• pH = 6-9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • < 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• See Table 2-7 for other recommended limits. • If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 ml, should be provided if this waiting period is not adhered to. • See Section 3.4.3 for recommended treatment reliability.

(U.S. Environmental Protection Agency, 2004)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Recreational Impoundments Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed	• Secondary [4] • Filtration [5] • Disinfection [6]	• pH = 6-9 • ≤ 10 mg/l BOD [7] • ≤ 2 NTU [8] • No detectable fecal coli/100 ml [9,10] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • Turbidity - continuous • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Reclaimed water should be non-irritating to skin and eyes. • Reclaimed water should be clear and odorless. • Nutrient removal may be necessary to avoid algae growth in impoundments. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Fish caught in impoundments can be consumed. • See Section 3.4.3. for recommended treatment reliability.
Landscape Impoundments Aesthetic impoundment where public contact with reclaimed water is not allowed	• Secondary [4] • Disinfection [6]	• ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Nutrient removal may be necessary to avoid algae growth in impoundments. • Dechlorination may be necessary to protect aquatic species of flora and fauna. • See Section 3.4.3 for recommended treatment reliability.
Construction Use Soil compaction, dust control, washing aggregate, making concrete	• Secondary [4] • Disinfection [6]	• ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous		• Worker contact with reclaimed water should be minimized. • A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 ml, should be provided when frequent work contact with reclaimed water is likely. • See Section 3.4.3 for recommended treatment reliability.
Industrial Reuse Once-through cooling	• Secondary [4] • Disinfection [6]	• pH = 6-9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to areas accessible to the public	• Windblown spray should not reach areas accessible to workers or the public.
Recirculating cooling towers	• Secondary [4] • Disinfection [6] (chemical coagulation and filtration [5] may be needed)	• Variable depends on recirculation ratio (see Section 2.2.1) pH = 6-9 • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14] • 1 mg/l Cl_2 residual (minimum) [11]	• pH - weekly • BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to areas accessible to the public. May be reduced or eliminated if high level of disinfection is provided.	• Windblown spray should not reach areas accessible to workers or the public. • Additional treatment by user is usually provided to prevent scaling, corrosion, biological growths, fouling and foaming. • See Section 3.4.3 for recommended treatment reliability.
Other Industrial Uses	Depends on site specific uses (See Section 2.2.3)				
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation	• Variable • Secondary [4] and disinfection [6] (minimum)	Variable, but not to exceed: • ≤ 30 mg/l BOD [7] • ≤ 30 mg/l TSS • ≤ 200 fecal coli/100 ml [9,13,14]	• BOD - weekly • TSS - daily • Coliform - daily • Cl_2 residual - continuous		• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Possible effects on groundwater should be evaluated. • Receiving water quality requirements may necessitate additional treatment. • The temperature of the reclaimed water should not adversely affect ecosystem. • See Section 3.4.3 for recommended treatment reliability.

(U.S. Environmental Protection Agency, 2004)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Groundwater Recharge By spreading or injection into aquifers not used for public water supply	• Site-specific and use dependent • Primary (minimum) for spreading • Secondary [4] (minimum) for injection	• Site-specific and use dependent	• Depends on treatment and use	• Site-specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers • See Section 2.5 for more information. • For spreading projects, secondary treatment may be needed to prevent clogging. • For injection projects, filtration and disinfection may be needed to prevent clogging. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers	• Secondary [4] • Disinfection [6] • May also need filtration [5] and/or advanced wastewater treatment [16]	• Secondary [4] • Disinfection [6] • Meet drinking water standards after percolation through vadose zone	Includes, but not limited to, the following: • pH - daily • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent • BOD - weekly • Turbidity - continuous	• 500 ft (150 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness to the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 6 months prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil, percolation rate, thickness of vadose zone, native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • See Sections 2.5 and 2.6 for more information. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • $\le$ 2 NTU 8 • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • $\le$ 3 mg/l TOC • $\le$ 0.2 mg/l TOX • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on site-specific conditions.	• The reclaimed water should be retained underground for at least 9 months prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met a the point of injection. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Sections 2.5 and 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Augmentation of surface supplies	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • $\le$ 2 NTU [8] • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • $\le$ 3 mg/l TOC • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• Site-specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • See Sections 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.

(U.S. Environmental Protection Agency, 2004)

Minimum area requirement for DEWATS components

Minimum requirement area of DEWATS

Precinct	Densification scenario	SA1	Additional population	Typical consumption pp (L/P/d)	Total water consumption rate (m^3/d)	Wastewater generation rate (m^3/d)	Area of septic tank (m^2)	Area of ABR (m^2)	Volume of ABR (m^3)	Sludge generation rate (L/P/d)	Sludge production volume (L/D)	Sludge production yearly (m^3)	Area of VF (m^2)	Area of HF (m^2)	Area of SF (m^2)	Total area
Leumeah	Low	A	817.8	100.0	81.8	65.4	32.7	65.4	65.4	0.1	81.8	29.8	245.3	425.3	78.5	847.2
		A1	153.7	100.0	15.4	12.3	6.1	12.3	12.3	0.1	15.4	5.6	46.1	79.9	14.8	159.2
		A2	664.1	100.0	66.4	53.1	26.6	53.1	53.1	0.1	66.4	24.2	199.2	345.3	63.8	688.0
		Q*	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		R	352.9	100.0	35.3	28.2	14.1	28.2	28.2	0.1	35.3	12.9	105.9	183.5	33.9	365.6
		Total	1,170.7	100.0	117.1	93.7	46.8	93.7	93.7	0.1	117.1	42.7	351.2	608.8	112.4	1,212.9
	High	A	2,473.7	100.0	247.4	197.9	98.9	197.9	197.9	0.1	247.4	90.3	742.1	1,286.3	237.5	2,562.8
		A1	617.7	100.0	61.8	49.4	24.7	49.4	49.4	0.1	61.8	22.5	185.3	321.2	59.3	639.9
		A2	890.3	100.0	89.0	71.2	35.6	71.2	71.2	0.1	89.0	32.5	267.1	463.0	85.5	922.4
		A3	649.6	100.0	65.0	52.0	26.0	52.0	52.0	0.1	65.0	23.7	194.9	337.8	62.4	673.0
		A4	171.1	100.0	17.1	13.7	6.8	13.7	13.7	0.1	17.1	6.2	51.3	89.0	16.4	177.3
		A5	145.0	100.0	14.5	11.6	5.8	11.6	11.6	0.1	14.5	5.3	43.5	75.4	13.9	150.2
		Q*	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		R	2,668.0	100.0	266.8	213.4	106.7	213.4	213.4	0.1	266.8	97.4	800.4	1,387.4	256.1	2,764.0
		R1	2,128.6	100.0	212.9	170.3	85.1	170.3	170.3	0.1	212.9	77.7	638.6	1,106.9	204.3	2,205.2
		R2	814.9	100.0	81.5	65.2	32.6	65.2	65.2	0.1	81.5	29.7	244.5	423.7	78.2	844.2
		Total	5,141.7	100.0	514.2	411.3	205.7	411.3	411.3	0.1	514.2	187.7	1,542.5	2,673.7	493.6	5,326.8
Campbelltown	Low	B	2,636.1	100.0	263.6	210.9	105.4	210.9	210.9	0.1	263.6	96.2	790.8	1,370.8	253.1	2,731.0
		B1	307.4	100.0	30.7	24.6	12.3	24.6	24.6	0.1	30.7	11.2	92.2	159.8	29.5	318.5
		B2	394.4	100.0	39.4	31.6	15.8	31.6	31.6	0.1	39.4	14.4	118.3	205.1	37.9	408.6
		B3	69.6	100.0	7.0	5.6	2.8	5.6	5.6	1.1	76.6	27.9	20.9	36.2	6.7	72.1
		B4	788.8	100.0	78.9	63.1	31.6	63.1	63.1	0.1	78.9	28.8	236.6	410.2	75.7	817.2
		B5	290.0	100.0	29.0	23.2	11.6	23.2	23.2	0.1	29.0	10.6	87.0	150.8	27.8	300.4
		B6	301.6	100.0	30.2	24.1	12.1	24.1	24.1	0.1	30.2	11.0	90.5	156.8	29.0	312.5
		B7	121.8	100.0	12.2	9.7	4.9	9.7	9.7	0.1	12.2	4.4	36.5	63.3	11.7	126.2
		B8	362.5	100.0	36.3	29.0	14.5	29.0	29.0	1.1	398.8	145.5	108.8	188.5	34.8	375.6
		C	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		D	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		H	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		L	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		M	3,520.6	100.0	352.1	281.6	140.8	281.6	281.6	0.1	352.1	128.5	1,056.2	1,830.7	338.0	3,647.3
		M1	1,725.5	100.0	172.6	138.0	69.0	138.0	138.0	0.1	172.6	63.0	517.7	897.3	165.6	1,787.6
		M2	203.0	101.0	20.5	16.4	8.2	16.4	16.4	1.1	223.3	81.5	61.5	106.6	19.7	212.4
		M3	350.9	102.0	35.8	28.6	14.3	28.6	28.6	2.1	736.9	269.0	107.4	186.1	34.4	370.8
		M4	382.8	103.0	39.4	31.5	15.8	31.5	31.5	3.1	1,186.7	433.1	118.3	205.0	37.9	408.5
		M5	397.3	104.0	41.3	33.1	16.5	33.1	33.1	4.1	1,628.9	594.6	124.0	214.9	39.7	428.1
		M6	461.1	105.0	48.4	38.7	19.4	38.7	38.7	5.1	2,351.6	858.3	145.2	251.8	46.5	501.6
		O	165.3	100.0	16.5	13.2	6.6	13.2	13.2	0.1	16.5	6.0	49.6	86.0	15.9	171.3
		P	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		Total	6,322.0	100.0	632.2	505.8	252.9	505.8	505.8	0.1	632.2	230.8	1,896.6	3,287.4	606.9	6,549.6
	High	B	2,636.1	100.0	263.6	210.9	105.4	210.9	210.9	0.1	263.6	96.2	790.8	1,370.8	253.1	2,731.0
		B1	307.4	100.0	30.7	24.6	12.3	24.6	24.6	0.1	30.7	11.2	92.2	159.8	29.5	318.5
		B2	394.4	100.0	39.4	31.6	15.8	31.6	31.6	0.1	39.4	14.4	118.3	205.1	37.9	408.6
		B3	69.6	100.0	7.0	5.6	2.8	5.6	5.6	1.1	76.6	27.9	20.9	36.2	6.7	72.1
		B4	788.8	100.0	78.9	63.1	31.6	63.1	63.1	0.1	78.9	28.8	236.6	410.2	75.7	817.2
		B5	290.0	100.0	29.0	23.2	11.6	23.2	23.2	0.1	29.0	10.6	87.0	150.8	27.8	300.4
		B6	301.6	100.0	30.2	24.1	12.1	24.1	24.1	0.1	30.2	11.0	90.5	156.8	29.0	312.5
		B7	121.8	100.0	12.2	9.7	4.9	9.7	9.7	0.1	12.2	4.4	36.5	63.3	11.7	126.2
		B8	362.5	100.0	36.3	29.0	14.5	29.0	29.0	1.1	398.8	145.5	108.8	188.5	34.8	375.6
		C	1,247.0	100.0	124.7	99.8	49.9	99.8	99.8	0.1	124.7	45.5	374.1	648.4	119.7	1,291.9
		C1	545.2	100.0	54.5	43.6	21.8	43.6	43.6	0.1	54.5	19.9	163.6	283.5	52.3	564.8
		C2	701.8	100.0	70.2	56.1	28.1	56.1	56.1	0.1	70.2	25.6	210.5	364.9	67.4	727.1
		D	3,859.9	100.0	386.0	308.8	154.4	308.8	308.8	0.1	386.0	140.9	1,158.0	2,007.1	370.6	3,998.9
		D1	884.5	100.0	88.5	70.8	35.4	70.8	70.8	0.1	88.5	32.3	265.4	459.9	84.9	916.3
		D2	1,551.5	100.0	155.2	124.1	62.1	124.1	124.1	0.1	155.2	56.6	465.5	806.8	148.9	1,607.4
		D3	284.2	100.0	28.4	22.7	11.4	22.7	22.7	0.1	28.4	10.4	85.3	147.8	27.3	294.4
		D4	437.9	100.0	43.8	35.0	17.5	35.0	35.0	0.1	43.8	16.0	131.4	227.7	42.0	453.7
		D5	371.2	100.0	37.1	29.7	14.8	29.7	29.7	0.1	37.1	13.5	111.4	193.0	35.6	384.6
		D6	330.6	100.0	33.1	26.4	13.2	26.4	26.4	0.1	33.1	12.1	99.2	171.9	31.7	342.5
		H	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		L	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		M	3,520.6	100.0	352.1	281.6	140.8	281.6	281.6	0.1	352.1	128.5	1,056.2	1,830.7	338.0	3,647.3
		M1	1,725.5	100.0	172.6	138.0	69.0	138.0	138.0	0.1	172.6	63.0	517.7	897.3	165.6	1,787.6
		M2	203.0	101.0	20.5	16.4	8.2	16.4	16.4	1.1	223.3	81.5	61.5	106.6	19.7	212.4
		M3	350.9	102.0	35.8	28.6	14.3	28.6	28.6	2.1	736.9	269.0	107.4	186.1	34.4	370.8
		M4	382.8	103.0	39.4	31.5	15.8	31.5	31.5	3.1	1,186.7	433.1	118.3	205.0	37.9	408.5
		M5	397.3	104.0	41.3	33.1	16.5	33.1	33.1	4.1	1,628.9	594.6	124.0	214.9	39.7	428.1
		M6	461.1	105.0	48.4	38.7	19.4	38.7	38.7	5.1	2,351.6	858.3	145.2	251.8	46.5	501.6
		O	165.3	100.0	16.5	13.2	6.6	13.2	13.2	0.1	16.5	6.0	49.6	86.0	15.9	171.3
		P	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		Total	11,428.9	100.0	1,142.9	914.3	457.2	914.3	914.3	0.1	1,142.9	417.2	3,428.7	5,943.0	1,097.2	11,840.3

Detailed information for the design of low densification scenario

Precinct	Level of centralisation	SA1	Area of septic tank (m^2): Number in design	Area of septic tank (m^2): Exceed minimum requirement	Area of ABR (m^2): Number in design	Area of ABR (m^2): Exceed minimum requirement	Area of VF (m^2): Number in design	Area of VF (m^2): Exceed minimum requirement	Area of HF (m^2): Number in design	Area of HF (m^2): Exceed minimum requirement	Area of SF (m^2): Number in design	Area of SF (m^2): Exceed minimum requirement	Total: Number in design	Total: Exceed minimum requirement	Capital cost: From	Capital cost: To	Area of VF+HF (m^2)	Stormwater harvesting (m^3)	Evaporation (m^3)
Leumeah	Low (Cluster A1 and A2 have separate wetlands)	A	33.75	3.2%	72.60	11.0%	247.88	1.0%	426.96	0.4%	86.50	10.2%	867.69	2.4%	209,999	316,751	674.84	528.47	1,012.26
		A1	6.75	9.8%	14.52	18.1%	46.24	0.3%	81.00	1.3%	22.50	52.5%	171.01	7.4%	39,681	59,834	127.24	99.64	190.86
		A2	27.00	1.6%	58.1	9.3%	201.64	1.2%	345.96	0.2%	64.00	0.4%	696.68	1.3%	170,317	256,917	547.60	428.83	821.40
		Q*	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0	0	0.00	0.00	0.00
		R	14.52	2.9%	30.72	8.8%	106.09	0.2%	184.96	0.8%	47.6	40.5%	383.89	5.0%	90,515	136,541	291.05	227.92	436.58
		Total	48.27	3.1%	103.32	10.3%	353.97	0.8%	611.92	0.5%	134.10	19.3%	1251.58	3.2%	300,514	453,293	965.89	756.39	1,448.84
	Moderate (Clusters in A have shared wetlands)	A	33.75	3.2%	72.60	11.0%	246.49	0.5%	432.64	1.7%	83.20	6.0%	868.68	2.5%	211,286	318,703	679.13	531.83	1,018.70
		A1	6.75	9.8%	14.52	18.1%	-	-	-	-	-	-	-	-					
		A2	27.00	1.6%	58.1	9.3%	-	-	-	-	-	-	-	-					
		Q*	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0	0	0.00	0.00	0.00
		R	14.52	2.9%	30.72	8.8%	106.09	0.2%	184.96	0.8%	47.6	40.5%	383.89	5.0%	90,515	136,541	291.05	227.92	436.58
		Total	48.27	3.1%	103.32	10.3%	352.58	0.4%	617.60	1.4%	130.80	16.4%	1252.57	3.3%	301,801	455,245	970.18	759.75	1,455.27
	High (All share wetlands)	A	33.75	3.2%	72.60	11.0%	353.44	0.6%	615.04	1.0%	124.00	10.3%	1244.07	2.6%	301,291	454,471	968.48	758.42	1,452.72
		A1	6.75	9.8%	14.52	18.1%													
		A2	27.00	1.6%	58.1	9.3%													
		Q*	0.00	0.0%	0.00	0.0%													
		R	14.52	2.9%	30.72	8.8%													
		Total	48.27	3.1%	103.32	10.3%	353.44	0.6%	615.04	1.0%	124.00	10.3%	1244.07	2.6%	301,291	454,471	968.48	758.42	1,452.72
Campbell town	Low (Clusters have seperate wetlands except for B2 & B3, B7 & B8, M1 & M2)	B	109.59	3.9%	224.28	6.4%	797.42	0.8%	1,391.88	1.5%	267.90	5.9%	2791.07	2.2%	680,263	1,026,307	2,189.30	1,714.44	3,283.95
		B1	13.23	7.6%	27.00	9.8%	94.09	2.0%	163.84	2.5%	32.00	8.4%	330.16	3.7%	80,206	120,992	257.93	201.98	386.90
		B2	15.87	0.6%	34.68	9.9%	139.24	0.0%	243.36	0.9%	46.80	5.1%	488.83	1.7%	118,997	179,502	382.60	299.61	573.90
		B3	3.00	7.8%	5.88	5.6%													
		B4	32.67	3.5%	63.48	0.6%	237.16	0.2%	416.16	1.5%	81.60	7.8%	831.07	1.7%	202,689	305,868	653.32	511.61	979.98
		B5	12.00	3.4%	23.52	1.4%	88.36	1.6%	153.76	2.0%	28.00	0.6%	305.64	1.7%	75,113	113,349	242.12	189.60	363.18
		B6	13.23	9.7%	27.00	11.9%	92.16	1.9%	158.76	1.2%	31.50	8.8%	322.65	3.3%	78,103	117,803	250.92	196.50	376.38
		B7	5.07	4.1%	12.00	23.2%	146.41	0.8%	256.00	1.7%	48.00	3.2%	512.72	2.2%	125,156	188,793	402.41	315.13	603.62
		B8	14.52	0.1%	30.72	5.9%													
		C	-	-	-	-	-	-	-	-	-	-	-	-					
		D	-	-	-	-	-	-	-	-	-	-	-	-					
		H	-	-	-	-	-	-	-	-	-	-	-	-					
		L	-	-	-	-	-	-	-	-	-	-	-	-					
		M	145.74	3.5%	294.96	4.7%	1,079.63	2.2%	1,884.08	2.9%	360.90	6.8%	3765.31	3.2%	920,032	1,388,238	2,963.71	2,320.88	4,445.57
		M1	69.12	0.1%	138.72	0.5%	580.81	0.3%	1,011.24	0.7%	190.80	3.0%	2016.64	0.8%	493,989	745,434	1,592.05	1,246.73	2388.08
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%	108.16	0.7%	190.44	2.3%	34.50	0.4%	378.34	2.0%	92,780	139,977	298.60	233.83	447.90
		M4	15.87	0.6%	34.68	9.9%	118.81	0.4%	207.36	1.1%	43.20	14.1%	419.92	2.8%	101,448	153,030	326.17	255.42	489.26
		M5	17.28	4.6%	34.68	4.9%	125.44	1.2%	219.04	1.9%	44.40	11.9%	440.84	3.0%	106,984	161,418	344.48	269.76	516.72
		M6	20.28	4.7%	38.88	0.4%	146.41	0.8%	256.00	1.7%	48.00	3.3%	509.57	1.6%	124,831	188,379	402.41	315.13	603.62
		O	6.75	2.1%	14.52	9.8%	50.41	1.7%	88.36	2.8%	18.80	18.5%	178.84	4.4%	43,140	65,080	138.77	108.67	208.16
		P	-	-	-	-	-	-	-	-	-	-	-	-					
		Total	262.08	3.6%	533.76	5.5%	1,927.46	1.6%	3,364.32	2.3%	647.60	6.7%	6735.22	2.8%	1,643,435	2,479,626	5,291.78	4,143.99	7,937.67
	Moderate (Each SA1 has separate wetlands)	B	109.59	3.9%	224.28	6.4%	795.24	0.6%	1,383.84	1.0%	260.40	2.9%	2773.35	1.6%	677,197	1,021,657	2,179.08	1,706.44	3,268.62
		B1	13.23	7.6%	27.00	9.8%													
		B2	15.87	0.6%	34.68	9.9%													
		B3	3.00	7.8%	5.88	5.6%													
		B4	32.67	3.5%	63.48	0.6%													
		B5	12.00	3.4%	23.52	1.4%													
		B6	13.23	9.7%	27.00	11.9%													
		B7	5.07	4.1%	12.00	23.2%													
		B8	14.52	0.1%	30.72	5.9%													
		C	-	-	-	-	-	-	-	-	-	-	-	-					
		D	-	-	-	-	-	-	-	-	-	-	-	-					
		H	-	-	-	-	-	-	-	-	-	-	-	-					
		L	-	-	-	-	-	-	-	-	-	-	-	-					
		M	145.74	3.5%	294.96	4.7%	1,056.25	0.0%	1,831.84	0.1%	342.40	1.3%	3,671.19	0.7%	897,346	1,353,831	2,888.09	2,261.66	4,332.14
		M1	69.12	0.1%	138.72	0.5%													
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%													
		M4	15.87	0.6%	34.68	9.9%													
		M5	17.28	4.6%	34.68	4.9%													
		M6	20.28	4.7%	38.88	0.4%													
		O	6.75	2.1%	14.52	9.8%	50.41	1.7%	88.36	2.8%	18.80	18.5%	178.84	4.4%	43,140	65,080	138.77	108.67	208.16
		P	-	-	-	-	-	-	-	-	-	-	-	-					
		Total	262.08	3.6%	533.76	5.5%	1,901.90	0.3%	3,304.04	0.5%	621.60	2.4%	6623.38	1.1%	1,617,683	2,440,568	5,205.94	4,076.77	7,808.91
	High (All share wetlands)	B	109.59	3.9%	224.28	6.4%	1,900.96	0.2%	3,294.76	0.2%	631.40	4.0%	6622.96	1.1%	1,614,617	2,435,918	5,195.72	4,068.77	7,793.58
		B1	13.23	7.6%	27.00	9.8%													
		B2	15.87	0.6%	34.68	9.9%													
		B3	3.00	7.8%	5.88	5.6%													
		B4	32.67	3.5%	63.48	0.6%													
		B5	12.00	3.4%	23.52	1.4%													
		B6	13.23	9.7%	27.00	11.9%													
		B7	5.07	4.1%	12.00	23.2%													
		B8	14.52	0.1%	30.72	5.9%													
		C	-	-	-	-													
		D	-	-	-	-													
		H	-	-	-	-													
		L	-	-	-	-													
		M	145.74	3.5%	294.96	4.7%													
		M1	69.12	0.1%	138.72	0.5%													
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%													
		M4	15.87	0.6%	34.68	9.9%													
		M5	17.28	4.6%	34.68	4.9%													
		M6	20.28	4.7%	38.88	0.4%													
		O	6.75	2.1%	14.52	9.8%													
		P	-	-	-	-													
		Total	262.08	3.6%	533.76	5.5%	1,900.96	0.2%	3,294.76	0.2%	631.40	4.0%	6,622.96	1.1%	1,614,617	2,435,918	5,195.72	4,068.77	7,793.58

Detailed information for the design of high densification scenario

Precinct	Level of centralisation	SA1	Area of septic tank (m^2): Number in design	Area of septic tank (m^2): Exceed minimum requirement	Area of ABR (m^2): Number in design	Area of ABR (m^2): Exceed minimum requirement	Area of VF (m^2): Number in design	Area of VF (m^2): Exceed minimum requirement	Area of HF (m^2): Number in design	Area of HF (m^2): Exceed minimum requirement	Area of SF (m^2): Number in design	Area of SF (m^2): Exceed minimum requirement	Total: Number in design	Total: Exceed minimum requirement	Capital cost: From	Capital cost: To	Area of VF+HF (m^2)	Stormwater harvesting (m^3)	Evaporation (m^3)
Leumeah	Low (Clusters have separate wetlands)	A	102.54	3.6%	207.36	4.8%	748.05	0.8%	1,298.72	1.0%					635,770	959,228	2,046.77	1,602.83	3,070.16
		A1	25.23	2.1%	52.92	7.1%	187.69	1.3%	324.00	0.9%					159,027	239,914	511.69	400.70	767.54
		A2	36.75	3.2%	75.00	5.3%	268.96	0.7%	466.56	0.8%					228,509	344,757	735.52	575.99	1,103.28
		A3	27.00	3.9%	52.92	1.8%	196.00	0.6%	338.56	0.2%					165,941	250,391	534.56	418.61	801.84
		A4	7.68	12.2%	14.52	6.1%	51.84	1.0%	92.16	3.6%					44,737	67,497	144.00	112.77	216.00
		A5	5.88	1.4%	12.00	3.4%	43.56	0.1%	77.44	2.7%					37,556	56,670	121.00	94.76	181.50
		Q*	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%					0	0	0.00	0.00	0.00
		R	126.36	18.4%	248.28	16.3%	918.98	14.8%	1,599.56	15.3%					781,698	1,179,542	2,518.54	1,972.27	3,777.81
		R1	87.48	2.7%	173.28	1.8%	640.09	0.2%	1,115.56	0.8%					544,915	822,247	1,755.65	1,374.85	2,633.48
		R2	38.88	19.3%	75.00	15.0%	278.89	14.1%	484.00	14.2%					236,783	357,295	762.89	597.42	1,144.34
		Total	228.90	11.3%	455.64	10.8%	1667.03	8.1%	2898.28	8.4%					1,417,468	2,138,771	4,565.31	3,575.09	6,847.97
	Moderate (Each SA1 share one set of wetlands)	A	102.54	0.04	207.36	4.8%	745.29	0.4%	1,296.00	0.8%					634,126	956,735	2,041.29	1,598.53	3,061.94
		A1	25.23	0.02	52.92	7.1%													
		A2	36.75	0.03	75.0	5.3%													
		A3	27.00	0.04	52.9	1.8%													
		A4	7.68	0.12	14.5	6.1%													
		A5	5.88	0.01	12.0	3.4%													
		Q*	0.00	0.00	0.00	0.0%	0.00	0.0%	0.00	0.0%					0	0	0.00	0.00	0.00
		R	126.36	0.18	248.28	16.3%	835.21	4.3%	1,444.00	4.1%					709,899	1,070,647	2,279.21	1,784.85	3,418.82
		R1	87.48	0.03	173.28	1.8%													
		R2	38.88	0.19	75.00	15.0%													
		Total	228.90	0.11	455.64	10.8%	1,580.50	2.5%	2,740.00	2.5%					1,344,025	2,027,382	4,320.50	3,383.38	6,480.75
	High (All share wetlands)	A	102.54	3.6%	207.36	4.8%	1,544.49	0.1%	2,683.24	0.4%					1,316,194	1,985,172	4,227.73	3,310.74	6,341.60
		A1	25.23	2.1%	52.92	7.1%													
		A2	36.75	3.2%	75.0	5.3%													
		A3	27.00	3.9%	52.9	1.8%													
		A4	7.68	12.2%	14.5	6.1%													
		A5	5.88	1.4%	12.0	3.4%													
		Q*	0.00	0.0%	0.00	0.0%													
		R	126.36	18.4%	248.28	16.3%													
		R1	87.48	2.7%	173.28	1.8%													
		R2	38.88	19.3%	75.00	15.0%													
		Total	228.90	11.3%	455.64	10.8%	1,544.49	0.1%	2,683.24	0.4%					1,316,194	1,985,172	4,227.73	3,310.74	6,341.60

Precinct	Level of centralisation	SA1	Area of septic tank (m^2)		Area of ABR (m^2)		Area of VF (m^2)		Area of HF (m^2)		Area of SF (m^2)		Total		Capital cost		Area of VF+HF (m^2)	Stormwater harvesting (m^3)	Evaporation (m^3)
			Number in design	Exceed minimum requirement	Number in design	Exceed minimum requirement	Number in design	Exceed minimum requirement	Number in design	Exceed minimum requirement	Number in design	Exceed minimum requirement	Number in design	Exceed minimum requirement	From	To			
Campbell town	Low (Clusters have seperate wetlands except for B2 & B3, B7 & B8, M1 & M2)	B	109.59	3.9%	224.28	6.4%	797.42	0.8%	1,391.88	1.5%	267.90	5.9%	2791.07	2.2%	680,263	1,026,307	2,189.30	1,714.44	3,283.95
		B1	13.23	7.6%	27.00	9.8%	94.09	2.0%	163.84	2.5%	32.00	8.4%	330.16	3.7%	80,206	120,992	257.93	201.98	386.90
		B2	15.87	0.6%	34.68	9.9%	139.24	0.0%	243.36	0.9%	46.80	5.1%	488.83	1.7%	118,377	178,706	382.60	299.61	573.90
		B3	3.00	7.8%	5.88	5.6%									619	796			
		B4	32.67	3.5%	63.48	0.6%	237.16	0.2%	416.16	1.5%	81.60	7.8%	831.07	1.7%	202,689	305,868	653.32	511.61	979.98
		B5	12.00	3.4%	23.52	1.4%	88.36	1.6%	153.76	2.0%	28.00	0.6%	305.64	1.7%	75,113	113,349	242.12	189.60	363.18
		B6	13.23	9.7%	27.00	11.9%	92.16	1.9%	158.76	1.2%	31.50	8.8%	322.65	3.3%	78,103	117,803	250.92	196.50	376.38
		B7	5.07	4.1%	12.00	23.2%	146.41	0.8%	256.00	1.7%	48.00	3.2%	512.72	2.2%	121,955	184,679	402.41	315.13	603.62
		B8	14.52	0.1%	30.72	5.9%									3,200	4,114			
		C	50.70	1.6%	106.08	6.3%	377.00	0.8%	657.64	1.4%					321,460	484,988	1,034.64	810.23	1,551.96
		C1	21.87	0.3%	48.00	10.1%	163.84	0.2%	289.00	1.9%					140,828	212,437	452.84	354.62	679.26
		C2	28.83	2.7%	58.08	3.4%	213.16	1.2%	368.64	1.0%					180,632	272,551	581.80	455.61	872.70
		D	160.08	3.7%	325.80	5.5%	1163.35	0.5%	2034.64	1.4%					993,521	1,498,956	3,197.99	2,504.35	4,796.99
		D1	36.75	3.9%	75.00	6.0%	265.69	0.1%	466.56	1.4%					227,528	343,269	732.25	573.42	1,098.38
		D2	63.48	2.3%	130.68	5.3%	466.56	0.2%	817.96	1.4%					399,022	602,024	1,284.52	1,005.91	1,926.78
		D3	12.00	5.6%	23.52	3.4%	86.49	1.4%	148.84	0.7%					73,076	110,260	235.33	184.29	353.00
		D4	18.75	7.0%	38.88	11.0%	132.25	0.7%	231.04	1.5%					113,049	170,518	363.29	284.49	544.94
		D5	15.87	6.9%	30.72	3.4%	112.36	0.9%	196.00	1.5%					95,749	144,471	308.36	241.48	462.54
		D6	13.23	0.0%	27.00	2.1%	100.00	0.8%	174.24	1.4%					85,099	128,413	274.24	214.76	411.36
		H	-	-	-	-	-	-	-	-	-	-	-	-					
		L	-	-	-	-	-	-	-	-	-	-	-	-					
		M	145.74	3.5%	294.96	4.7%	1,079.63	2.2%	1,884.08	2.9%					920,032	1,388,238	2,963.71	2,320.88	4,445.57
		M1	69.12	0.1%	138.72	0.5%	580.81	0.3%	1,011.24	0.7%					493,989	745,434	1,592.05	1,246.73	2,388.08
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%	108.16	0.7%	190.44	2.3%					92,780	139,977	298.60	233.83	447.90
		M4	15.87	0.6%	34.68	9.9%	118.81	0.4%	207.36	1.1%					101,448	153,030	326.17	255.42	489.26
		M5	17.28	4.6%	34.68	4.9%	125.44	1.2%	219.04	1.9%					106,984	161,418	344.48	269.76	516.72
		M6	20.28	4.7%	38.88	0.4%	146.41	0.8%	256.00	1.7%					124,831	188,379	402.41	315.13	603.62
		O	6.75	2.1%	14.52	9.8%	50.41	0.02	88.36	2.8%					43,140	65,080	138.77	108.67	208.16
		P	-	-	-	-	-	-	-	-									
		Total	472.86	3.4%	965.64	5.6%	3467.81	1.1%	6056.60	1.9%					2,958,416	4,463,570	9,524.41	7,458.57	14,286.62
	Moderate (in southern side of the railway, each SA1 has separate wetlands; in northern side of the railway, D1 & D2 share one set of wetlands, the other clusters share one set of wetlands)	B	109.59	3.9%	224.28	6.4%	795.24	0.6%	1,383.84	1.0%	260.40	2.9%	2773.35	1.6%	677,197	1,021,657	2,179.08	1,706.44	3,268.62
		B1	13.23	7.6%	27.00	9.8%													
		B2	15.87	0.6%	34.68	9.9%													
		B3	3.00	7.8%	5.88	5.6%													
		B4	32.67	3.5%	63.48	0.6%													
		B5	12.00	3.4%	23.52	1.4%													
		B6	13.23	9.7%	27.00	11.9%													
		B7	5.07	4.1%	12.00	23.2%													
		B8	14.52	0.1%	30.72	5.9%													
		D	160.08	3.7%	325.80	5.5%					-	-	-	-					
		D1	36.75	3.9%	75.00	6.0%	734.41	0.1%	1,267.36	0.1%					622,049	938,468	2,001.77	1,567.59	3,002.66
		D2	63.48	2.3%	130.68	5.3%													
		D3	12.00	5.6%	23.52	3.4%	806.56	0.7%	1,398.76	0.7%	-	-	-	-	696,339	1,048,083	2,205.32	1,726.99	3,307.98
		D4	18.75	7.0%	38.88	11.0%													
		D5	15.87	6.9%	30.72	3.4%													
		D6	13.23	0.0%	27.00	2.1%													
		C	50.70	1.6%	106.08	6.3%													
		C1	21.87	0.3%	48.00	10.1%													
		C2	28.83	2.7%	58.08	3.4%													
		H	-	-	-	-	-	-	-	-	-	-	-	-					
		L	-	-	-	-	-	-	-	-	-	-	-	-					
		M	145.74	3.5%	294.96	4.7%	1,056.25	0.0%	1,831.84	0.1%					897,346	1,353,831	2,888.09	2,261.66	4,332.14
		M1	69.12	0.1%	138.72	0.5%													
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%													
		M4	15.87	0.6%	34.68	9.9%													
		M5	17.28	4.6%	34.68	4.9%													
		M6	20.28	4.7%	38.88	0.4%													
		O	6.75	2.1%	14.52	9.8%	50.41	1.7%	88.36	2.8%					43,140	65,080	138.77	108.67	208.16
		P	-	-	-	-	-	-	-	-									
		Total	472.86	3.4%	965.64	5.6%	3442.87	0.4%	5970.16	0.5%					2,925,002	4,412,892	9,413.03	7,371.34	14,119.55
	High (All share wetlands)	B	109.59	3.9%	224.28	6.4%	3,433.96	0.2%	5,959.84	0.3%					2,919,233	4,404,142	9,393.80	7,356.28	14,090.70
		B1	13.23	7.6%	27.00	9.8%													
		B2	15.87	0.6%	34.68	9.9%													
		B3	3.00	7.8%	5.88	5.6%													
		B4	32.67	3.5%	63.48	0.6%													
		B5	12.00	3.4%	23.52	1.4%													
		B6	13.23	9.7%	27.00	11.9%													
		B7	5.07	4.1%	12.00	23.2%													
		B8	14.52	0.1%	30.72	5.9%													
		C	50.70	1.6%	106.08	6.3%													
		C1	21.87	0.3%	48.00	10.1%													
		C2	28.83	2.7%	58.08	3.4%													
		D	160.08	3.7%	325.80	5.5%													
		D1	36.75	3.9%	75.00	6.0%													
		D2	63.48	2.3%	130.68	5.3%													
		D3	12.00	5.6%	23.52	3.4%													
		D4	18.75	7.0%	38.88	11.0%													
		D5	15.87	6.9%	30.72	3.4%													
		D6	13.23	0.0%	27.00	2.1%													
		H	-	-	-	-													
		L	-	-	-	-													
		M	145.74	3.5%	294.96	4.7%													
		M1	69.12	0.1%	138.72	0.5%													
		M2	8.67	5.7%	17.28	5.4%													
		M3	14.52	1.4%	30.72	7.3%													
		M4	15.87	0.6%	34.68	9.9%													
		M5	17.28	4.6%	34.68	4.9%													
		M6	20.28	4.7%	38.88	0.4%													
		O	6.75	2.1%	14.52	9.8%													
		P	-	-	-	-													
		Total	472.86	3.4%	965.64	5.6%	3433.96	0.2%	5959.84	0.3%					2,919,233	4,404,142	9,393.80	7,356.28	14,090.70

Cost for low densification scheme

Calculating of annual costs of DEWATS - Leumeah low den low cen											
planning and site supervision cost				investment cost						total annual cost	
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)	main structures of 20 years' durability	secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)	total an-nual cost (including land)	total annual cost (excluding land)
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.
1,200	650	500	2,350	150,000	133,602 222,670	300,514 453,293			586,466 828,313	61,875 97,195	56,100 91,420
wastewater data				annual capital costs							
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability	on main structures of 20 years' lifetime (incl. plan-ning fees)	on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year	l.c./year	l.c./year	l.c./year	l.c./year
94	534	1.6	3	3.85%	1.04	5,775	9,871 16,338	21,990 33,083	0	0	30,938 48,597
operational cost						income from biogas and other sources					explanation
cost of personal for operation, maintenance and repair	cost of material for operation, maintenance and repair	cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost		daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m^3 CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m^3
l.c./year	l.c./year	l.c./year	l.c./year	l.c./year			l.c./litre	l.c./year	l.c./year	l.c./year	
155 210	260 305	50	0	465 565		12	2.69	7,164	0	7,164	

Calculating of annual costs of DEWATS - Leumeah low den mod cen											
planning and site supervision cost				investment cost						total annual cost	
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)	main structures of 20 years' durability	secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)	total an-nual cost (including land)	total annual cost (excluding land)
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.
1,200	650	500	2,350	150,000	133,146 221,910	301,801 455,245			587,297 829,505	61,996 97,368	56,221 91,593
wastewater data				annual capital costs							
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability	on main structures of 20 years' lifetime (incl. plan-ning fees)	on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year	l.c./year	l.c./year	l.c./year	l.c./year
94	534	1.6	3	3.85%	1.04	5,775	9,838 16,283	22,084 33,225	0	0	30,998 48,684
operational cost						income from biogas and other sources					explanation
cost of personal for operation, maintenance and repair	cost of material for operation, maintenance and repair	cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost		daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m^3 CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m^3
l.c./year	l.c./year	l.c./year	l.c./year	l.c./year			l.c./litre	l.c./year	l.c./year	l.c./year	
155 210	260 305	50	0	465 565		12	2.69	7,164	0	7,164	

Calculating of annual costs of DEWATS - Leumeah low den hig cen											
planning and site supervision cost				investment cost						total annual cost	
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)	main structures of 20 years' durability	secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)	total an-nual cost (including land)	total annual cost (excluding land)
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.	l.c.
1,200	650	500	2,350	150,000	157,794 262,990	301,291 454,471			611,435 869,811	65,501 103,221	59,726 97,446
wastewater data				annual capital costs							
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability	on main structures of 20 years' lifetime (incl. plan-ning fees)	on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year	l.c./year	l.c./year	l.c./year	l.c./year
94	534	1.6	3	3.85%	1.04	5,775	11,628 19,266	22,047 33,169	0	0	32,750 51,611
operational cost						income from biogas and other sources					explanation
cost of personal for operation, maintenance and repair	cost of material for operation, maintenance and repair	cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost		daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m^3 CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m^3
l.c./year	l.c./year	l.c./year	l.c./year	l.c./year			l.c./litre	l.c./year	l.c./year	l.c./year	
155 210	260 305	50	0	465 565		12	2.69	7,164	0	7,164	

Calculating of annual costs of DEWATS - Campbelltown low den low cen

planning and site supervision cost				investment cost									total annual cost			
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.	
1,200	650	500	2,350	150,000	406,188	676,980	1,643,435	2,479,626			2,201,973	3,308,956	174,102	295,730	168,327	289,955

wastewater data				annual capital costs										
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs	
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year		l.c./year		l.c./year	l.c./year	l.c./year	
506	534	1.6	3	3.85%	1.04	5,775			119,497	180,211	0	0	87,051	147,865

operational cost										income from biogas and other sources					explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m³ CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year					l.c./litre	l.c./year	l.c./year	l.c./year		
155	210	260	305	50	0	465	565			67	2.69	38,686	0	38,686		

Calculating of annual costs of DEWATS - Campbelltown low den mod cen

planning and site supervision cost				investment cost									total annual cost			
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.	
1,200	650	500	2,350	150,000	534,174	890,290	1,617,683	2,440,568			2,304,207	3,483,208	170,362	290,058	164,587	284,283

wastewater data				annual capital costs										
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs	
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year		l.c./year		l.c./year	l.c./year	l.c./year	
506	534	1.6	3	3.85%	1.04	5,775			117,627	177,375	0	0	85,181	145,029

operational cost										income from biogas and other sources					explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m³ CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year					l.c./litre	l.c./year	l.c./year	l.c./year		
155	210	260	305	50	0	465	565			67	2.69	38,686	0	38,686		

Calculating of annual costs of DEWATS - Campbelltown low den hig cen

planning and site supervision cost				investment cost									total annual cost			
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.	
1,200	650	500	2,350	150,000	564,510	940,850	1,614,617	2,435,918			2,331,477	3,529,118	169,917	289,383	164,142	283,608

wastewater data				annual capital costs										
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs	
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year		l.c./year		l.c./year	l.c./year	l.c./year	
506	534	1.6	3	3.85%	1.04	5,775			117,404	177,037	0	0	84,959	144,691

operational cost										income from biogas and other sources					explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m³ CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year					l.c./litre	l.c./year	l.c./year	l.c./year		
155	210	260	305	50	0	465	565			67	2.69	38,686	0	38,686		

Cost for high densification scheme

Calculating of annual costs of DEWATS - Leumeah high den low cen

planning and site supervision cost				investment cost									total annual cost			
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.	
1,200	650	500	2,350	150,000	207,396	345,660	1,417,468	2,138,771			1,777,214	2,636,781	186,191	311,214	180,416	305,439

wastewater data				annual capital costs										
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs	
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year		l.c./year		l.c./year	l.c./year	l.c./year	
411	534	1.6	3	3.85%	1.04	5,775	15,229	25,268	103,090	155,462	0	0	93,096	155,607

operational cost										income from biogas and other sources					explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m³ CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year					l.c./litre	l.c./year	l.c./year	l.c./year		
155	210	260	305	50	0	465	565			55	2.69	31,463	0	31,463		

Calculating of annual costs of DEWATS - Leumeah high den mod cen

planning and site supervision cost				investment cost									total annual cost			
salaries for planning and supervision	transport and allowance for visiting or staying at site	cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation	main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability	total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.	l.c.	l.c.	l.c.	l.c.	l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.	
1,200	650	500	2,350	150,000	231,438	385,730	1,344,025	2,027,382			1,727,813	2,565,462	179,018	300,857	173,243	295,082

wastewater data				annual capital costs										
daily waste-water flow	strength of waste-water inflow	COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)	interest factor q=1+i	on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime	on equipment of 6 years' lifetime	total capital costs	
m^3/d	mg/l COD	mg/l	mg/l COD	%		l.c./year	l.c. /year		l.c./year		l.c./year	l.c./year	l.c./year	
411	534	1.6	3	3.85%	1.04	5,775	16,975	28,178	97,757	147,374	0	0	89,509	150,429

operational cost										income from biogas and other sources					explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH 4 , 50% dissolved)	price 1 litre of kerosene (1m³ CH 4 =0.85 l kerosene)	annual income from biogas per annum	other annual income or savings (e.g. fertili-ser, fees))	total income per annum	l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year					l.c./litre	l.c./year	l.c./year	l.c./year		
155	210	260	305	50	0	465	565			55	2.69	31,463	0	31,463		

Calculating of annual costs of DEWATS - Leumeah high den hig cen																				
planning and site supervision cost						investment cost											total annual cost			
salaries for planning and supervision		transport and allowance for visiting or staying at site		cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation		main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability		total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.		l.c.	l.c.		l.c.		l.c.		l.c.	
1,200		650		500	2,350	150,000		249,828	416,380	1,316,194	1,985,172				1,718,372	2,553,902	177,647	299,179	171,872	293,404
wastewater data						annual capital costs														
daily waste-water flow		strength of waste-water inflow		COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)		interest factor q=1+i		on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime		on equipment of 6 years' lifetime		total capital costs	
m³/d		mg/l COD		mg/l	mg/l COD	%				l.c./year	l.c. /year		l.c./year		l.c./year		l.c./year		l.c./year	
411		534		1.6	3	3.85%		1.04		5,775	18,310	30,403	95,736	144,309	0		0		88,823	149,589
operational cost										income from biogas and other sources									explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH_4 , 50% dissolved)		price 1 litre of kerosene (1m³ CH_4 =0.85 l kerosene)	annual income from biogas per annum		other annual income or savings (e.g. fertili-ser, fees))		total income per annum		l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year						l.c./litre	l.c./year		l.c./year		l.c./year			
155	210	260	305	50	0	465	565			55		2.69	31,463		0		31,463			

Calculating of annual costs of DEWATS - Campbelltown high den low cen																				
planning and site supervision cost						investment cost											total annual cost			
salaries for planning and supervision		transport and allowance for visiting or staying at site		cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation		main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability		total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.		l.c.	l.c.		l.c.		l.c.		l.c.	
1,200		650		500	2,350	150,000		680,628	1,134,380	2,958,416	4,463,570				3,791,394	5,750,300	401,736	686,399	395,961	680,624
wastewater data						annual capital costs														
daily waste-water flow		strength of waste-water inflow		COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)		interest factor q=1+i		on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime		on equipment of 6 years' lifetime		total capital costs	
m³/d		mg/l COD		mg/l	mg/l COD	%				l.c./year	l.c. /year		l.c./year		l.c./year		l.c./year		l.c./year	
914		534		1.6	3	3.85%		1.04		5,775	49,589	82,535	214,975	324,260	0		0		200,868	343,200
operational cost										income from biogas and other sources									explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH_4 , 50% dissolved)		price 1 litre of kerosene (1m³ CH_4 =0.85 l kerosene)	annual income from biogas per annum		other annual income or savings (e.g. fertili-ser, fees))		total income per annum		l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year						l.c./litre	l.c./year		l.c./year		l.c./year			
155	210	260	305	50	0	465	565			121		2.69	69,936		0		69,936			

Calculating of annual costs of DEWATS - Campbelltown high den low cen																				
planning and site supervision cost						investment cost											total annual cost			
salaries for planning and supervision		transport and allowance for visiting or staying at site		cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation		main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability		total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.		l.c.	l.c.		l.c.		l.c.		l.c.	
1,200		650		500	2,350	150,000		680,628	1,134,380	2,958,416	4,463,570				3,791,394	5,750,300	401,736	686,399	395,961	680,624
wastewater data						annual capital costs														
daily waste-water flow		strength of waste-water inflow		COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)		interest factor q=1+i		on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime		on equipment of 6 years' lifetime		total capital costs	
m³/d		mg/l COD		mg/l	mg/l COD	%				l.c./year	l.c. /year		l.c./year		l.c./year		l.c./year		l.c./year	
914		534		1.6	3	3.85%		1.04		5,775	49,589	82,535	214,975	324,260	0		0		200,868	343,200
operational cost										income from biogas and other sources									explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH_4 , 50% dissolved)		price 1 litre of kerosene (1m³ CH_4 =0.85 l kerosene)	annual income from biogas per annum		other annual income or savings (e.g. fertili-ser, fees))		total income per annum		l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year						l.c./litre	l.c./year		l.c./year		l.c./year			
155	210	260	305	50	0	465	565			121		2.69	69,936		0		69,936			

Calculating of annual costs of DEWATS - Campbelltown high den hig cen																				
planning and site supervision cost						investment cost											total annual cost			
salaries for planning and supervision		transport and allowance for visiting or staying at site		cost for waste-water analysis	total planning cost incl. overheads and acquisition	cost of plot incl. site preparation		main structures of 50 years' durability (sewer)		main structures of 20 years' durability		secondary structures of 10 years' durability	equipment and parts of 6 years' durability		total investment cost (incl. land and planning)		total an-nual cost (including land)		total annual cost (excluding land)	
l.c.		l.c.		l.c.	l.c.	l.c.		l.c.		l.c.		l.c.	l.c.		l.c.		l.c.		l.c.	
1,200		650		500	2,350	150,000		897,744	1,496,240	2,919,233	4,404,142				3,969,327	6,052,732	427,575	730,317	421,800	724,542
wastewater data						annual capital costs														
daily waste-water flow		strength of waste-water inflow		COD/BOD ratio of inflow	strength of waste-water outflow	rate of interest in % p.a. (bank rate minus inflation)		interest factor q=1+i		on investment for land	on main structures of 50 years' durability		on main structures of 20 years' lifetime (incl. plan-ning fees)		on secondary structures of 10 years' lifetime		on equipment of 6 years' lifetime		total capital costs	
m³/d		mg/l COD		mg/l	mg/l COD	%				l.c./year	l.c. /year		l.c./year		l.c./year		l.c./year		l.c./year	
914		534		1.6	3	3.85%		1.04		5,775	65,354	108,809	212,130	319,945	0		0		213,787	365,159
operational cost										income from biogas and other sources									explanation	
cost of personal for operation, maintenance and repair		cost of material for operation, maintenance and repair		cost of power (e.g. cost for pumping)	cost of treatment additives (e.g. chlorine)	total operational cost				daily biogas production (70% CH_4 , 50% dissolved)		price 1 litre of kerosene (1m³ CH_4 =0.85 l kerosene)	annual income from biogas per annum		other annual income or savings (e.g. fertili-ser, fees))		total income per annum		l.c. = local currency; mg/l = g/m³	
l.c./year		l.c./year		l.c./year	l.c./year	l.c./year						l.c./litre	l.c./year		l.c./year		l.c./year			
155	210	260	305	50	0	465	565			121		2.69	69,936		0		69,936			