Urban Ecology and the Design of a Green Infrastructure Network based on Catchments for urban Auckland, New Zealand

----- The Oakley Creek Catchment Case Study
ABSTRACT

The pressures of global population growth, migration and increasing urban densities present significant issues which can negatively impact on the health of cities. These pressures are more evident in midsize global cities (Allen et al., 2016) where there are often significant conflicts between the development of human infrastructure and the maintenance of natural ecosystems. The conflict leads many times to major environmental degradation.

Urban studies tend to describe development patterns negatively, and often point to environmental problems that stem from development, such as landscape fragmentation (Forman, 2014), degrading water quality (Marjorie van Roon et al., 2004), flooding and increasing water-borne pollution (Pickett et al., 2013; Pickett & Cadenasso, 2007), reduction of green space and biodiversity (Wu, 2014). However, many of these authors reflect on the values and opportunities that arise from urban development to link ecology and urban development through green space networks as described by Borrett (2014), Derbyshire and Wright (2014), Li et al. (2015) and Niemelä (1999).

This project explores a new, valuable and sustainable urban development paradigm through creating a new Green Infrastructure Network (GIN) model based on hydrological catchment in urban Auckland. This GIN connects current LID and WSD stormwater management practices, as is already in use at present, with a new sustainable spatial mode for intensified urban area.

The Oakley Creek catchment is used as a case study to show the details and functions of the GIN. Through classifying Oakley Creek catchment into four scales: 1 block scale; 2 neighbourhood scale; 3 community scale and 4 urban stream scale to form a ‘nested catchment’. Then manage the catchment by designed GIN nodes and corridors to deal with multiple urban environmental and hydrological issues.

Additionally, design a local area network (LAN) model and shared infrastructures in the GIN to create social and economic benefits to the local community. The new GIN and LAN models show the interrelated character of ecological, social and economic conditions in a local community design.
Keywords: urban ecology; green infrastructure network; green space network; integrated catchment management; stormwater management; local area network; shared infrastructure
ACKNOWLEDGEMENTS

Thanks to my supervisor Daniel Irving. I could not finish this final design and thesis without his support. Thanks for him encouraging me and also providing me a lot of brilliant ideas.

Thanks to the MLA Academic leader Matthew Bradbury, who gave me a lot of encouragements and supports to go through the multiple difficulties during my study.

Thanks to the staff at Fulton Hogan Limited for showing me the construction of Te Auaunga Awa-Walmsley and Underwood parks project. I appreciated learning of the current Oakley creek channel retrofit technologies and methods, which were essential for the development of my project.

Thanks to Xinxin Wang, who was always supportive of this project and who advised me on how to improve the rationale of my design works.

Also thanks to my MLA classmates. We have enjoyed each other’s company during our studies and encouraged each other to achieve our project goals.
ABBREVIATIONS

AC Auckland Council
ADM Auckland Design Manual
ARI Annual Recurrence Interval
CMP Catchment Management Plan
DEC Department of Environmental Conservation
GIN Green Infrastructure Network
GI Green Infrastructure
GIS Geographic Information System
ICM Integrated Catchment Management
LAN Local Area Network
LID Low Impact Design (NZ) or Low Impact Development (US)
NZ New Zealand
TP Technical Publication
USEPA United States Environmental Protection Agency
WSD Water Sensitive Design
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1.0 INTRODUCTION
1.1 Research Questions

Main Question
How can a catchment-based green infrastructure network better achieve low-impact storm water attenuation goals for urban and community development in Auckland in the context of climate change?

Sub-questions
How well does existing green infrastructure deal with flooding and seconding pollution issues via existing overland flows and stormwater management?

How can Low-Impact Design (LID) and stormwater management methods better utilize a range of values (i.e., ecological, economic and social) to accomplish urban design objectives for Auckland city?

Within the boundaries of unitary plan, is it possible to create a Green Infrastructure Network (GIN) that provides positive environmental change for urban development?
1.2 Research Rationale

Urban Environmental Problems of Midsize Global Cities

As Auckland, New Zealand, joins the rank of rapidly expanding mid-sized globally-oriented cities, it faces a range of urban issues that raise questions about long-term urban sustainability (Wu, 2014; Pickett et al., 2013).

At present, almost half of all humans on earth live in urban areas. By 2030, it has been predicted that greater than two-thirds of the human population will live have been born in, or immigrated to cities (The United Nations, 2014). The pressure to develop and improve liveable cities is largely driven by the need to expand infrastructure networks and find a more adaptive model for shaping environmental and social programs. The health of future cities will depend on the quality of the solutions to these issues, especially to cope with global, natural, and environmental change.

Ecology has become a central topic of long-term urban sustainability (Wu et al., 2014). The pressure to expand urban infrastructure often has negative ecological problems. For example, the construction of roads or other impervious surfaces can break the integrity of land and landscape elements such as ecological ‘patches’ (Viles, 2001). This leads to fragmentation and a decrease in the quality of local ecologies. The balance between urban ecology and expansion of cities is difficult to reconcile.

With the rapid increase in concentration and density of mid-sized global centres, cities such as Auckland are confronted with several critical problems: the deterioration or reduction of green space caused by landscape fragmentation (Wu, 2014; Jongman et al., 2008), decreasing biodiversity (Andersson & Colding, 2014), urban pollution (Pickett et al, 2013; Pickett & Cadenasso, 2008), and urban hydrological problems such as flooding. These problems result in costly damage to urban infrastructure and disruption to people.

In the last 25 years, landscape fragmentation has been studied in relation to the quality of urban life, especially in North American and European cities (Forman, 2014). One study shows that landscape fragmentation results in deterioration of green spaces (Richardson et al., 2010). As the green spaces can help filter pollution in air and water,
produce oxygen, mitigate heat absorption by asphalt and concrete, provide a habitat for birds and other wildlife, and also associated with lower levels of physician-assessed morbidity, as well as lower mortality risks (Richardson et al., 2010), the degradation of green spaces has a negative impact to healthy urban lifestyle.

The reduction of green spaces has also led to the decline of land-based vegetation along with the invertebrates, reptiles, and birds (Meurk, 2003). The biodiversity show the ecosystem health of an urban area because of its intrinsic importance and the resource capabilities of the cities (Meurk, 2003). Therefore, there is a degradation of measurable ecological services which provide multiple values to local people (Perrings, Folke & Maler, 1992). Especially in a New Zealand and Auckland context, many animals are endangered as a result of habitat loss (Marjorie van Roon et al., 2004).

Urban pollution is another serious environmental problem. It is correlated with population increases in cities (Colding & Barthel, 2013). Cities now account for about 60% of all residential water use, 75% of energy use, 80% of the timber used for industrial purposes, and 80% of human greenhouse gas emissions (Grimm et al, 2008; Newman, Beatley & Boyer, 2009). It contributes to contaminants and multiple wastes, which have a significant negative impact on air and water quality.

Water is a source of life and food. It provides great opportunities for environments, recreation, and even energy production. Especially in New Zealand, fresh water is one of the most precious resources. It is even a central part of the identity, particularly for iwi (Land and Water Forum, 2010). But currently fresh water has come under increasing pressure in the last 20 years (Land and Water Forum, 2015) and the water quality continues to decline.

One of the water quality issues Auckland currently facing is ‘urban stream syndrome’ (Kennedy, 2017): blooming algal, fatal toxic pollutants, increased water temperature which harmful to freshwater insects, molluscs and fish. This issue is caused by wastewater discharging directly to the water body. It demands a more collaborative approach to water management.

Additionally, the integrated urban hydrological cycle is affected as green spaces degrading. For example, natural infiltration mechanism is influenced by the high
percentage of the impervious paving (Wu, 2014). Most of the stormwater previously infiltrate into underground now become runoff, which contributes to serious flooding problems in a heavy storm event. After overflows, the bacterial level increases dramatically, which threatens the health of the vegetation and the hydrological environment (Kennedy, 2017).

Despite many critical reviews of the urban environmental problems and negative impacts of urban development, cities account for only a small part of the earth's space, occupying less than 1% of the terrestrial land (Schneider, Friedl & Potere, 2010). But by way of concentrating human effort, innovation and development, cities offer opportunities to improve human well-being for a large population. The Human Development Index shows that GDP per capita, life expectancy, and education have increased as the city growing (Millennium Ecosystem Assessment, 2005; Raudsepp-Hearne et al., 2010).

At present and in the future, cities are still important for human development. The spread of urban area cannot be stopped. But urban ecological condition is getting worse. There is a correlation between the increase in human development and the decline of ecosystems, noted as the ‘environmentalist’s paradox’ (Wu, 2014).

Therefore, a more sustainable and environmentally friendly urban development paradigm is required to solve the ‘environmentalist’s paradox’ issue. Although infrastructure developments are intended to support urban populations, without a strong green infrastructure system that offer urban ecological benefits, infrastructure developments may bring a negative aspect to ecological services of citizens.
Environmental Problems in Urban Auckland

Auckland is the biggest city in New Zealand. Currently, it is facing urban spreading issue, which is driven by population increase and migration (Sassen, 2001). Though this urbanization has brought many economic and social benefits to local people in Auckland, the negative environmental problems cannot be ignored.

According to Auckland Council (2013), Auckland’s green space makes a major contribution towards Auckland’s quality of life and physical attractiveness. These green spaces can help manage the flow of stormwater, improve air quality, mitigate climate change, protect biodiversity, express the values and history of Auckland, provide venues and opportunities for experiences and events that bring businesses thus adding economic benefits to local communities, tourists and workers to Auckland (Auckland Council, 2013).

However, Auckland is facing green space erosion, fragmentation and reduction problems (Jongman, 2008), which have a negative impact on the urban life. It also leads to New Zealand’s special species such as fernbirds, shoveler, black mudfish being endangered (Marjorie van Roon et al., 2004) because of the habitat fragmentation, loss, and isolation (Collinge, 1996; Adriaensen et al, 2003).

Air pollution and greenhouse gas emission are also key issues for Auckland. As the population continues to grow, it is estimated that by 2025 Auckland’s carbon emissions will be 46 percent higher than current levels, and, by 2040, energy use will have climbed by almost two-thirds (Doesburg, 2014).

Additionally, Auckland faces issues such as flooding and associated water pollution issues, which could increase in the context of climate change.

In urban areas, headwater streams are being replaced by headwater streets (Kimberly, Jarden & Jennifer, 2016). The streams were replaced by pipes in order to increase drainage efficiency, resulting in high volumes of stormwater to urban streams and sewer networks. As the population has increased dramatically over the recent decades, the infrastructure of Auckland has come under increasing pressure. The old stormwater drainage pipes are not large enough to endure the load of increasing storm runoff. This
overflow potentially causes flooding, erosion at the end of these pipes, pollution and degradation of aquatic ecosystems, and the discharge of raw sewage into the environment when sewers overflow.

Flooding events in Auckland have caused damage to city infrastructure and made it inconvenient for people to live. For example, the storm event of March 2017 in Auckland that flooded hundreds of properties caused damage in the thousands of dollars (NZ Herald, 2017).

Auckland Council data showed the Auckland region has 52,000 properties sitting in a flood plain, and that heavy storms, rainwater runoff and low-lying land could pose a flood risk to about 16,000 properties in the Auckland region (NZ Herald, 2017). Over the next 30 years, as changes to its temperature and rainfall, Auckland could face more frequent storms which would lead to flooding and rising sea-level problems.
Advantages

- Offer opportunities
  Bring safety infrastructure and more employment opportunities to citizens to improve human well-being for a larger number

- Economy and education.
  The Human Development Index shows that life expectancy, GDP per capita, and education has gradually increased in relation to the growth of cities (Millennium Ecosystem Assessment, 2005; Raudsepp-Hearne et al., 2010).

- People settlement
  In New Zealand, urban dwellers account for up to 86% of total people (Meurk, 2003).

Disadvantages

- Urban pollution and disaster
  Increase life and industrial waste, air pollution, water waste and pollution, etc;
  Flooding, infrastructure damage problems;
  River bank erosion

- Reduction of green space
  Landscape fragmentation;
  Decrease self-perceived health, bring higher blood pressure, higher levels of overweight and obesity, higher levels of physician-assessed morbidity, higher mortality risks (Richardson et al., 2010).

- Reduction of biodiversity
  New Zealand’s special species such as fernbirds, shoveler, black mudfish are in danger (Marjorie van Room, 2004).

Table 1.1. Advantages and disadvantages of urbanization in NZ (Author, 2018)
Green Infrastructure Network to Solve Urban Ecological Issues

As urban ecological problems increase it is important to reconsider the function of existing green spaces in terms of the role and value these spaces may have in the hydrological cycle and in terms of urban ecology. More specifically, these spaces could also relieve pressure on city infrastructure. A city green space network is an appropriate way to achieve these goals (Jordán et al., 2003; Parker et al., 2008; Esbah et al., 2009). It is increasingly considered a suitable approach to improve the ecological value of urban green space and the urban environment (Li, 2015) as well as to bring multiple benefits to local communities.

Connectivity was used by landscape ecologists to describe a landscape’s structural and functional continuity in space and time (Forman, 1986). The connected green space network can bring a lot of ecological benefits to the urban environment (Li et al., 2015). For instance, it can protect biodiversity which dependents on the connectivity of habitat patches linked by the ecological corridors. Through these corridors, natural populations and threatened habitats of native plants and animals can be survived (Perrings, Folke & Maler, 1992).

Additionally, the green space network can help to recover natural hydrology function such as self-purify ability as well as to offer recreational opportunities for local people to organize social activities and relax. It has been considered as a proper way to deal with the ‘environmentalist’s paradox’ problems in urban area (Wu, 2014).

In the Auckland context, in order to solve urban ecological problems, Auckland Council has set out to support local ecologies by way of the Parks and Open Spaces Strategic Action Plan in order to make Auckland the world’s most liveable city (Auckland Council, 2013). The target is to create a green space network across Auckland by linking the parks, open spaces and streets over the next 10 years.

This proposed green space network can help manage stormwater, improve air and water quality, reduce flood risk, help mitigate climate change, enhance native biodiversity, create opportunities for people to move around the city so as to help all Aucklanders easily access and enjoy the parks and open spaces. These goals guide designers, environmentalism, ecologists and other related experts to analyze the current
urban ecological issues, redesign the city green spaces, and restore the urban ecosystem in a macroscopic view. However, it needs further detailed research based on different local areas’ atmosphere and conditions.

Auckland Council is also introducing the Low Impact Design (LID) and the Water Sensitive Design stormwater management practices in green spaces to deal with the urban hydrological problems in Auckland. There are also proposals in the Unitary Plan to have less development in the green zones and to obey regulations and limitations for
constructing buildings to minimize the risk of flooding (NZ Herald, 2017).

Combined the green space network with stormwater management, LID, and WSD, a green infrastructure network (GIN) is proposed for urban Auckland in this project. The GIN not only has the ecological functions as a connected green space network in the high impervious surface area but also has engineering functions that can release the pressure of the grey infrastructure especially the stormwater drainage system to add social and even economic benefits to the city.

The GIN can keep a balance between city infrastructure and green environment, between the hard landscape and the soft landscape. A well-designed GIN can have multiple functions including urban ecological recovery, hydrological conservation, and as an amenity for surrounding communities.
1.3 Aims & Objectives

Although city expanding and developing can never be entirely predicted or controlled, planning and design work based on urban ecological knowledge, and sustainability principles can influence and guide the city in more desirable direction (Wu, 2014).

To balance the relationships between urban ecology and urban development, a new and sustainable development paradigm will be proposed. This paradigm aims to construct an ecological GIN based on the integrated catchment management method. The GIN can help form a stormwater neutrality environment, conserve indigenous wildlife species habitats, release the pressure of grey infrastructure, provides a more adaptive way to cope with global environmental changes in the future, increase healthy living condition and people’s well-being to deal with the ‘environmentalist’s paradox’.

This GIN will combine current LID and WSD stormwater management practices with a new urban spatial model to protect, preserve, and restore the urban ecology as an integrated ecosystem. This urban spatial model will add more ecological, hydrological, social and even economic benefits to local people.

A better understanding of the ‘environmentalist’s paradox’ relation requires scrutiny with more detailed data at local and regional scales (Wu, 2014). Therefore, this project will not only focus on the large city scale but also focus on the local area and community scale. It will add multiple benefits to the neighbourhood through a stated urban community design process thus to contribute to more detailed solutions for environmental problems in Auckland.
Figure 1.3. Concept effect picture of ‘sponge catchment’ (Author, 2018)
Additionally, this project also aims to create a sustainable GIN system which is economic smart to maintain. Kennedy (2017) supposed that the community would value, activate and protect the facilities if it can bring multiple benefits to them (Kennedy, 2017). So the sustainable consumption and maintenance mode will be created for local communities to encourage local people to maintain it consciously.

The targets of the GIN are as follows:

- Redesign current green space and design new open spaces where there are potential functions of decreasing the total volume, peak flow and flow velocity of stormwater based on integrated catchment management method and Unitary Plan. Install currently practiced LID and WSD stormwater management devices in it.

- Restoration and maintenance of the connectivity among diverse green spaces such as parks, reserves by identification of potential corridors to protect biodiversity and to add multiple ecological benefits in urban Auckland.

- Diverse the GIN functions. Add other benefits such as social and recreational benefits in it.

- Increase economic benefits, thus incentivizing local people to make an effort to maintain the GIN.
Types | Ecological benefits | Social benefits | Economic benefits
--- | --- | --- | ---
1 | Auckland’s hydrological conditions will be maintained and protected, including maintaining the base stream flows, balancing the hydrologic cycle, improving water quality, reducing downstream sedimentation and pollution, preventing flooding. | To provide multiple functional spaces such as playgrounds, outdoor classroom, communication and recreational places. | Add commercial uses to activate the community. |
2 | To offer green corridors linking other ecological importance areas to enhance the integrity functions of natural ecosystem. | To create opportunities for local people gathering and communication through shared infrastructures. | Decrease the maintenance cost by creating cooperation mechanism and sustainable consumption pattern. |
3 | To protect biodiversity. | To design walkways, cycle paths, pedestrian paths to make people move around the neighborhoods easily. | TableI.2. Visions and benefits of this project (Author, 2018)
1.4 Methodology

Literature Review

1. Related Concepts, Methods & Case Study

The related theories, technologies, and approaches to form the urban ecological GIN will be studied through reading relevant professional books and viewing literature. Learn other scholars’ ideas about how to solve the urban ecological problems. This will offer guidance and reference for the follow-up research to construct a rational urban ecological GIN and to create a sustainable and livable eco-city.

Moreover, cases related to constructing GIN nodes and corridors will be studied and analyzed to learn the proper construction techniques, principles, components, and thoughts. The advantages and disadvantages aspects including ecological, social and economic impacts of these cases will be evaluated to provide a reference for the suitable practice development of the GIN.

2. Policies, Codes, and Documents

The existing policies, codes, and documents related to this project will be investigated to evaluate the current environmental conditions in urban Auckland area. They will also provide rational support, assumptions and possibilities for the follow-up GIN design.
Design Methods

1. GIS Analysis

Geography Information System (GIS) is a scientific and efficient methodology to analyze on-site and off-site problems. It will be used to analyze different contents such as land use area, impervious surface area, hydrological conditions, and elevation conditions of Oakley Creek catchment to form an integrated catchment management map and to support a rational GIN design.
2. LID & WSD Methods

Low Impact Design or Low Impact Development (LID) is defined as ‘an innovative land planning and design approach which seeks to maintain a site’s predevelopment ecological and hydrological function through the protection, enhancement, or mimicry of natural processes.’ (DEC, n.d.)

Water Sensitive Design (WSD) represents the best practice approach for stormwater management, taking into consideration whole-of-life costs (Auckland Council, 2015).

The LID and WSD methods will be used to manage stormwater and to conserve or reuse natural features. The strategies include naturalization of piped streams, restoration of riparian vegetation, installation of stormwater management devices such as wetland, swales, ponds, rain gardens, etc. (Marjorie van Roon et al., 2004). These devices protect water quality and prevent flooding problem by the combined effects of filtration, infiltration, adsorption, biological uptake, evaporation, storage of runoff close to its source, which also can improve the physical, biological and ecological environment of the city (Meurk, 2003; Heathcote, 2009).

There are existing LID and WSD stormwater management devices installed in New Zealand. For example, swale filters with native sedges, rushes and New Zealand flax are being used along the roads, and rain gardens are being promoted to clean rain runoff from buildings (Meurk, 2003).

To design a rational and proper ecological GIN for Auckland, the current and typical LID and WSD stormwater management devices and practices in New Zealand will be studied. Most of the materials come from TP10 (the technical publications) and GD04 (Water Sensitive Design for Stormwater) of Auckland Council. New stormwater storage and filtration devices will also be learned for searching a more economical and efficient way to deal with the storm runoff.
3. Hedonistic Sustainability Method

The hedonistic sustainability concept is a thought that can inspire landscape architects to deal with the ‘environmentalist’s paradox’ problem, which shows the correlation between human development and degraded urban ecosystems (Wu, 2008). The term popularized by the Danish architect Bjarke Ingels, who emphasizes the interaction of people and spaces, and the role of sustainability within this interaction. It proposes designing cities and buildings as double ecosystems that are both environmentally sustainable and economically profitable thus protecting or even improving people’s current lifestyles (Quirk, 2014). Hedonistic Sustainability method will be used to design a local area network and the shared infrastructure system in the GIN to help improve urban ecology as well as to increase the quality of urban life.
Practice / Design Work / Evaluation

1. Practice

Develop a practice of Auckland ecological GIN construction based on a mix of different mediums including documentation, investigation, and research from the previous study. Then add Auckland characteristics in this GIN.

This will be formulated through review of documents, photographs, sketches, drawings and graphics. The primary aim of this practice is to ensure the GIN is designed reasonably and legitimately.

2. Design Work

Select the most representative site to design urban ecological GIN. Use pre-learned theories and technologies to conduct rational analysis, the planning work, and the detailed designs. The steps are as follows:

- Choose a specific site to study.
- Conduct an on-site investigation and research on the selected area.
- Analyze the hydrology conditions, elevation conditions, characteristics of existing and potential landscape green spaces, etc. via GIS analysis.
- Use the pre-learned theories, technologies and data to create rational GIN based on catchment conditions. Renew and retrofit existing GI facilities. Add ecological, social and economic functions through taking consideration of multiple influences.
- Analyze the designed conditions of the GIN

3. Evaluation

Conclude general principles and methods of constructing urban ecological GIN in Auckland. Evaluate the values of this project.
1.5 Summary

In this chapter, the urban environmental problems of midsize global cities and specific urban environmental problems in Auckland, New Zealand were studied to show the research rationale. The primary environmental problems in Auckland are green space fragmentation, biodiversity decreasing, flooding, water and air pollution.

A green infrastructure network (GIN) model is proposed to deal with the urban environmental issues. The GIN combines the functions of the green space network and city infrastructure together to bring multiple benefits to local people.

The aim of this project is to create an ecological GIN. In this GIN, the current LID and WSD stormwater management practices are utilized to form a whole stormwater management system. It also creates a new urban spatial model which brings ecological, hydrological, social and even economic benefits to deal with the ‘environmentalist’s paradox’.

The methodology includes the literature review, design methods, and process of the design. The literature review is about related concepts and methods, case study, and policies, codes, and documents. Design methods included GIS analysis, LID and WSD methods, and the Hedonistic Sustainability method (Quirk, 2014). The process of the design consists of the practice, the design work and the evaluation as last step.
LITERATURE REVIEW
2.1 Related Concepts

Urban Ecology

Urban ecology is a study of spatiotemporal patterns, environmental impacts, and sustainability of urbanization with the emphasis on biodiversity, ecosystem processes, and ecosystem services (Wu, 2014). It shows the relationships between humans or other organisms living in cities and their surroundings in the context of an urban environment (Niemela, 1999). It raises questions about how human and ecological processes can coexist in human-dominated systems to construct more sustainable cities. Urban ecology needs to be studied to plan and build environmentally friendly and sustainable cities, and also improve the human well-being for the long-term (Wu, 2014).
Green Space Network and GIN

The idea of the green space network was proposed at the beginning of the 20th century in great metropolitan places of both the Eastern and Western Europe cities, such as London, Moscow, Berlin, Prague and Budapest (Kavaliauskas, 1995). This idea aimed to develop a green-belt system that interconnected the city and the nature areas (Jongman et al., 2004).

Green space network is formed based on three landscape elements: patch, corridor, matrix (Forman, 1995) which forms the ‘patch–corridor–matrix’ model (Forman & Godron, 1986). This model can be applied to study the connectivity of green spaces. Patch is defined as a relatively homogeneous area that differs from its surroundings which have a definite shape and spatial configuration. Corridors are strips of a particular type of landscape differing from adjacent land on both sides. Matrix is the ‘background ecological system’ of a landscape (Forman & Godron, 1986). A green space network can be defined as an interconnected system of corridors which connect the patches, or ‘nodes’ to form an integral green spaces system (Forman, 1995), which creates ecological, recreational and cultural benefits (Fabos, 1995).

In different countries, the idea of green space network is different. The nature conservation policies and green corridor system developments in urbanized areas are also varied (Jongman et al., 2004). In America, corridors are referred to ‘greenways’ (Jongman et al., 2004) and a green space network is defined as the ‘linear open spaces’ established along natural corridors, such as riverfronts, or overland along railroad (Little, 1990; Flink & Sears, 1993).

Green infrastructure is defined as technologies and practices that use natural systems or engineered systems to maintain or enhance overall community and environmental values and provide utility services for stormwater management (Mayhew et al., 2016). Green infrastructure includes both built infrastructure such as green device and non-built green space such as parks, woodland areas and agricultural areas (Andrzej &
A green infrastructure network (GIN) can not only be treated as a green space network which creates connectivity among patches, recovering urban ecology, improve the hydrological health of the urban ecosystem, thus dealing with flooding and water pollution problems, but also can offer cost-effective constructed infrastructure (Mayhew et al., 2016) to bring social and economic benefits to the sustainable local communities.
Catchment and ICM

To analyze and solve the hydrological problems of Auckland, the ‘catchment’ and ‘integrated catchment management’ method are studied.

A catchment is a land area where the storm runoff is passing through and collected. The runoff can be purified, filtered, and stored in a healthy catchment. The purpose of the catchment analysis is to understand the catchment regarding its surface water, groundwater and land use, and how these aid in either regulating or disrupting the water cycle (Boon et al., 1992).

The catchment is the most appropriate unit for water management (Heathcote, 2009) and human interactions management (Marjorie van Roon et al., 2004). A scientific ecological restoration solution also can be found through analyzing the conditions of catchments (Meyer, 2000).

As urban spreading, ecological issues such as water pollution, sedimentation, and impervious pavement make urban catchments unhealthy (Georges River, 2018). To deal with this issue, an integrated catchment management (ICM) (Fenemor et al., 2011) is studied. It is a process that recognizes the catchment as the appropriate organizing unit for understanding and managing ecosystem processes in a context that includes social, economic and political considerations. It guides communities towards an agreed vision of sustainable natural resource management in the catchment (Fenemor et al., 2011).
2.2 Construction of GIN Corridors in Urban area

Corridors are important in GIN construction as they can act as the connectors between green patches (Forman & Godron, 1986). There are appropriate theories and methods to construct GIN corridors in an urban area to solve the urban environmental problems caused by urbanization and infrastructure construction.

Viles (2001) supposed that the roads could be the linker of different green patches, though they are usually for transportation use instead of ‘ecological corridor’ use. According to Viles’s point of view, there is an opportunity to use the New Zealand road network as greenways or ‘ecological corridor’ to achieve partial integration between conservation such as protecting the wildlife habitat and land use systems (Viles, 2001). Meurk (2003) also supposed that all avenues corridors need to be explored to overcome the biodiversity decline.

In addition, the urban stream (Beca, 2015) and linked parks (Zube, 1995) are also the green space corridors to link the fragmented green spaces.

Austin did some research about the width and scale of the green corridor and the proper planting designs that can make the wild species adapt to human environment well in the urban area. It is concluded that 10–30 m wide corridors are sufficient for species moderately or highly adapted to human activity (Austin, 2013). He also did some research about the proper ways to develop green corridors in the city and found where to install the human infrastructure in these corridors. This could avoid disturbing wild animals and keep a balance between the housing developing and biodiversity. It can offer a guide for the construction of the GIN corridors.

In GIN corridor system, every green space is important to provide a resting site or some specific habitats for wild animals in the urban environment. Though there are private green spaces cannot provide public access to people, they still provide multiple ecosystem services for biodiversity. Everyone plays a vital role in this issue, such as private green spaces owners and other stakeholders. Their decisions and behaviors will be vital to the success of the GIN construction.
2.3 LID&WSD Stormwater Management Devices

- Current Practices & Devices

LID and WSD stormwater management practices and devices can maintain groundwater levels, slow down the rapid runoff, let water seep down into the ground through infiltration, and reuse the stormwater (Auckland Council, 2015). In rainy season or during flooding period, the stormwater can be discharged quickly through the infiltration and storage, avoid severe flooding and runoff pollution problems. In the dry season, the water can be reused for irrigation and other purposes.

The current and primary LID and WSD stormwater management practices and devices which are practicing in NZ are pond, wetland, extended detention, sand filter, bioswale, filter strip, rain garden, infiltration trench, infiltration drywell, porous pavement, green roof, and tank or chamber (Auckland Council, 2003).

These devices are studied to apply in an integrated stormwater management system to help to build GIN nodes and corridors.
Based on the TP10 (Auckland Council, 2003), the function, benefits, limitations of each of these practices and devices are analyzed as follows:
<table>
<thead>
<tr>
<th>Practices &amp; Devices</th>
<th>Function</th>
<th>Water quantity</th>
<th>Water quality</th>
<th>Limitations</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ponds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry pond</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Ongoing maintenance needs, less water quality treatment performance than wet ponds</td>
<td>Hold large water volume</td>
</tr>
<tr>
<td>Wet pond</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Minimum contributing drainage area is 2-3 hectares</td>
<td>Hold large water volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All ponds should not be deeper than 2 meters</td>
<td></td>
</tr>
<tr>
<td><strong>Wetland</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Applied in large area</td>
<td>Hold large water volume; Are better than ponds for urban stormwater treatment because of the dense Vegetation</td>
</tr>
<tr>
<td><strong>Detention practices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended detention</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Applied in large area</td>
<td>Hold large water volume; Combined use with ponds</td>
</tr>
<tr>
<td><strong>Filtration practices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand filter</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Majority of sediments are in the coarse fraction; Most suited for catchments less than four hectares.</td>
<td>Can be used for high percentages of impervious surfaces</td>
</tr>
<tr>
<td>Biofiltration</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Suited for small catchments of less than one hectare; Accept concentrated flow</td>
<td>Can be used in residential, commercial and industrial sites; can take the place of conventional stormwater conveyance systems</td>
</tr>
<tr>
<td>Filter strip</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Suited for small catchments of less than one hectare; Accept flow as distributed or sheet flow before they become concentrated</td>
<td>Can be used in residential, commercial and industrial sites</td>
</tr>
<tr>
<td>Rain garden</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Suited for small catchments of less than one hectare</td>
<td>Can be used in residential and commercial sites</td>
</tr>
<tr>
<td>Infiltration trench</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Applied in small area</td>
<td>With a large length to width ratio, can be used in narrow and limited space area.</td>
</tr>
<tr>
<td>Infiltration drywell</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Accept runoff only from roofs; Receive lower suspended solids loadings</td>
<td>It is underground and does not represent a loss of site area</td>
</tr>
<tr>
<td>Porous pavement</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Applied in areas where there is a low volume of traffic or overflow parking, and where subsoils have not been so compacted as to reduce the infiltration rate to below 3 mm/hr</td>
<td>Can be used to create road and parking lot surfaces</td>
</tr>
<tr>
<td>Green roof</td>
<td></td>
<td>-</td>
<td>✓</td>
<td>Accept runoff only from roofs; Relatively costly</td>
<td>Reduce overall site imperviousness and the resulting storm runoff</td>
</tr>
<tr>
<td>Tank or chamber</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>Only can be implemented as a part of an integrated approach</td>
<td>Stormwater inside can be reused</td>
</tr>
</tbody>
</table>

Table 2.1 Current stormwater management practices and devices in NZ (Author, 2018)
New Stormwater Storage and Filtration Devices

Water Matrix Tank Module

Water Matrix Tank Modules are prefabricated rainwater harvesting blocks consist of collapsed panels, folded liner, and filtration carpet. They can be quick and effortless installed that conform to the needs of any underground rainwater harvesting system.
DRAINMAX Tunnel

It is a stormwater delivering facility which has the extra function of temporary stormwater storage, local infiltration, and attenuation of runoff from sewage plants. During heavy storm events, stormwater can be retained directly at the source. Most of the runoff can infiltrate into the ground and slowly released into the stormwater or sewage system, therefore ease the pressure on the pipework. It has enormous storage capacity, minimum space requirement, and quick installation.

Figure 2.4. DRAINMAX Tunnel (Image source: online)
**Geomedia Augmented Biofiltering**

Bioinfiltration can be used to improve bacterial removal from stormwater. There is a study examined the mechanism of bacterial removal in bioinfiltration system during intermittent infiltration of stormwater. The results show that intermittent flow can mobilize some of the attached bacteria from traditional bioinfiltration geomedia, thereby making the bioinfiltration system as a net source of bacteria.

This device can increase saturation and augmenting bioinfiltration geomedia with iron oxide coated sands to increase removal and decrease detachment of bacteria during intermittent infiltration of stormwater. This can be used to reduce the maintenance cost of bioinfiltration system.

![Comparison between conventional biofiltering and geomedia augmented biofiltering system DRAINMAX Tunnel (Image source: online)](image-url)
Other Filters

There are coarse and fine filters, ultra-violet light, ozonation, and charcoal under-bench filters, which can be used to purify potable water use runoff.
2.4 Case study of GIN Nodes and Corridors

The GIN nodes or green patches are specific places that can collect, infiltrate and store the stormwater from surrounding areas and GIN corridors.

The GIN corridors are connectors of GIN nodes. The most crucial role of these corridors is to deliver stormwater to GIN nodes. They also have the functions of infiltrating, purifying stormwater runoff.

Cases which have the potential to be the GIN nodes and corridors are studied. The strengths and weaknesses are also analyzed as a reference for next stage of the research and design.

Figure 2.7. Case study of GIN nodes and GIN corridors (Author, 2018)
GIN Nodes

- Edinburgh Gardens Rain Garden, Melbourne, Australia

Figure 2.8. Master plan, cross section, and pictures of the rain garden of Edinburgh Gardens (GHD Pty Ltd, 2010)
It is a 700m$^2$ rain garden which provides a sustainable source of treated stormwater for the parks, mature trees, and sporting fields. The filtered water is collected into a 200KL underground storage tank. The water is used to irrigate existing trees within the Gardens thus reducing potable water use for irrigation.

**Strengths:** The gross pollutant trap, rain garden, proper planting, filter media, the underground pipe, and storage facility are combined to form a stormwater treatment system to purify, infiltrate and store the storm runoff from surrounding green spaces step by step and reuse the runoff for irrigation. This combined work decreases the risk of flooding and water pollution of Edinburgh Gardens and also brings the hydrological and even economic benefits to local people.

**Weaknesses:** The pump, pipes, and underground storage tank need to be inspected and maintained frequently. It may damage the whole system if the pump doesn’t work. Additionally, the pump and pipes for irrigation will need costly power and energy.
Elmwood Park Stormwater Diversion Project, Omaha, Nebraska, the U.S.

In this case, a series of colored concrete weirs were constructed to drop the flows down the ravine in this park. The off-line bioretention gardens above the weirs help infiltrate rainwater and recharge local groundwater. Those facilities help clean first flush flows from 26 acres of the adjacent neighborhood and prevent downstream flooding.

**Strengths:** This green infrastructure helps slow down the runoff and store it temporarily on a relatively steep slope. It makes progress of increasing the ecological and hydrological benefits for a large local area.

**Weaknesses:** The concrete weirs need to be fixed if there is any damage to it. The planted vegetation on the weirs needs to be maintained to prevent undesired overgrowth from taking over this area thus decreasing the storage and infiltration abilities of this system.
**Serramonte Library Stormwater Garden, California, the U.S.**

In this case, front lawn of the library was replaced by four rain gardens and a bioswale. When it rains, approximately four acres of impervious surface can drain into the gardens through curb cuts and channels in the parking lot. Runoff from those surfaces is slowed by the plants and filtered by a special soil mix, after which it returns to the storm drainage system, cleaner than when it entered.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>84-98</td>
</tr>
<tr>
<td>Copper</td>
<td>83-99</td>
</tr>
<tr>
<td>Mercury (total)</td>
<td>18-78</td>
</tr>
<tr>
<td>Mercury (dissolved)</td>
<td>47-44</td>
</tr>
<tr>
<td>Nickel</td>
<td>20-79</td>
</tr>
<tr>
<td>Lead</td>
<td>51-98</td>
</tr>
<tr>
<td>Zinc</td>
<td>55-58</td>
</tr>
<tr>
<td>PAHs (polycyclic aromatic hydrocarbons)</td>
<td>90-97</td>
</tr>
<tr>
<td>PCDD (polychlorinated dibenzenes)</td>
<td>44-85</td>
</tr>
<tr>
<td>SSC (suspended sediment concentration)</td>
<td>70-81</td>
</tr>
<tr>
<td>COD (chemical oxygen demand)</td>
<td>78-83</td>
</tr>
</tbody>
</table>

*Various methods were used to calculate reductions in pollutants.

Figure 2.10. Master plan and pictures of Serramonte Library stormwater garden (CMG Landscape Architecture, n.d.)
**Strengths:** The garden can purify the storm runoff from surrounding impervious surface such as in parking areas. The four rain gardens and a bioswale treat the stormwater step by step to maximum the runoff purification ability. This is a good case to deal with the runoff from high percentage impervious surface area.

**Weaknesses:** Because the area of the surrounded impervious pavement is large, the dust, litter, oil, and grease are keeping increasing the contaminant of the soil in rain gardens and the bioswale as time passing by. The debris and accumulated sediments need to be removed as the contaminant may have the bad influence on the environment. The plants in the gardens also need to be managed to prevent overgrowth.
- **Water Square Bentemplein, Rotterdam, Netherlands**

Water square consists of several concrete basins of different depth. It has the function of buffering stormwater storage at street level. During heavy storm event, those basins are temporarily submerged to relieve Rotterdam’s sewage system.

When it rains, the water of the surrounding surfaces and rooftops are collected in the basins forming small lakes as a visual sense in the square. When downpour happens, the basins can be used as a simple pool for boating. At the time the city’s canal system has enough capacity to allow the runoff flow to the nearest open water again, the stored water slowly disappears to make room for the various utilities such as basketball court, gathering space and other recreational spaces once more (De Urbanisten, n.d.).

<table>
<thead>
<tr>
<th>Dry periods</th>
<th>Rainy period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide an attractive meeting and recreational place for city residents</td>
<td>Water storage</td>
</tr>
<tr>
<td></td>
<td>Improve the quality of open water, prevent unpurified water from running directly into the River</td>
</tr>
<tr>
<td></td>
<td>Water playing court and waterscape area</td>
</tr>
</tbody>
</table>

| Table2. Functions of water square in different weather conditions (Author, 2018) |

Pilot Square is one of these water squares which show the stormwater management and landscape changes details before and after a heavy storm event.

Figure2.11. Different landscapes in different storm events at Pilot Square (De Urbanisten, n.d.)
**Strengths:** The water square not only makes money invested in water storage facilities visible and enjoyable but also generates opportunities to create environmental quality and identity to central spaces in neighborhoods (De Urbanisten, n.d.). It is one of the most future oriented-leading ideas applicable to squares, as well as an innovative solution for the temporary storage of rainwater excess in an intensified urban area.

**Weaknesses:** The material, construction and maintain price is high (Boer, 2010), so the water squares are usually located in high consumption areas such as community centre area where there is a high density of population.
Analysis and Summary

Compared with above four cases, the previous two are parks which have more soft surface and green space. The last two cases show how to deal with the runoff from more hard surface areas. Therefore, no matter what kind of surfaces are, there will be proper methods to construct the GIN nodes which can act as the crucial point to collect and store stormwater from surrounding area thus releasing the pressure of grey infrastructure.

To analyze the possibility to use these practices and methods in Auckland, the comparison table has been produced to show the rainfall and temperature conditions data of these countries where cases located.

The outcome shows that the highest average annual temperature among these cities is California, the U.S., which is 17.1 °C. The lowest is 9.6°C in Rotterdam, Netherlands. Auckland’s is 15.2°C, which is higher than in Rotterdam and lower than in the U.S. Thus, in temperature aspect, it is feasible to construct these facilities as GIN nodes in Auckland. However, in rainfall condition, Auckland has the most significant quantity of average annual rainfall of 1284mm among these cities. The size and volume capacity of these facilities need to be larger to deal with more storm runoff when applied in Auckland.
<table>
<thead>
<tr>
<th>Countries</th>
<th>Data</th>
<th>Rainfall and Temperature Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne, Australia</td>
<td>Average annual temperature: 14.8 °C</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 666 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 55.5 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td>Nebraska, the U.S.</td>
<td>Average annual temperature: 10.5 °C</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 836 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 69.7 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td>California, the U.S.</td>
<td>Average annual temperature: 17.1 °C</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 119 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 9.9 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td>Rotterdam, Netherlands</td>
<td>Average annual temperature: 9.6 °C</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 782 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 65.2 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td>Auckland, New Zealand</td>
<td>Average annual temperature: 15.2 °C</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 1284 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 107 mm.</td>
<td><a href="#">Graph</a></td>
</tr>
</tbody>
</table>

Table 2.3. Rainfall and temperature conditions of different cities (Author, 2018)
GIN Corridors

1. Green Streets

Green streets are long, narrow corridors which incorporate depressed planted areas, typically located between the roadway pavement and the sidewalk, into the overall design of the street by using natural infrastructure solutions such as trees, bioswales, and rain gardens to complement a wide range of streetscape appearances (USEPA, n.d.).

Green streets can reduce and control the flow of stormwater runoff directly at the source or from the nearby roadway by collecting runoff in the intentionally designed planted areas. The runoff can be slowed down and absorbed before it is transmitted to the larger stormwater management system or drainage system.

<table>
<thead>
<tr>
<th>Ecological Benefits</th>
<th>Social Benefits</th>
<th>Economic Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve water quality</td>
<td>Improve pedestrian and bicycle safety</td>
<td>Reduce the need for expensive gray stormwater infrastructure</td>
</tr>
<tr>
<td>Replenished groundwater supplies</td>
<td>Traffic calming created by curb extensions</td>
<td>Improve property values created by the improved neighborhood aesthetics</td>
</tr>
<tr>
<td>Reduced urban heat island effect</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3. Co-benefits of green streets (Authors, 2018)
Maywood Avenue Stormwater Volume Reduction Project, Toledo, Ohio, the U.S.

The green infrastructures consist of bio-retention ponds, homeowner rain gardens, rain barrels, pervious concrete pavements for sidewalks, driveways and alleys reservoir under the porous sidewalks to reduce storm runoff, improve water quality and store stormwater as a cyclic utilization resource (Naturally Resilient Communities, n.d.). The bioswales spanned the length of both sides of Maywood Avenue as green corridors.

Particularly, the residents can choose plants in the rain gardens in front of their homes. They will maintain the rain gardens in exchange. There are also partners such as local and regional governments, federal and state agencies, local universities, environmental organizations and consulting engineering firms. They cooperate to each other to help build and maintain these facilities.

This project improves water quality, decreases flooding while contributes to neighborhood beautification. The average amount of storm runoff along Maywood Avenue decreased 64% after completion.
Strengths: This green street gives a chance to purify and infiltrate the runoff from the street impervious pavement, brings habitat back to local birds or other animals, and also creates the plants’ maintenance pattern. This pattern allows the local people to manage their own rain gardens by choosing the plants they like. It is a good combination of the streetscape with their front yardscape.

Weaknesses: The bioswales on both sides of the street narrows the width of the street. It leads to less space for parking. It may narrow the street even more as the quantity of the cars increasing.
The SW 12th Avenue Green Street, Portland, Oregon, the U.S.

This street retrofit project demonstrates the way to design both new and existing streets in highly urbanized areas. It combines pedestrians, on-street parking, street trees, street lighting, signage, and stormwater planters within an eight-foot-wide space (Perry, 2008). The landscaped stormwater planters can capture and infiltrate about 8,000 square feet of street runoff, estimated at 180,000 gallons.

**Strengths:** This project not only manages street runoff but also maintains strong pedestrian circulation and on-street parking. It has the direct environmental and aesthetical benefits in the urban streetscape.

**Weaknesses:** The maintenance is demand. The relatively narrow bioswales areas are too small to deal with all of the contaminants from the large impervious street pavement areas. As the contaminate increasing in the planters, the soil or the plants in it need to be changed.

Figure 2.14. Plan of the SW 12th avenue stormwater planter (Image source: online)
Long Bay Planning Streets, North Shore, Auckland, New Zealand

Long Bay Planning Streets is a local green street case in Auckland. In this case, streets are designed as part of a ‘treatment train’ (Auckland Council, 2015): a series of rain gardens, swales, pervious paving, and wetlands are constructed as part of the stormwater management system. They are also landscaped to add aesthetic features for the neighbourhood. The wetland is the final stop of the storm runoff in this catchment before it enters the Awaruku stream and the sea. Houses incorporate rainwater tanks for re-use on site and in the building.

It has the specific street system: the primary road network supports new main entrance to the Regional Park, facilitate easy access to village centre and schools. The secondary road network has a high level of connectivity and permeability plus a comprehensive network of links for pedestrians and cyclists (ADM, n.d.).
One of the special designed streets is the ‘Garden Street’. This type of street is designed as shared, attractive, connected, and high amenity public space spaces in low traffic environments. The street includes visitor parking for each lot, stormwater treatment devices, amenity planting and multipurpose hard landscaping.

On this street, houses incorporate rain water tanks for re-use on site and in the building. It blends the planting in the front yard and the on-street landscaping to create a connected landscape and maximum used space.

**Strengths:** This project is a good case to show how to design green streets and use street-side space efficiently in an intensified residential area to install landscaped stormwater management devices and to create multiple recreational spaces for people to use.

**Weaknesses:** The on-site survey shows that there is an overgrowing problem of the plants in bioswales. The plant maintenance may be costly in this project to keep the plants working well in these stormwater management devices.
• Growing Vine Street Project, Seattle, the U.S

This project is designed for urban neighborhoods to clean storm runoff through biofiltration and the science of filtering water-borne pollutants with plants and other organisms, allow the water to follow the course of the natural watershed while creating green spaces for people and wildlife.

Some areas have a relatively steep slope. Thus the landscaped bioswales on both sides of the steep street are designed with steps and platforms to deal with the elevation differences. It shows how to deal with runoff on steep slopes and how to create aesthetical living green spaces which located in different elevation levels.

Figure 2.19. Pictures of Vine Street (Image source: online)
Analysis and Summary

Compared with above four cases, the previous three are to deal with the storm runoff from streets areas where the slope is not steep. On the contrary, the last case shows how to deal with the streets runoff from steeper slope. No matter what slopes are, there are methods to construct green streets and to create multiple recreational spaces inside of these green streets.

Compared with other three cities, Auckland has the highest average annual temperature and rainfall index. The green streets need to be adapted to local weather conditions. The size of these bioswales corridors need to be redesigned to deal with more runoff in intensified rainfall events. The indigenous wet-tolerant plants also need to be appropriately chosen for street-side bioswales.
<table>
<thead>
<tr>
<th>Countries</th>
<th>Data</th>
<th>Rainfall and Temperature Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toledo, Ohio, the U.S.</td>
<td>Average annual temperature: 9.9 °C.</td>
<td><img src="image" alt="Temperature Graph" /></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 839 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 70mm.</td>
<td></td>
</tr>
<tr>
<td>Portland, Oregon, the U.S.</td>
<td>Average annual temperature: 11.9 °C.</td>
<td><img src="image" alt="Temperature Graph" /></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 1001 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 83.4 mm.</td>
<td></td>
</tr>
<tr>
<td>Seattle, the U.S</td>
<td>Average annual temperature: 13.8 °C.</td>
<td><img src="image" alt="Temperature Graph" /></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 969 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 80.8mm.</td>
<td></td>
</tr>
<tr>
<td>Auckland, New Zealand</td>
<td>Average annual temperature: 15.2 °C.</td>
<td><img src="image" alt="Temperature Graph" /></td>
</tr>
<tr>
<td></td>
<td>Average annual rainfall: 1284 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average monthly rainfall: 107 mm.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.5. Rainfall and temperature conditions of different cities (Author, 2018)
2. Connected Parks

- The Emerald Necklace in Boston, MA, the U.S.

The Emerald Necklace was designed by Frederick Law Olmsted. It consists of a 4.5 km² chain of parks linked by parkways and waterways in Boston and Brookline, Massachusetts, and stretches over 5 miles throughout the city of Boston (Zube, 1995). Some links of the Emerald Necklace not only offer an opportunity for recreation in a wooded nature environment but also are ecologically important to urban wilds. These links provide nesting places for migratory birds and improve the air quality of the city. Some inspirations can be gained from this case for GIN construction in Auckland, as there are many parks, roadside green space but fewer linkers of these green patches and less social infrastructure.
The Park Connector Network in Singapore

The Park Connector Network is an island-wide network of linear open spaces around major residential areas, linking up parks and nature sites. It creates a lot of recreational and social spaces. It is a model for high-density districts. The buildings on both sides of the stream all face towards the streams or water bodies. It makes a positive spatial mode for waterscape.

Figure 2.21. Stream scape of the park connector network (Image source: online)
The BIG U in Manhattan, New York City, the U.S.

The BIG U is a 10-mile protective landscape belt. It was proposed by Bjarke Ingels Group (Quirk, 2014) based on concepts of social infrastructure and hedonistic sustainability. This project aims to protect lower Manhattan in New York City from floodwater, storms and other impacts of a changing climate. It also provides many social and environmental benefits to the community.

There are rain gardens, ecological wetland, green corridors, salt-tolerant trees and plants inside of this big belt to improve environmental benefits for waterfront environment. It also has resilience infrastructures such as the bridging berm, deployable walls, battery berm to defend flooding, and a maritime museum to observe tidal variations and sea level rise.

The BIG U is a case that combines the urban ecology and social infrastructure to form an integrated centre which connects residential, commercial, and even recreational functional areas. It not only creates a sustainable city which has a lot of ecological benefits but also offers people opportunities to do many social activities. It brings a lot of social, ecological, and even economic benefits to Manhattan.
Social facilities have multiple functions.

Figure 2.22. The BIG U Plan (Image source: online)

Figure 2.23 Social facilities of the big U (Image source: online)
Analysis and Summary

Compared with all of these connected parks cases, the previous two are located in the inland and the last one is in the coastal area. Thus the concepts of constructing connected parks corridors can be used in different locations. The green space patches in different zones are connected by these linkers thus forming an integral green space network to deal with the ecological, hydrological and social problems in cities.

Based on the rainfall and temperature conditions analysis below, the average annual rainfall in Auckland is 1284 mm, which is higher than in Singapore and lower than in the U.S. Therefore, connected parks can be used in Auckland and adapt to the local rainfall and temperature conditions well.
<table>
<thead>
<tr>
<th>Countries</th>
<th>Data</th>
<th>Rainfall and Temperature Conditions</th>
</tr>
</thead>
</table>
| **Boston, MA, the U.S.** | Average annual temperature: 9.8 °C.  
 Average annual rainfall: 1122 mm.  
 Average monthly rainfall: 93.5mm. | ![Bar chart showing rainfall and temperature for Boston] |
| **Singapore**    | Average annual temperature: 26.8 °C.  
 Average annual rainfall: 2378 mm.  
 Average monthly rainfall: 198 mm. | ![Bar chart showing rainfall and temperature for Singapore] |
| **Manhattan, New York, the U.S.** | Average annual temperature: 12.1 °C.  
 Average annual rainfall: 1144 mm.  
 Average monthly rainfall: 95.3mm. | ![Bar chart showing rainfall and temperature for Manhattan] |
| **Auckland, New Zealand** | Average annual temperature: 15.2 °C.  
 Average annual rainfall: 1284 mm.  
 Average monthly rainfall: 107 mm. | ![Bar chart showing rainfall and temperature for Auckland] |

Table 2.6. Rainfall and temperature conditions of different cities (Author, 2018)
3. Creek Corridors

• Te Auaunga Awa (Oakley Creek) –Walmsley and Underwood Parks Project, Auckland, NZ

Te Auaunga (Oakley Creek) Awa-Walmsley and Underwood Parks Project is a current Oakley Creek renewal project to deal with 1.3km of the stream channel. This area has the conditions of a highly modified concrete-lined channel, low water quality, no riparian planting and a lack of vegetation providing shade to the stream. The stream channel and existing culverts are not sized to pass the 1 in 100 year Annual Recurrence Interval (ARI) flood event thus contributing to habitable floor flooding in the surrounding area (Beca, 2015).

The previous concrete creek channel was redesigned to form a more natural channel to provide habitat for wildlife, create recreational open space for local people, and prevent flooding in this area.

Figure 2.24. Stream channel realignment plan of Te Auaunga Awa-Walmsley and Underwood Parks Project (Image source: online)
Undertake flood mitigation and stream rehabilitation works:

- Naturalisation of the stream profile
- Replacement of culverts at Richardson Road and Beagle Avenue with bridges
- Installation of additional culverts at Sandringham Road
- Extension and riparian planting
- Upgrades to Walmsley and Underwood Parks

Figure 2.25. A redesigned v-shaped channel in Underwood parks (Beca, 2015)

Figure 2.26. On-side survey of Te Auaunga Awa-Walmsley and Underwood Parks Project (Author, 2018)
**Strengths:** This project reduces the extent of the flood plain and habitable floor flooding. It adds terrestrial and aquatic ecological values, provides habitats for flora, fauna, and increases in-stream biodiversity.

**Weaknesses:** There is lack of waterfront entertainment facilities and positive spaces. People even turn back of their house to the creek.

![Image](image-url)

*Figure 2.27. The constructing house and creek channel (Author, 2018)*
La Rosa Gardens Reserve Stream Daylighting Project in Green Bay, Auckland, NZ

This project liberated 180 meters of the streams from underground pipes, restoring them to a more natural state and added natural features such as rocks, stones, and tree branches. There are also plantings, walkways, and spaces for sitting, playing, relaxing, and public artworks.

It increases public amenity, provides outdoor classroom opportunities, helps with water treatment, reduces flow velocities, diminishes flooding potential, increases biodiversity, provides a terrestrial wildlife corridor, and creates the ‘natural connections’ of surrounding green spaces.
• Bishan Park and Kallang River Restoration, Singapore

This project transformed 2.7 kilometers of the Kallang River into a dynamic natural ecosystem through changing the previously concrete drainage channel to the natural stream. It creates new recreation opportunities while helping protect the city from flooding.

The concrete from the old canal was reused to form the ‘Recycle Hill’. New river crossings and bridges connected the previously separated neighborhoods. Plants were chosen for natural cleansing properties. Soil bioengineering techniques were also used to combine plant material with traditional engineering to help retain soil on the river’s banks. This project prevents flooding, reduces the heat-island effect, and offers recreational spaces for local people.
Figure 2.29. Master Plan of Bishan Park and Kallang River Restoration project (Image source: online)

Figure 2.30. Detailed designs of Bishan Park and Kallang River Restoration project (Image source: online)

Combined plants, natural materials and engineering techniques to stabilize riverbanks and prevent soil erosion.

100% reuse

Natural water filtration

Bridge and water accessible space

Different open spaces
2.5 New Methods of GIN Construction

The Integrated Catchment Management Method

In Ancient Rome, the city was divided into several small parts by orthogonal roads to form the ‘centuriation’ based on a grid plan (Martínez et al., 2011). If there was an emergent event happened, the specific point where the event located could be found by guards quickly. Surrounding roads could be cut off to prevent adverse influence spreading or escaping if it was a dangerous person. This method turns out to be an easy way to navigate and control the whole city.

This method can be used to manage and control the hydrological catchment. The whole catchment area can be treated as the city. The sub-catchment inside of it can be treated as different zones inside of the city. If water pollution or flooding problems happened in one of the sub-catchment, this area could be controlled easily through cutting down the control points of this area to prevent the pollution spreading out to other areas.
The Stormwater Distribution Method

In the Ancient Rome aqueduct system (Ancient Roman Aqueducts, n.d.), the water was delivered through the siphon pipe. This method can be used to decrease the energy and maintenance cost of the stormwater distribution system of the GIN.

Siphon water pump can be used at the end of the siphon pipe to pump out the water. Different from other pumps, siphon pump is an energy saver and has fewer maintenance fees. The water can keep flowing out automatically after turning on this pump at very beginning using siphon effect.
**The Sustainable Consumption and Maintenance Method**

To make it a more sustainable and less costly GIN, a sustainable consumption and maintenance method of GIN need to be created to deliver, store and reuse stormwater in a smart economic way. To achieve this goal, the case of consumption and maintenance pattern of Tesla Energy has been learned.

People spend a lot of money on power each year. But the cost of generating and delivering electricity is high. There are also peak-demand hours in the morning and the evening, known as ‘peak shaving’ (Terdiman, 2015) which contributes to most of the people’s power budget and make high pressure on city power grid. To encourage people to use renewable energy and save money, as well as to release the pressure of city power grid in peak times, a sustainable power collection, consumption, and maintenance system has been applied by Tesla Energy.

There is a solar panel to collect the solar energy and stored in Powerwall, which acted as the ‘home battery.’ It can be used to charge for the electric vehicle, as well as for appliances, lights, security, and internet. The more batteries are bought, the more solar powers can be stored and used. Therefore, the money spends on the power can be less. They can even make money by transferring the extra energy to their neighbors’ Powerwalls. The price will be lower than using the grid. This method can decrease the pollution of power station, release the pressure of grid, develop the renewable energy, and even make economic benefits to local people.

![Diagram of Tesla Energy's sustainable consumption and maintenance method](image)
It is a ‘marketing one’s own products’ model. People can use the renewable power created by their facilities to save money and to protect the environment. People protect it automatically as it brings not only the convenience but also economic benefits. This model can help build a sustainable and conservation-oriented society for the future city.

The weaknesses of this case are the high price of the batteries and related facilities of the system. The capability of collecting the solar power in cloudy or rainy days also decreases. Thus as the biggest power delivering network at present, the grid is still needed. However, this method of power consumption and maintenance takes sustainability and green products into account for future generations which can offer inspiration for building sustainable GIN in Auckland.
2.6 Policies and Documents

There are existing policies and documents which show the provisions of future urban development targets such as the way to manage the river and water quality and to use the related stormwater management methods and devices for Auckland city. These documents show the importance and rationale to build an ecological city in the future and also give the legal and rightful support for GIN construction in Auckland.

**Auckland Regional Policy Statement (ARPS)**

According to objective 8.3 in this document, it needs to maintain water quality in water bodies and coastal waters, and to enhance water quality which is degraded mainly for protection of aquatic ecosystems, recreation, food gathering, water supply, cultural and aesthetic purposes. This objective shows the importance of protecting water quality in Auckland.

**Resource Management Act (RMA)**

This document shows the needs to manage, develop and protect natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and also their health and safety. This document provides the provisions to guide resources protection during GIN design.

**Auckland Council Regional Plan: Air, Land and Water (ACRP: ALW)**

The policy 7.4.10 of this document shows that the permanent diversion of an existing permanent river or stream shall be considered inappropriate unless there is no practicable alternative method to the diversion, or the diversion will result in an overall net benefit to the environment, or it is consistent with the Urban River and Stream Management Framework. This document offers the reference to consider the rationale to design the recreational facilities in the framework of GIN.
Auckland Council Low Impact Design Guidelines (TP10)

This document shows the current proper low impact design methods and devices for stormwater management and the provisions about how and where these devices should be used. The design of the GIN is based on these devices and the provisions to make sure it can be used in the real green infrastructure retrofit or urban design projects in the future.

Water Sensitive Design for Stormwater (GD04)

This document guides the application of water sensitive design (WSD) to land use planning and land development, with a specific focus on stormwater and freshwater management. It gives the reference of how to design water sensitive urban environment and how to make a more sustainable and intensified spatial mode for future Auckland city. The design of the GIN and the open spatial mode for Auckland will be more rational based on this document.
2.7 Summary

This chapter shows the literature review related to the GIN design and construction.

Firstly, the related concepts such as landscape ecology, urban ecology, green network, green infrastructure network, catchment, and ICM are introduced and discussed.

Secondly, the current ways to construct GIN corridors are introduced to show the existing practices and theories of forming the GIN corridors thus offering a reference for the following GIN design work.

Then, the current LID and WSD stormwater management practices and devices, and the new devices were studied.

Next, the cases of ecological GIN nodes and corridors are introduced to show the current stormwater management practices for solving the storm runoff pollution and flooding problems. These cases also show the current methods to connect green space patches through green streets, connected parks, and streams, which can bring multiple benefits in an urban area.

In addition, the new GIN construction methods were discussed to give a reference for searching more efficient and sustainable ways for GIN construction and maintenance. These methods are the integrated catchment management method, the stormwater distribution method and the new sustainable consumption and maintenance method.

At last, the policies and documents such as ARPS, RMA, and TP10 are studied to make it rational to design a sustainable and proper GIN for Auckland.
3.0 SITE ANALYSIS & ASSESSMENT
3.1 Site Choice

The whole urban hydrological catchment area consists of several large stream catchments. All of these catchments follow the same mechanism to deliver the storm runoff from top hill to lowest natural water body. Oakley Creek catchment area is chosen in Auckland urban zone for case study to form the integrated catchment management system as well as to create the GIN based on the catchment analysis.

Figure 3.1. Location of the Oakley Creek catchment area (Author, 2018)

Different urban stream catchments in Auckland, NZ

Figure 3.2. Auckland urban stream catchments analysis (Author, 2018)
The reasons for choosing this catchment are as follows:

- The Oakley Creek is the largest and longest uninterrupted urban stream in Auckland City. It has a large catchment area with complex hydrological conditions and different landscapes. There is a wide variety of flora and fauna, both native and exotic, including heron, weta, and eels to protect. Therefore, it has the potential to become a major part of a green corridor in Auckland city and provide ecological and wildlife links across the wider Auckland region.

- An estimated 84% of its catchment is urbanized. There are typical urbanization problems such as pollution and flooding which threaten and decrease and urban life quality of local people.

- There are almost 50 hectares of green space as parks and reserves exist and nearly continuous, but not ecologically connected to each other (Beca, 2015). This will be a great opportunity to study the connection between these fragmented green spaces and to improve the urban ecological functions of the GIN.

- Currently, the Oakley Creek is played a drainage role. As the ‘receiving environment,’ it receives pollution from the runoff of its whole catchment area. The runoff contains the less-visible concoction of metals, greases, oils, nutrients, and bacteria, which flow into this creek in heavy storm events. This causes severe environmental problems such as flooding, water pollution, as well as the unswimmable beaches (Kennedy, 2017), which need to be dealt with seriously.
Figure 3.3. Fragmented parks and reserves (Author, 2018)
3.2 Current Conditions of Oakley Creek Catchment

Oakley Creek is an 11.5-kilometer watercourse (Beca, 2015), extending from the headwaters near Hillsborough Road ridge at Mt Roskill across the isthmus to the discharge location in the Waitemata Harbour at Waterview. It is the longest urban stream in the Auckland isthmus area with a catchment area of approximately 12.3 km². It has a Maori name called Te Auaunga. The maximum altitude of this catchment is 134m. The average catchment imperviousness is 49%.

To make a rational GIN, GIS maps have been made to analyze the basic conditions such as slope, elevation, hydrological conditions of the Oakley Creek.
Slope Analysis

This map shows that in Oakley Creek catchment area, the borderland is steeper and the central land is flatter. The borderlands include mountains and surrounding height hills. The steepest zones, marked by red colour, are slope areas of two mountains: Mount Roskill and Mount Albert, and banks areas of the Oakley Creek main channel. Methods need to be taken to deal with the elevation problems of these areas in the GIN.

Figure 3.4. Slope analysis map of the Oakley Creek catchment area (Author, 2018)
Elevation Analysis

This map shows the elevation conditions of the Oakley Creek catchment area. It can be seen that the northwest region is lower than the southeast region. The runoff flows from southeast area to northwest area. The area marked by blue colour is the downstream catchment area. The red colour shows the upstream catchment area. It also illustrates that the highest zones of this catchment are in the top of the two mountains, and in southern high hill zones, where there is lightest water pollution because of the most upstream locations.

Figure 3.5. Elevation analysis map of the Oakley Creek catchment area (Author, 2018)
Hydrological Condition Analysis

This map shows the overland flow path, flood prone area, flood sensitive area, and flood plain of the Oakley creed catchment. The trace of the creek channel can be generally recognized through the overland flow path. However, many creek branches have been buried or by straightened by concrete channels. This makes it impossible to see all branches of the Oakley Creek in city. The overland flow path can help define the previous locations of these branches.

Most of the flood prone areas and flood plains areas are located in green spaces such as parks, reserves, golf courses, which are close to the overland flow path. These areas are in the relatively low positions where there are less residential or commercial buildings because of the flooding. Thus it has the potential to construct green infrastructure nodes and corridors to manage stormwater and to create recreational spaces in these places.
Figure 3.6. Hydrological conditions analysis map of the Oakley Creek catchment area (Author, 2018)
As urban area spreading, the aquifer level decreases dramatically because of the increasing impervious surface area. In intensified areas where there are more impervious surfaces, the aquifer level is lower. This will bring negative impact to urban hydrological health. Thus, it needs to pay attention to the stormwater infiltration ability when designing the GIN.

Figure 3.7. Diagram of aquifer level difference before and after urbanization (Author, 2018)
Drainage System Analysis

This map shows different types of stormwater drainage pipes of Oakley Creek catchment. They are cesspit lead, connection lead, main pipe, perforated pipe, and watercourse or open drain. It helps to define where the open channels of the stream and branches located. It also helps to find the way to connect GIN with this system.

Figure 3.8. Drainage system analysis map of the Oakley Creek catchment area (Author, 2018)
Land Use Analysis

This map helps to analyze the type and locations of different land use areas of the Oakley Creek. There are four land use types: business, open space, residential, and special purpose use. It illustrates that the residential area is large and the open spaces area in it are relatively small and fragmented. Most of the open spaces are located near the creek channel. Thus it has the potential to connect these open spaces with the channel to form a green space network.

Figure 3.9. Land use analysis map of the Oakley Creek catchment area (Author, 2018)
Figure-ground Relationship Analysis

The building surface and impervious pavement area is ‘figure,’ which marked by black colour. The open space area is ‘ground.’ It can be seen that the impervious surface area accounts for a large percentage of the whole Oakley Creek catchment area. The smaller open spaces are dispersed inside of the impervious surface area.
Kerblines Analysis

According to Viles (2001), roads or streets are potential corridors which can link different green patches. The kerblines analysis map shows the locations of the main roads in the Oakley Creek catchment area. It can be treated as an existing network which can support the design of the street-side bioswales corridors later on.

Figure 3.11. Kerblines analysis map of the Oakley Creek catchment area (Author, 2018)
The Unitary Plan Analysis

This map shows the Unitary Plan of Oakley Creek catchment area. This plan is a future-based urban land use and construction plan which illustrates the locations and types of the future residential, open space, business, rural, coastal, etc. areas. The GIN will be designed within the frame of this plan to form a new urban spatial mode with multiple benefits to support a sustainable Auckland city construction in the future.
3.3 On-site Survey & Photographic Study

The Oakley Creek is the longest green corridor in this catchment. It provides multiple ecological values to Auckland city. A successful GIN will have an intimate connection with this channel. Thus, there is an on-site survey to figure out the specific environmental problems of the Oakley Creek. Photos are taken to show the existing hydrological conditions of this creek.

Four sites are chosen. They are located in upstream, midstream and downstream respectively. The upstream site is number 4 site, which shows the ecological conditions of Keith Hay Park and surrounding residential area. The midstream sites are the number 2 site and the number 3 site which located in Alan Wood Reserve Park, and Walmsey and Underwood Parks respectively. The downstream site is Oakley Esplanade, where the creek water quality is the worst.
According to the survey, the water quality of upstream creek is the best. The most significant ecological problem in this area is the concrete channeled creek branch, which has the only function of the drain. The runoff from surrounding rooftops is drained directly into the channel through pipes without any filtration. This leads to the downstream creek water pollution. There are also no recreational designs or entertainment facilities around these channels.

There is a security fence of Oakley Creek channel close to Keith Hay Park. This stops people getting closer to this creek. Though it protects people from dropping, it decreases the recreational potential along this stream.

Additionally, there are also unutilized flood plain lawn area and overgrowing plants along the creek channel in this upstream catchment area.
Figure 3.15. Conditions of the upstream area of the Oakley Creek catchment (Author, 2018)

Compared with the upstream water quality, the midstream and downstream water quality are worse, especially in Oakley Esplanade. The water even has grey or blue colour and it is smelly because the stormwater runoff is not enough treated. Most of the contaminants come from upstream area, surrounding rooftops, and surrounding impervious pavement.
Additionally, the storm flows are fast when it rains, especially in the downstream area. This leads to potential flooding issue. There is also a large area of the impervious surface in downstream area. Most of them consist of parking lots, squares and roads. Therefore, the green spaces are more fragmented compared with the upstream area.

In conclusion, the environmental problems of the Oakley Creek include water pollution, heavy storm flows causing flooding, a large area of impervious pavement, concrete channeled creek, and fragmented green spaces. There are also negative spaces and the lack of recreational facilities.
3.4 Development Potential of the Site

Though there are many urban environmental problems of the Oakley Creek catchment area, there is potential to build the GIN to deal with these problems and to recover the urban ecology.

Firstly, though the green space in this area is fragmented, the total area is still large, especially in residential area. The land use map shows the percentage of the residential area is high. However, the green space area in the yard of every single house is large. These green spaces are potential public open space if the current residential building mode changed to a more intensified mode in the future. These public open spaces are proper areas to design GIN nodes or corridors.

Secondly, most parts of the Oakley Creek channel are connected. This provides potential to create a longest connected GIN corridor in this catchment area. Though some branches are channeled with the concrete bank, or buried under the buildings, the ecological and hydrological functions of this creek can be recovered through daylighting and naturalizing these channels. In addition, the kerblines map also shows the existing roads and streets network of this catchment. These are the potential positions to use street-side green spaces forming GIN corridors.

Additionally, there are existing stormwater management devices such as rain gardens and bioswales in some parts of this catchment. This offers a chance to create a whole stormwater management system within the GIN based on these devices.

Though there are no or less recreational and social facilities around these fragmented green spaces. After design, it will provide multiple social opportunities for local people through connected green space network and shared infrastructure.
3.5 Summary

This chapter showed the analysis of basic conditions of the chosen Oakley Creek catchment area.

Firstly, the reasons for choosing this site were discussed. It has a large catchment area with complex hydrological conditions, different landscapes, fragmented green spaces. The urban ecological conditions and problems are typical.

Secondly, the current basic conditions of the Oakley Creek catchment were analyzed based on the GIS map. These maps showed the existing slope, elevation, hydrological, drainage system, land use, figure-ground relationship, kerblines, and the unitary plan conditions of this site. It is essential to adjust design measures to local conditions when creating a GIN.

Then, it showed the Oakley Creek on-site survey and photographic study. This study illustrated the current ecological conditions and problems of the Oakley Creek and its catchment. Four sites were chosen to show the detail problems such as the water pollution, the flooding, the concrete channeled creek branch, and fragmented green spaces.

At last, the development potential of this site was analyzed. It showed that though there are many urban environmental problems in this area, there is still potential to create a connected GIN inside of it and to design a new intensified urban spatial model to provide multiple benefits to local people.
4.0DESIGN
4.1 Design Scope & Objectives

To deal with urban environmental problems in Auckland, a new GIN model is created based on integrated catchment management method. It can offer temporary stormwater solutions, water pollution solutions, and bring multiple benefits to local people. The primary functions of this GIN as follows:

- Gives more time to replace aging infrastructure;
- Adds value to stormwater management including delivering, purifying, infiltrating, filtering, and storing stormwater;
- Adds value to private individual households;
- Brings ecological, social, and economic benefits to the community.

The main methods are:

- Organize city by catchments;
- Organize neighbourhoods by sub-catchments;
- Organize local area network (LAN) by shared infrastructure.

Figure 4.1. Diagram of a new runoff flow direction and reuse mode (Author, 2018)
4.2 New Stormwater Management Pattern

Grey infrastructure includes pipes, pumps, and ditches engineered by people to manage stormwater. Such systems require technical engineering, frequent maintenance, and often need to be upgraded. Recently these systems are expanding to meet the growing demands of sprawling urban areas at a high cost (Soil Science Society of America, n. d.). This could be solved by using green infrastructure (GI). Erickson supposed the GI can mitigate the need for cost of gray infrastructure (Erickson, 2006) and even make multiple co-benefits.

In Auckland, the current stormwater treatment method is to channel the runoff directly to the natural water body using grey infrastructure such as drainage pipes. There is less infiltration, filtration, and storage process. Therefore, to construct a more sustainable city, a new stormwater management pattern is proposed to solve these hydrological problems as well as to bring multiple benefits to local people.

This pattern combines green infrastructure with gray infrastructure and changes Auckland city’s traditional drainage mode to a more sustainable stormwater management mode thus adding more ecological benefits to stormwater management and bringing economic benefits to investors as well as consumers of the local community.

The stormwater runoff will be purified, infiltrated, and stored at first in the GI. Then the treated overflow is guided to the grey infrastructure or other GI.
Figure 4.2. Previous and designed stormwater management pattern in urban area (Author’s previous university study group, 2018)

Figure 4.3. Previous and designed neighbourhood stormwater management pattern in urban Auckland (Author, 2018)
4.3 Level Classification of Stormwater Management Devices

Stormwater practices are only valid when they are used in the right place (Auckland Council, 2003). Therefore, several levels of the LID and WSD stormwater management devices and practices for the GIN are classified corresponding to the different scales of the catchment areas and different levels of storm runoff control requirements.

TP10 (Auckland Council, 2003) is studied to make a rational classification. According to this document, practices that rely on vegetative or filter media such as rain garden, bioswale, and porous pavement are appropriate for smaller catchment areas. Ponds and wetlands are more suitable for larger catchment areas.

These devices and practices contributing to construction of the GIN of Oakley Creek catchment area are classified into three levels.

<table>
<thead>
<tr>
<th>LID and WSD stormwater management devices level</th>
<th>Constituent elements</th>
<th>Functions</th>
<th>Runoff direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong> (block scale)</td>
<td><strong>For GIN nodes:</strong> green roofs, rain gardens, pervious pavements, filter strips</td>
<td>Light rainfall runoff control</td>
<td>Overflow to level 2 devices</td>
</tr>
<tr>
<td></td>
<td><strong>For GIN corridors:</strong> bioswales, sand filters, infiltration trenches, infiltration drywells</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Level 2</strong> (neighbourhood and community scale)</td>
<td><strong>For GIN nodes:</strong> small wetlands, extended detention, ponds</td>
<td>Medium-sized rainfall runoff control</td>
<td>Overflow to level 3 devices</td>
</tr>
<tr>
<td></td>
<td><strong>For GIN Corridors:</strong> bioswales, sand filters, infiltration trenches</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Level 3</strong> (urban stream catchment scale)</td>
<td><strong>For GIN nodes:</strong> large wetlands</td>
<td>Heavy rainfall runoff control</td>
<td>Overflow to natural water body</td>
</tr>
<tr>
<td></td>
<td><strong>For GIN Corridors:</strong> Constructed streams</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1. Level classification of the LID and WSD stormwater management devices (Author, 2018)
Level 1 (block scale)

The level 1 stormwater management devices are installed in the block scale GIN nodes and corridors for the source control and the light rainfall runoff management.

The devices including green roofs, rain gardens, pervious pavements, and filter strips are used for the construction of block scale GIN nodes. The devices such as bioswales, sand filters, infiltration trenches, and infiltration drywells are for the development of block scale GIN corridors.
The Geomedia Augmented Biofiltering, coarse and fine filters, ultra-violet light, ozonation, charcoal under-bench filters are used to remove the contaminant of the stormwater in this level to filter the potable used stormwater in residential area.

After infiltration and filtration, the stormwater is collected into tanks, chambers or Water Matrix Tank Module at last. The extra stormwater runoff will overflow into the drainage pipe or level 2 devices.
Level 2 (neighbourhood and community scale)

The level 2 stormwater management devices are installed in the GIN nodes and corridors of the neighbourhood and community scale catchments. They can manage medium-sized rainfall runoff.

The devices including small wetlands, extended detention, and ponds are for the construction of the neighbourhood and community scale GIN nodes. The devices such as bioswales, sand filters, and infiltration trenches are for the construction of corridors. DRAINMAX Tunnel is used in this level to deliver a relatively large amount of the stormwater runoff.

These devices receive the overflow from level 1 devices. The extra runoff will overflow into level 3 devices.
Level 3 (urban stream catchment scale)

The level 3 stormwater management devices are for construction of GIN nodes and corridors of the urban stream catchment scale. These devices can manage heavy rainfall runoff.

The devices including large lakes and wetlands are used to construct the GIN nodes. The constructed streams are used to construct GIN corridors.

The runoff overflow from level 2 devices can be managed and stored. The extra runoff will overflow into the natural water body.
4.4 Integrated Catchment Management System

The Practice of Integrated Catchment Management Method

The integrated catchment management method is practiced based on the ICM and Ancient Rome city control mode to control the stormwater step by step through the system along the overland flow path.

If a pollution issue happened in one specific site, the nearest control point could be cut off to prevent contaminant spreading. Seen from the below diagram, if it was not sure where the pollution came from, it could be assure that the number 1 sub-catchment area is not the pollution source area because it is the downstream sub-catchment. On the contrary, one of the number 2, 3, 4 sub-catchments might be the area where the pollution source is located. To find this pollution source, the control points located at the lowest place of each of these sub-catchments could be closed to check out the water quality inside of the each area. The pollution source could be found easily through this method.

![Figure 4.7. Diagram of the catchment control method analysis (Author, 2018)]
This method can not only deal with the water pollution problem but also can allow the stormwater runoff infiltrate, filtrated and stored step by step through these points and corridors.

The whole catchment area can be divided into several sub-catchments and sub-sub-catchments if necessary to manage the water pollution and flooding problems. Control points are built at the lowest positions of each of the sub-catchments and the sub-sub-catchments to control the specific negative hydrological event occurred inside of them.

There will be several catchment divisions until it reaches the smallest sub-catchment area which is not necessary to divide anymore. Then the whole catchment can be studied easily based on several different scales. The entire catchment runoff also can be controlled from the smallest scale to the largest scale.

Figure 4.8. Diagram of the macroscopic catchment divisions (Author, 2018)
As shown in the following figure, runoff flows from the higher point to the lower point based on the elevation surface. The water is accumulated throughout the procedure. The more quantity of water is accumulated, the more contribution land area there will be.

The scale 1 sub-catchment area is the smallest contribution land area in highest place of the whole catchment. The scale 1 control point is located in the lowest position of this small area.

Several small areas form a larger sub-catchment, which is defined as the scale 2 sub-catchment. The control point of the scale 2 sub-catchment is located in the lowest place of this whole area. Using the same method, larger scales such as scale 3 and scale 4 can be defined if it is necessary. All of the different scales sub-catchments have the specific control points located in the lowest place of each of these areas.

Different control points have different levels of abilities to infiltrate, purify and store the storm runoff. Thus the runoff can be managed and controlled step by step until it overflows to the lowest natural water body.

![Figure 4.9. Runoff flow direction and accumulation (Author, 2018)](image-url)
Catchment Divisions

Based on the integrated catchment management (ICM) method, the whole catchment can be controlled easily by divisions. The division rationality is crucial to this procedure because it has a direct impact on the following design and the rational outcome of the project.

Water Sensitive Design for Stormwater (Auckland Council, 2015) has been studied to define the different ‘scales.’ According to this document, the complementary planning scales of the ‘region,’ the ‘community,’ the ‘neighbourhood,’ and the ‘block’ had been defined to promote WSD outcomes (Auckland Council, 2015). In this project, these scales are used for catchment divisions.

The largest catchment scale: ‘urban stream catchment scale’ is defined in this project. The whole city area can be divided into several urban stream catchments areas according to urban hydrological conditions. Thus the urban stream catchments can be treated as the basic components of the whole city catchment to study. The Oakley Creek catchment is one of the biggest urban stream catchments in Auckland.
The ‘community scale’ is defined to describe the scale of big sub-catchments of the urban stream catchment. It is a relatively large scale which includes several ‘neighbourhood’ scale sub-sub-catchments.

The ‘neighbourhood scale’ is a crucial scale in this project. It shows the details and functions of the GIN and LAN. According to Auckland Council (n.d.), a ‘neighbourhood’ can be defined as a 400m radius circle if the boundaries are less obvious. This distance is recognized as the distance people will happily walk to meet their daily needs, and typically equates to a five-minute walking distance (Auckland Council, n.d.). In this project, this distance is used to define the ‘neighbourhood scale.’

The whole catchment is keep dividing for several times until the furthest distance in the sub-catchment is less than 400m*2=800m to form a neighbourhood scale sub-catchment. In a neighbourhood scale sub-catchment area, the furthest distance is between 300m and 800m, 300m is the shortest distance. If the furthest distance in a sub-catchment area is below 300 meters, then it is classified into the block scale micro-catchment area. This kind of micro-catchment area does not show in the ICM plan map because it is too small.

In this project, the ‘block scale’ is the smallest scale which shows all the details of the catchment control facilities and devices. The furthest distance in a block scale sub-catchment area is below 300 meters.

As for Oakley Creek catchment, there are three divisions.
This division is to define the main branches of the Oakley Creek. If the furthest distance in a sub-catchment is longer than 300 meters, it will be defined as the main branch catchment of the Oakley Creek and show in the division map. After division, it forms 53 sub-catchments and a central control area. The control points are located in the lowest points of these sub-catchments. These points are also located in and around central control area.

Except these points, the central control area also consists of the Oakley Creek main channel and several micro-catchments. The furthest distance in these micro-catchments is shorter than 300m. Because these micro-catchments are too small, the runoff from these micro-catchments is purified by rain gardens or bioswales first and is guided directly into the stream channel.
In each of these large sub-catchments, there are sub-branches which have their own contribution catchments. These catchments are sub-sub-catchments of Oakley Creek.

Among all these sub-catchments, the furthest distances in the number 7, 12, 13, 14, 17, 21, 23, 24, 31, 31, 49, 51, 52 sub-catchments are all longer than 800 m. Thus they are divided again to form smaller sub-sub-catchments.

The furthest distance in a sub-sub-catchment is longer than 300m. After division, each of the previous sub-catchments forms several sub-sub-catchments and also a central control area to control these sub-sub-catchments.
Third division

After the second division, the furthest distance in some sub-sub-catchments is still longer than 800m. They need to be divided again until all of these sub-catchments conform to the neighbourhood distance figure advocated by Auckland Council. Thus make sure they are small enough to be managed and controlled. There is also central control area in each of these sub-sub-catchments.
There are three divisions of the Oakley Creek catchment area. After divisions, all of the sub-catchments showing on the map have a furthest distance between 300 m and 800 m. This method makes it easy to control every small sub-catchment. It can also manage the storm runoff efficiently step by step from small catchment scale to large catchment scale through control points and corridors.
Integrated Catchment Management Plan

The Oakley Creek integrated catchment management (ICM) plan map shows below. The whole control system consists of control points and contribution corridors. They are all located in or near the different scales of central control areas.

The control point is located in the lowest position of each of the sub-catchments. These points are varied from the central open spaces to the detention parks or wetlands depending on the size of the sub-catchments they need to control. The main function of the control point is to purify, infiltrate and store the storm runoff temporarily. If the water pollution event happened, the control point could be closed down to stop the pollution spreading to downstream.

The control points are installed along the central control areas. They are all located at the intersection points of the mainstream and branches to control the whole branch catchments easily and conveniently. The primary functions of the control point are to store the stormwater runoff temporarily and control water quality.

The contribution corridors are located in the central control areas. Different scales of contribution corridors are located in different scales of central control areas. The primary function of these corridors is delivering the storm runoff to the control points.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Location</th>
<th>Contribution corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban stream</td>
<td>Main central control area</td>
<td>Streams</td>
</tr>
<tr>
<td>Community scale</td>
<td>Sub central control area</td>
<td>Constructed streams</td>
</tr>
<tr>
<td>Neighbourhood</td>
<td>Small central control area</td>
<td>Bioswales; Sand filters; Infiltration trenches; Infiltration drywells</td>
</tr>
<tr>
<td>Block scale</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2. Locations of different contribution corridors (Author, 2018)
Introduction

- The Oakley creek catchment area can be divided three times to form several sub-catchments. The furthest distance in a sub-catchment area is between 300m and 800m.

- A sub-catchment is divided into sub-sub-catchments if the furthest distance inside this sub-catchment area is longer than 800m.

- A central control area is using to manage sub-catchments. The control points are located in these areas. These points can be parks and wetlands where there are large stormwater storage devices.

- There are different stages of central control areas and control points which located in the lowest place of each sub-catchment and sub-sub-catchment.

Figure 4.15. Oakley Creek integrated catchment management plan (Author, 2018)
There are four different scales in Oakley Creek catchment area. They are introduced respectively from the large scale to the small scale below.
Scale 4: Urban Stream Scale

Urban stream scale is the largest catchment scale to show the integrated hydrological conditions of the Oakley Creek. In this scale, the main channel of the Oakley Creek is the contribution corridor. The runoff comes from the sub-catchments flows into the main channel at last. From the upstream to the downstream of this corridor, the amount of the runoff keeps increasing.

Scale 3: Community Scale

This scale shows how to control big branch sub-catchment of Oakley Creek. In this scale sub-catchment area, the largest control point is a large stormwater wetland which is located in the lowest point of this sub-catchment. This wetland can store a large quantity of runoff comes from the whole sub-catchment.

The contribution corridor is the constructed stream. As this sub-catchment is big enough to accumulate a relatively large quantity of runoff, it can form the small natural creek: the tributaries or branches easily. In fact, some tributaries still exist currently. However, most of them are channeled by hard revetment or concrete, or even buried underground to meet the demand of urban spreading. To construct a sustainable green infrastructure network in the future, these channeled or buried tributaries are naturalized and daylighted in this project to receive more storm runoff, release the pressure of the old drainage system, and give enough time for people to renew or fix the current drainage pipes which are not large enough to meet the need of urban dramatically growing.
**Scale 2: Neighbourhood Scale**

In this scale, it shows the way to control small branch sub-catchment of Oakley Creek. In this area, the control point is a detention park which is located in the lowest point of this sub-catchment.

The contribution corridors are sand filters, bioswales, and infiltration trenches. The most common corridor in this project is the street-side bioswale corridor because of its multiple ecological and landscape benefits ([Missouri Botanical Garden, n.d.](#)).

A ‘local area network’ (LAN) is created in this scale using Hedonistic Sustainability method (Quirk, 2014). ‘Local area’ is a block scale micro-catchment area. This network connects all of these micro-catchments through a sustainable stormwater distribution system.

There is a stormwater storage device such as a tank in control point of each local area. It helps to store the stormwater thus decreasing the total volume of runoff in a heavy storm event. They are connected to each other through siphon pipes. The more connected it is, the better the system works. If one of these devices is broken, the overflow can even go to the stormwater system, or be channeled to another stormwater storage device.

All of these local areas are linked to each other through street-side bioswale corridors thus forming a ‘nested network.’ If the runoff is too much to store in one control point, the overflow will go to another local area through these corridors.

The stored water from these local areas can be used for residential use, landscaping and irrigation of the urban farming garden in it. In winter time, there is a lot of rainfall in Auckland. A large quantity of runoff might overflow to the sewer. The polluted water might flow to the stream causing flooding and bad water quality problems. This network can not only deal with these problems through releasing the pressure of stormwater drainage system, but also add value to the local community, as the storm runoff can be stored in winter time, and reuse when people need it.
According to TP10 (Auckland Council, 2003), about 65% of household water demand can be met from stormwater collected from roofs. The figure shows the total water demand is 500 L/day in an average 3-member household. Thus it would be able to use 325 L/day of rainwater.

Based on GIS analysis, there are approximately 17734 households in Oakley Creek catchment area. The total amount of household water demand in Oakley Creek catchment per year is 500*365*17734 = 3.2 billion L. The total amount of household water demand can be met from stormwater collected is 3.24*65%≈2.1 billion L, which is worth about 3.1 million NZ dollars according to the water price data from the Watercare Organisation. Thus, this LAN can not only release the pressure of the drainage system, bring hydrological and ecological benefits, but also can bring economic benefits to local people.
Figure 4.18. Construction of the LAN (Author, 2018)
**Scale 1: Block scale**

This scale shows the details of the GIN. In this scale micro-catchment area, the control point is central open space, located in the relatively low position of each micro-catchment area. The contribution corridors are sand filters, bioswales, infiltration trenches, and infiltration drywells.
### Figures

<table>
<thead>
<tr>
<th>Figures</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>Catchment scales</td>
<td>Block scale</td>
<td>Neighbourhood scale</td>
<td>Community scale</td>
<td>Urban stream scale</td>
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<tr>
<td>Furthest distance in catchment(m)</td>
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<td>10–30</td>
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<td>400–1200</td>
<td>1200–8000</td>
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<td>Control points</td>
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<td>Devices</td>
<td>Stormwater storage devices</td>
<td>Location</td>
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<td>Central open spaces</td>
<td>Rain gardens; Porous pavement; Filter strips; Green roofs</td>
<td>Underground tanks</td>
<td>Underground; Open-air</td>
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<td>Small detention parks</td>
<td>Small wetlands; Extended detention; Ponds(dry or wet)</td>
<td>Underground tanks; Small wetland; Ponds(dry or wet)</td>
<td>Open-air</td>
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<td></td>
<td>Large detention parks</td>
<td>Wetlands</td>
<td>Wetlands</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 4.3. Construction and formation of integrated catchment management system (Author, 2018)
From block scale to the large natural urban stream scale, the storm runoff is purified, infiltrated, filtered and stored step by step until it overflows to the sea which can receive the cleanest and minimize the volume of storm runoff at last. This integrated catchment management system can purify runoff, reduce the peak flow and total amount of stormwater, prevent flooding, and release the pressure of grey infrastructure. This system can also bring economic benefits, especially applied in the intensified city like Auckland where the construction of infrastructure and urban ecology are always at odds.
4.5 Formation of the GIN Frame

Based on the Oakley Creek integrated catchment management plan, the GIN frame is designed through several steps as follows.

Basic Riparian Buffer

The first step is to design the basic riparian buffers of Oakley Creek and the constructed streams to form the basic GIN corridors.

According to Austin (2013), the width of the stream corridor is about 10–30 m wide. This wide is sufficient for species moderately or highly adapted to human activity. Recommended by Auckland Council, a 10 m width vegetated area on each bank is the minimum. A wider strips of 20 m or more are encouraged (Auckland Council, 2015). In this project, a minimum of 10m width riparian buffer on each stream bank is designed for the constructed stream. A 20m width riparian buffer is designed for Oakley Creek main channel.
Figure 4.22. Basic Oakley Creek main channel buffer area (Author, 2018)
The ‘constructed streams’ include daylighting stream, naturalized stream and some new constructed stream. These streams are located in central control areas. They can accept and deliver a large quantity of storm runoff.
Combine the basic Oakley Creek main channel buffer area and the basic constructed stream buffer area together to form the total basic stream buffer area in Oakley Creek catchment.

This buffer area forms the basic GIN corridors. The designed riparian width is the basic width. It is different according to the upstream or downstream locations.

Figure 4.24. Total basic stream buffer area (Author, 2018)
Main Control Points Locations
This step is to define the locations of the main control points. These points are nodes of the GIN system.

Wetland Park Locations
There are 12 community scale sub-catchments of Oakley Creek which the contribution catchment area is larger than 30 hm². The wetland park is designed at the lowest point of each sub-catchment. As the large control point, the functions of these wetland parks are to purify, infiltrate, filter, and store the overflow from other smaller scale GIN devices and the runoff from surrounding area.
Detention Park Locations

The control points of neighbourhood scale sub-sub-catchments areas are detention parks which located in the lowest points of these areas. The functions of these detention parks are to purify, infiltrate, filter, and store the storm runoff from the overflow of block scale micro-catchments inside of these areas.
Basic GIN Frame

Combine the basic GIN corridors and control points to form the GIN frame.
4.6 Master Plan

Site Choice

After first catchment division, it forms 53 sub-catchments. Among these catchments, the number 14 sub-catchment is chosen to draw a master plan. The reasons are as follows:

- The number 14 sub-catchment is the largest branch catchment of the Oakley Creek. There are all block scale, neighbourhood scale, and community scale sub-catchments in it which can be studied.

- There are all kinds of land uses such as residential, open space, business and special purpose use in it. It is crucial to show how the GIN can work efficiently in different land use areas to deal with urban ecological issues in different conditions.

- The percentage of the business area is highest among these sub-catchments according to the GIS analysis. Business area can make severe water pollution and flooding problems because of its large area of impervious surface and a large amount of wastewater.
Figure 4.28. Site choice (Author, 2018)
Table 4.4. GIS analysis-Area of each of Oakley Creek sub-catchments (Author, 2018)

<table>
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<tr>
<th>SN</th>
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Figure 4.29. GIS analysis-land use percentage of each of Oakley Creek sub-catchments (Author, 2018)
Site Analysis

The number 14 sub-catchment is the biggest sub-catchment of the Oakley Creek with an area of 1,892,143 m². The building area is 361,642.5 m and accounts for 19.1%. The impervious pavement area of 595,805.7 m accounts for 31.5%. The vegetated area of 934,694.8 m accounts for 49.4% of the total area according to GIS analysis. The entire impervious surface area accounts for about 51%. It is a relatively high percentage, and has the potential to cause ecological issues in the urban area.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Existing conditions</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Building area</td>
<td>361,642.5</td>
<td>19.1%</td>
</tr>
<tr>
<td>Impervious pavement area</td>
<td>595,805.7</td>
<td>31.5%</td>
</tr>
<tr>
<td>Vegetated area</td>
<td>934,694.8</td>
<td>49.4%</td>
</tr>
<tr>
<td>Total area</td>
<td>1,892,143</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.5. Current land use percentage of the number 14 sub-catchment of Oakley Creek (Author, 2018)
Figure-Ground Relationship Analysis

In the figure-ground relationship diagram, the black color shows the impervious surface, and the white color shows the vegetated area. The first diagram shows the spatial relationship between building area and vegetated area, the second shows the spatial relationship between impervious pavement area and vegetated area. The third one shows the relationship between impervious surface area and vegetated area. The percentage of impervious surface area is quite high through the directly visual display of this diagram.

Figure-30. Figure-ground relationship analysis of the chosen site (Author, 2018)
Elevation Analysis

It can be seen from the elevation analysis map that the south and west area is higher than east and north area. The highest area of this sub-catchment is the hilltop of the Mount Roskill.
Slope Analysis

The slope analysis map shows that the south and west area is steeper than central area, east area and north area. The steepest areas are located around the top of the mount Roskill, both sides of the southwestern motorway, and the low open space located at the west side of the Foodstuffs North Island Ltd industry building.
Hydrological Condition Analysis

Figure 4.3. Hydrological condition analysis map of the chosen site (Author, 2018)

Hydrological condition analysis map helps to find the specific locations to design the GIN nodes such as central open spaces, detention parks or wetlands and GIN corridors. The current flood prone areas and flood plains are the relatively low place of this site. Usually, these areas are existing open spaces. Therefore, they are redesign and reconstruct as a part of the GIN system.
Stormwater Drainage Pipe Diameter and Type Analysis

The stormwater drainage pipe diameter and type analysis show the locations of the drainage system. It also shows the current stormwater volume tolerance capacity of these pipes. This can help consider the size of the stormwater storage devices in the GIN to release the pressure of these drainage pipes and connect with these pipes properly.
Figure 4.3. Stormwater drainage pipe type analysis map of the chosen site (Author, 2018)
Unitary Plan Analysis

The Auckland Council unitary plan shows the designed land use of this sub-catchment in the future. There are residential-mixed housing urban zone, residential-terrace housing and apartment buildings zone, different open spaces zone, different business zones such as industry zone and town centre zone, strategic transport corridor zone, and so on. The following design shows how to create a GIN based on the proposed land uses and suggested functions of this unitary plan to offer a reference for the sustainable green infrastructure construction in future Auckland.
The master plan of this site is designed based on the integrated catchment management map and the previous site analysis.

There are several main land use areas. They are waterscape area, general vegetated area, lawn or shrubs area, bioswale corridors area, impervious surface area, and roads area respectively.

Most of the designed GIN nodes and corridors are existing low land, flood plain area, parks, reserves, and stream channels. The designed GIN form a connected parks system like in The Emerald Necklace case and The Park Connector Network case to link all of these green spaces together. It is combined with a pedestrian and cycle path. Therefore, people can go anywhere of the GIN quickly and safely.

The connected park system also provide habitat for local wildlife such as birds to protect the biodiversity.
Design Analysis

Functional Division Analysis

There are five different function zones on this site. They are residential-mixed housing urban zone, residential-terrace housing and apartment buildings zone, business-community centre zone, business-commercial zone, and business-industry zone respectively.

Figure 4.38. Functional division analysis (Author, 2018)
Catchment Division Analysis

According to the integrated catchment management map, this sub-catchment area is divided into twenty-two parts. They are twenty-one neighbourhood scale sub-sub-catchments and a constructed stream buffer area.

Figure 4.39. Catchment division analysis of the chosen site (Author, 2018)
Main Control Points and Constructed Stream Corridor Analysis

There are four central open spaces in the residential area. They are control points of block scale micro-catchments of this site. In addition, there are twenty-one detention parks which are located in the lowest point of neighbourhood scale sub-sub-catchments. These parks are the neighbourhood scale control points. There is also a wetland park at the lowest point of this entire site. It is the community scale sub-catchment control point.

The constructed stream corridor connects all of the neighbourhood scale control points together. The storm runoff can be delivered from the neighbourhood scale control points (detention parks) to the lowest wetland control point through this corridor. After infiltration, purification, and storage in the wetland park, the runoff overflow to the Oakley Creek natural channel at last.
Figure 4.40. GIN control points and constructed stream corridor analysis of the chosen site (Author, 2018)
Street-side Bioswale Corridors Analysis

There are two kinds of corridors: block scale and neighbourhood scale street-side bioswale corridors. The main function of these corridors is to deliver the storm runoff from the block scale control points (central open spaces) to neighbourhood scale control points (detention parks).

Figure 4.41. GIN Street-side bioswale corridors analysis of the chosen site (Author, 2018)
**Designed Building Type Analysis**

Based on the AC unitary plan analysis, three different building types are designed in this site. They are mixed housing, terrace housing and apartment building, business building type respectively. Business buildings consist of community centre building, commercial building, and industrial building.

The mixed housing refers to the house or apartment which has less than three floors (Auckland Council, 2016). Most of these houses remain untouched after the design compared to the houses in terrace housing and apartment buildings area. It shows how this GIN can still be constructed and worked well in existing house type condition if the local people won’t change their house style in the future.
Figure 4.42. Designed building type analysis of the site (Author, 2018)
Redesigned and Removed Building Analysis

This map shows the locations of the redesigned, removed and untouched buildings after design in this project.

To be better adapted to the GIN conditions, some business buildings are redesigned or removed to create a new spatial mode which can give more space for central open spaces, where the GIN control points such as detention parks can be installed inside. This new business urban spatial mode can not only offer more open space for the GIN thus bringing more ecological benefits, but also bring more social benefits such as recreational and communicate chances for local people. It can also attract business thus bringing economic benefits to this area.

The houses in the terrace housing and apartment buildings area are all redesigned to construct terrace housing or apartment buildings. This part of the design shows how the GIN can be built and works well in the intensified residential area.

In southern mixed housing area, though most of the houses are remain untouched, some of them near the constructed stream buffer area are removed because of its low position. These low locations have high flooding risk. Additionally, some houses located in the designed detention parks area are also removed or reconstructed as the apartment buildings.
Figure 4.43. Redesigned and removed building analysis of the site (Author, 2018)
Percentage Changes of Different Surface Areas

After design, the percentage of the vegetated area increases from 49% to 58%. Conversely, the portion of impervious surface areas including building areas and impervious pavement areas decrease from 51% to 42%. There are more green spaces and less impervious surface areas after design. Thus the urban ecological and hydrological conditions are improved through designing the GIN nodes and corridors, rearranging the current houses, and recreating a new open spatial mode.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Existing conditions</th>
<th>Designed conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (m²)</td>
<td>Percentage</td>
</tr>
<tr>
<td>Building area</td>
<td>361,642.5</td>
<td>19.1%</td>
</tr>
<tr>
<td>Impervious pavement area</td>
<td>595,805.7</td>
<td>31.5%</td>
</tr>
<tr>
<td>Vegetated area</td>
<td>934,694.8</td>
<td>49.4%</td>
</tr>
<tr>
<td>Total area</td>
<td>1,892,143</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.6. Percentage changes of different surface areas before and after design (Author, 2018)
4.7 Summary

This chapter mainly showed the design scope and objectives, the new stormwater management pattern, the level classification of the stormwater management devices, the construction of an ICM system, the formation of the GIN frame based on this system, and the master plan design work of the chosen site.

The ICM system allows the storm runoff to be treated step by step through small scale to large scale GIN control points and corridors based on the overland flow path.

The GIN frame of Oakley Creek catchment area can solve urban ecological and hydrological issues like flooding and water pollution, protect and improve the hydrological cycle of the urban environment. It can also provide multiple social and economic benefits to the intensified urban area.

A site was chosen to design a master plan to show the details of the GIN. This GIN is a future-based design created in the frame of the AC unitary plan.

After design, the total vegetated area and open spaces increase obviously. Though the quantity of the households increases too, the ecological condition is also improved because of the ecological functions of the GIN. This can allow the construction of city infrastructure and keep or even improve the urban ecology at the same time.
5.0 DETAILED DESIGN PROPOSAL
§ 5.1 Selected Areas

Three different land use areas are selected to introduce the details of this GIN. They are the residential-mixed housing urban area, residential-terrace housing and apartment buildings area, and business area. Business area includes the community area and the commercial area nearby. The GIN construction of industrial area is similar to the commercial area, so it is not selected.
5.2 Terrace Housing and Apartment Building Area

Neighbourhood Scale

It shows the GIN nodes or control points of this area, which consist of central open spaces (block scale) and detention parks (neighbourhood scale). It also shows the locations of the main street-side bioswales corridors.

According to the slope analysis, at the steeper position, a series of weirs are designed like in Elmwood Park Stormwater Diversion Project (Big Muddy Workshop, 2014) combined with the design street-side bioswale corridor to slow down the runoff.

Figure 5.2. Master Plan of the neighbourhood scale terrace housing and apartment building area (Author, 2018)
Spatial mode Analysis

Change the spatial mode from previous Export-oriented space to import-oriented space. Convert the previously unutilized area into multiple functional shared spaces for recreation. Build landscaped stormwater devices and planters inside of these shared spaces to capture, slow, purify, infiltrate, and store the storm runoff from surrounding streets and roofs.

Figure 5.3. Spatial mode change (Author, 2018)
Street Classification Analysis

Learn from the Long Bay street classification (ADM, n.d.). There are two kinds of streets in this design: block streets and main streets which have the width of 5 m and 8 m respectively. Block streets are located around the central open space. They are shared streets with motor vehicles and pedestrian or cycle use. The narrower width of the block streets allows the drivers to slow down and keep the pedestrian safety. Because the central open space is an import-oriented and positive space where there will be a lot of people existing and relaxing.

Figure 5.4. Street classification (Author, 2018)
Runoff Flow Direction Analysis

In a neighbourhood scale sub-catchment zone, runoff from the block scale micro-catchments inside of this zone is guided to each of the central open spaces through block scale street-side bioswale corridors. Inside of these central open spaces, there are storm runoff storage spaces and devices to store the runoff temporarily. Then, the overflow is guided to the neighbourhood scale detention park through the neighbourhood scale street-side bioswale corridors and overflow to the small wetland pond in the detention park at last. If there was still overflow, it would flow to the community scale GIN corridors.

Figure 5.5. Runoff flow direction (Author, 2018)
Infiltration Ability Comparison

As can be shown in the pre-unitary condition diagram, before urbanization, the infiltration ability was quite good in this area as there was less impervious surface and more vegetated area. The post-unitary condition diagram shows after urbanization, the quantity of the houses and the impervious pavement increased dramatically, which lead to the damage of the infiltration ability. Through redesigning the house style and rearranging the spatial mode, the infiltration ability of this area has increased compared to the post-unitary condition.

Figure 5.6. Infiltration ability comparison
(Author, 2018)
**Designed Hydrological Condition of Neighbourhood Scale Detention Park**

The A-A’ section effect picture shows the construction and designed hydrological condition of the neighbourhood scale detention park. There is a landscaped wetland pond in the middle area of the park. It can receive the storm runoff overflow from stormwater storage devices of block scale catchment. It can also purify and collect storm runoff from surrounding building roofs and impervious pavement.

Learn from the Edinburgh Gardens Rain Garden (GHD Pty Ltd, 2010) case, there are two kinds of water tanks designed near the wetland ponds. They are the underground tank and the aboveground tank respectively. The functions of these tanks are to purify and store the storm runoff for urban farming irrigation. People can choose which type of tanks they will use based on different terrain conditions.

Different from the costly irrigation system in Edinburgh Gardens Rain Garden case, the siphon pipes and pumps (Miles at el, n.d.) are used to distribute the stored stormwater to decrease the cost of maintenance and power. The urban farming area is designed in the lower place of this park. When irrigation needed, it only needs to turn on the siphon pump at one time. The stored rainwater would keep flowing automatically according to the principle of siphon and gravity.

In addition, this detention park can create multiple recreational opportunities and spaces for local people such as educational spaces, wandering spaces, communication spaces. The urban farming can also bring economic benefits to local people.
Figure 5.7. A-A’ section effect picture of neighbourhood scale detention park (Author, 2018)

1. Receive stormwater overflow from block scale stormwater storage devices (like tanks).
2. Purify and collect stormwater run off from surrounding building roofs and impervious pavement.
3. Create multiple recreational opportunities.
4. Create economic chances like urban farming.

Function:

Overflow Pipe (To drainage system)
Street-side Bioswale Corridor Analysis

The corridors consist of combined bioswales and wooden route. The hollow wooden path is a narrow traffic aisle for pedestrian or cycle use. It is also combined with the street-side parking areas based on the Long Bay street design (ADM, n.d.) to maximum the use of narrow street-side spaces. All of these designs form a ‘green street’ pattern in GIN.
The runoff is delivered from higher bioswale corridors to lower bioswale corridors step by step. The corridors can also purify, infiltrate and direct the storm runoff from surrounding rooftops and impervious pavement.

The neighbourhood scale street-side bioswale corridors deliver the runoff overflow from the block scale storm runoff storage devices to the neighbourhood scale detention park.
Percentage Changes of Different Surface Areas

After design, the impervious surface of this area decreases from 44% to 34%. The vegetated area increases from 56% to 66%. It shows more ecological benefits compared to the previous condition.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Existing conditions</th>
<th>Designed conditions</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Area (m²)</td>
<td>Percentage</td>
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<tr>
<td>Building area</td>
<td>22,056 (200 households)</td>
<td>16%</td>
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<tr>
<td>Impervious surface area</td>
<td>37,561</td>
<td>28%</td>
</tr>
<tr>
<td>Vegetated area</td>
<td>76,299</td>
<td>56%</td>
</tr>
<tr>
<td>Total area</td>
<td>135,916</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 5.1. Percentage changes of different surface areas (Author, 2018)

Figure 5.9. Percentage changes of different surface areas (Author, 2018)
**Designed Density of households and Population**

The amount of the households increases approximately 3~5 times than before. It can settle down 669~1115 households compared with the previous single house mode of 200 households.

After design:
Density of households: 49~82 households / hm2; 4900~8200 households / km2
Density of population: 147~246 people/ hm2; 14700~24600 people/ hm2

The density of households and population varied according to how many floors the apartment buildings have. According to the provision of H6 Residential - Terrace Housing and Apartment Buildings Zone (Auckland Council, 2016), the buildings must not exceed 16m in height. In this project, it designs maximum five floors for these apartment buildings.
Compared with current Auckland population density, which shows the most dense area in Auckland has the density of population of 10911 people/ km², there can be settled down 14700–24600 people in one hectare after design in this site. Therefore, it can meet the demand of the most intensified living environment in the residential area of urban Auckland.

<table>
<thead>
<tr>
<th>name</th>
<th>location</th>
<th>people/sq km</th>
</tr>
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<tbody>
<tr>
<td>Auckland Central East</td>
<td>Auckland City</td>
<td>10911</td>
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<tr>
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<td>Burbank</td>
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<td>Rowandale</td>
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<td>Puhinui</td>
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<tr>
<td>Oranga</td>
<td>Auckland City</td>
<td>4462</td>
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<tr>
<td>Hyperion</td>
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<td>Papatoetoe West</td>
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<td>Waitakere City</td>
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<tr>
<td>Viscount</td>
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<td>Aerere</td>
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<td>Ferguson</td>
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</tr>
<tr>
<td>Papatoetoe North</td>
<td>Manukau City</td>
<td>4049</td>
</tr>
</tbody>
</table>
Block Scale

One of the block scale micro-catchment area is chosen to show the details of the designed green infrastructure and spatial mode of the central open space, which is the block scale control point of the GIN.

The surrounded buildings all face towards the central open space to make a more positive spatial mode, which can bring multiple recreational activity chances for local people.

There are lawns, native shrubs and trees, pervious paving squares, a Maori style pavilion, a main bioretention area, a sinking green space area, and urban farming and education areas in central open space.

The LID stormwater management devices in and around the central open space consist of rain gardens, porous or pervious pavement, filter strips, bioswales, sand filters, infiltration trenches, and Infiltration drywells.

The sinking area with wet tolerant shrubs located in the lower zone of the central open space. It can store the stormwater temporarily. The pervious paving squares are designed around the sinking area to offer a variety of relaxing and recreational grounds for local people.
Designed Hydrology Condition of Central Open Space

The storm runoff from the roofs and impervious pavement of surrounding area can be purified and infiltrated through infiltration drywells, infiltration trenches, bioswales, main bioretention area step by step as in Serramonte Library Stormwater Garden case. Finally, the runoff is guided into the lowest place of this site, where there is a sinking area which has the ability of infiltration and temporarily runoff storage.
There is an underground tank located at higher place of this area. The storm runoff stored in the tank can be used to irrigate an urban farming garden through siphon pipes. This garden is designed in a lower position of this area to use the siphon pipe to irrigation.
There are three designed water level in this area to deal with the 10yr ARI, 50yr ARI, 100yr ARI events (Auckland Council, 2013) respectively. The overflow is directed by the overflow pipes to the drainage system or next level of LID stormwater management devices of the GIN.
Figure 5.13. C-C'
Cross-section of block scale central open space (Author, 2018)
Spatial mode Analysis

1. Change the spatial mode from export-oriented space to import-oriented space.

Figure 5.14. Import-oriented central open space (Author, 2018)

2. Create multiple recreational opportunities

Figure 5.15. Multiple recreational functions (Author, 2018)
Multiple recreational opportunities are created on this site through Hedonistic Sustainability concept and method (Quirk, 2014).

There is a Maori style pavilion located at a corner. This offers a view of Maori culture and also allows people to have a social contact like communication or conversation inside. The urban farming areas are designed for people to grow vegetables or fruits. They can also help to teach children about the types of these plants.

The shared fitness equipment in the higher squares is designed for people to use. It is also a good place for gathering. There is also a lower square connected by stone steps. It is a ‘water square’ with the changeable landscape inspired by Water Square case and the BIG U case.

In dry seasons, the lower square can be used as a performing area. People can seat at the stone stairs located in front of the performing square to enjoy a dance show or other performing shows. In rainy seasons, the lower square can be used as the shallow water pool, which offers a chance to get closer to the waterscape. The fences are designed to protect children from dropping.
Building Shade Analysis

Figure 5.16. Building shade changes during the daytime (Author, 2018)
According to the shade imitate analysis, it shows that the combined apartment buildings around the central open space are lighted well during the daytime in Auckland. All parts of these buildings can receive a direct daylight though the time is different. Among them, the inner part of the northern building receives the shortest daylight. The outer part of these building gets the relatively long time daylight.
In this project, there are three designed water levels based on different rainfall intensity conditions to deal with the 10 yr ARI, 50 yr ARI, 100 yr ARI events runoff respectively. Even in 100 yr ARI event, the water level would not be higher than the level of the highest square. Therefore, it will keep the surrounding buildings and people safe in all rainfall intensity levels.
Sustainable Consumption and Maintenance Pattern

Learn from the case of Tesla Energy, a sustainable consumption and maintenance pattern is designed for the GIN system to create an automatically protect mechanism and virtuous cycle to save maintenance fees and even bring economic benefits to local people.

The stormwater runoff from surrounding areas is collected in the underground tanks at last. The water can be used for washing machine, toilet, and garden irrigation. It can also be used to irrigate urban farming gardens.

The average consumption abilities for vegetables and fruits are $50 /dwelling/week in Auckland (Huggies, 2012), which means $2607 /dwelling/year. Some of this money can be saved through the design of the urban farming garden.

The larger tanks are used, the more storm runoff can be collected. Therefore, a larger area of vegetable gardens can be irrigated. People can even sell the vegetable to others with a lower price than in the supermarket. As the demand for vegetable decrease in the supermarket, the cost of the vegetables will fall. Therefore there are more calls for the larger tanks. It can help deal with more storm runoff to improve the hydrological health better. This sustainable, environmentally friendly and economic smart circle can bring ecological and even economic benefits to the whole community.
5.3 Traditional Single House Area

Neighbourhood Scale

To show how the GIN can work in existing traditional single house area, one site of this master plan is chosen to reveal the details of the GIN nodes and corridors in this area.

Figure 5.19. Master Plan of the neighbourhood scale traditional single house area (Author, 2018)
Catchment Management Analysis

The whole area is divided into several neighbourhood scale sub-catchment areas. The control points are located in the lowest places of these neighbourhood scale sub-catchments. Just like in terrace housing and apartment buildings area, the neighbourhood scale sub-catchment control points are detention parks. The corridors are street-side bioswale corridors.

Figure 5.20. Catchment control diagram
(Author, 2018)
Street-side Bioswale Corridors Analysis

This map shows different scales of the Street-side bioswale corridors in this area. They are block scale and neighbourhood scale street-side bioswale corridors respectively. The function is to deliver runoff step by step from surrounding areas to the detention parks at last.
Large size Urban Farming

Large size urban farming areas are located close to the larger stormwater storage areas, such as detention parks and wetland parks areas. The size of these urban farming areas can be varied on the different terrain conditions.

Figure 5.22. Large size urban farming (Author, 2018)
**Block Scale**

The block scale GIN consists of block scale street-side bioswale corridors and micro-urban farming strips.

**Micro Urban Farming**

The micro urban farming strips are located in the narrow backyards strips of each of the houses. These areas usually are unutilized or just for runoff delivering. Based on the current conditions, a micro-urban farming mode is designed to make the most of the land as well as to bring more ecological, social and even economic benefits to the neighbourhood.

It only needs 1~2 meters width of the strip in each backyard of the household to build a shared micro-urban farming area. The designed bioswales are combined with the farming strip to offer the irrigation water for vegetables. When it is rainy, the storm runoff can be collected first to irrigate these vegetables. Then the overflow is guided to the drainage system or the next stage of LID stormwater management devices of the GIN.

These vegetables can be planted by people living nearby or other engaged people who have the skills and love growing vegetables.

Figure 5.23. Location of the chosen block scale traditional single house area (Author, 2018)
There are three types of micro-urban farming modes as follows.

1. Isolation form: fence blocking

2. Sharing form: shared planting and picking space

3. Gathering form: shared planting and picking space

Figure 5.24. Micro urban farming mode in traditional single house area (Author, 2018)
1. Isolation Form: Fence Blocking
If people want to keep their backyards separately and privately, this mode can be used. There is the transparent fence between two backyards of different households to separate them apart. The fence can be used to plant vine vegetables. People can see each other through the fence when they were picking vegetables. Therefore, they can have social contact and communicate with each other conveniently.

2. Sharing Form: Shared Vegetables Planting and Picking Space
This mode uses the shared strips of two different households’ backyards to design a green infrastructure corridor using bioswales and s micro-urban farming strip inside of it. People can enter this narrow space through the entrance iron gates of their backyard. Then they can meet each other in this strip and pick up vegetables as well as communicate together.

3. Gathering Form: Shared Vegetables Planting and Picking Space
This form offers an opportunity for people to grow a whole vegetable garden in one of the chosen neighbor’s backyards if the owner of this house is a vegetable growing amateur.
5.4 Business Area

Master Plan

This area shows how to design an integrated centre under the frame of the unitary plan and the ecological GIN system. This centre consists of apartment residential, commercial and community central areas to make the most of the existing land. This design creates multiple utilizes and functions like ecological, social and economic functions inside of this intensified land use area, which can refer to future more intensified urban design in Auckland.
There is a detention park in the central zone of the business area to receive runoff overflow from block scale GIN devices. This park also can purity, infiltrate and store the storm runoff from roofs of surrounding business buildings and impervious pavements.
Functions of business area detention park:

1. Receive overflow from block scale stormwater storage devices.
2. Purify, infiltrate and store the stormwater runoff from roofs of surrounding business buildings and impervious pavements.
The overflow of the detention park is guided to the landscaped constructed stream. This stream flows across the whole business area to deliver the runoff overflow to the community scale wetland park as well to create multiple types of recreational open spaces for people to use when they are shopping.

The shopping malls are designed on both sides of the constructed stream. They all face towards this stream to create the natural stream sight view experience for people to enjoy when they are shopping or wandering around. The glass canopy of the base floor of the shopping mall can protect people from getting wet when it is rainy or from direct sun exposure. The designed wooden bridges connect the two sides of the stream allowing people to go through quickly and conveniently.
When it is rainy, the storm runoff from surrounding roofs and impervious pavement is collected through the bioswales and then flows into the stream-side rain gardens firstly. The rain gardens can purify and store runoff temporarily. Then the overflow is directed into the constructed stream slowly as last.
Spatial mode Analysis

All of these surrounding buildings are faced towards the central open space forming an inward and positive spatial mode. This spatial mode gives many positive recreational activity chances such as gathering and communication opportunities for people.
Traffic Route Analysis

The traffic network of this site connects all of these multiple functional spaces. It allows people to arrive at any points of this area quickly. The motor vehicle and pedestrian routes are separated in most of this area. But in areas such as the shared path area at the central plaza in front of the shopping mall, the routes are combined to make the most of the traffic space. It also allows the motor vehicle drivers to slow down their speed to assure the safety of the pedestrian who is going through this space.
5.5 Oakley Creek Reconstruction

As for community scale catchment, the GIN nodes are wetland parks. The GIN corridor which connects the GIN nodes is the Oakley Creek main channel. The creek banks are naturalized and daylighted to form a riparian buffer based on the 20m width vegetated area (Auckland Council, 2015). This buffer is acted as a flood plain area, a place for the native plants and animals settling in or passing through safely, and a filter to decrease the air and water pollution caused by the motor cars and untreated stormwater discharge.

The recycled materials such as concrete are used to create natural river banks, waterfront steps, and a variety of squares along the creek providing relaxing and social spaces like in Bishan Park and Kallang River Restoration project. There are also shared fitness and recreational facilities designed in these squares for people to relax.

After design, the Oakley Creek is not just a drainage channel anymore. Multiple recreational spaces and facilities change the previous negative isolated waterfront spatial mode to an attractive landscaped interacted spatial mode. The surrounding
houses are designed towards this creek space instead of turning their back to the creek.

In conclusion, this designed urban stream GIN corridor not only can solve the current flooding or water degradation issues, purify air quality condition, decrease the urban heat island effect of whole catchment, improve the biodiversity by riparian buffer so as to improve the urban ecological and hydrological health, but also can bring social and recreational benefits to local people.
5.6 Summary

This chapter showed the detail designs of the GIN in the chosen site. Three areas are selected. They are the residential-mixed housing urban area (traditional single house area), the residential-terrace housing and apartment buildings area and the business area respectively.

Firstly, the master plan and detail designs of the terrace housing and apartment buildings area were analyzed from neighbourhood Scale to block scale. In neighbourhood scale, the spatial mode, street classification, runoff flow direction, infiltration ability, designed hydrological condition of neighbourhood scale GIN node (detention park), street-side bioswale corridor, percentage changes of different surface areas, and designed density of households and population are analyzed respectively. In block scale, the designed hydrology condition of block scale GIN node (central open space), spatial mode, shade analysis of buildings, heavy rainfall conditions, and sustainable consumption and maintenance pattern are analyzed respectively.

Secondly, the master plan and detail designs of the traditional single house area were analyzed. In neighbourhood scale, the catchment control, street-side bioswale corridors, midsize and large-size urban farming are analyzed. In block scale, the combined bioswale corridor and micro-urban farming strips mode is designed.

Then, the master plan and detail designs of a business centre were analyzed. This centre consists of apartment residential area, commercial area and community central area. This new spatial mode brings multiple utilizes and functions in intensified land use area. Based on the master plan, the designed hydrology condition, spatial mode, and traffic route are analyzed.

Finally, it showed the reconstruction design of the Oakley Creek. After design, this urban stream GIN corridor can bring multiple benefits to urban ecology and infrastructure development.
CONCLUSION

The midsize global cities like Auckland are spreading because of the population growth (Allen et al., 2016). This leads to ‘environmentalist’s paradox’ (Wu, 2014): the city infrastructure construction and the decrease of the urban ecology, which results in multiple environmental problems like green space fragmentation, biodiversity decreasing, flooding, water pollution, and greenhouse gas emission. To deal with this issue, a green infrastructure network (GIN) model was proposed.

This GIN was constructed based on integrated catchment management (ICM) system, which was created by catchment divisions based on overland flow path. Within this system, the GIN nodes and corridors were found and defined based on the different locations along the overland flow path. Most of the GIN nodes and corridors were redesigned street-side green space strips, parks, reserves, open spaces, and streams. Some of them were new constructed stream and open spaces.

The current LID and stormwater management devices such as rain gardens, bioswales, and wetlands were classified into several levels and used as an integrated system in the GIN. Different levels of the devices were applied in different scales of GIN nodes and corridors to allow these devices to work as a ‘treatment train’ (Auckland Council, 2015) thus treating runoff step by step, maximum the GI functions of preventing flooding and pollution problems in the intensified urban area.

The fragmented green spaces were connected through GIN corridors to form a green space network. This network not only had the primary function of integral stormwater management but also had multiple environmental benefits such as the protection of the biodiversity, increase of urban heat island effect, and improvement of the urban air quality. The surrounding living environment was more natural, ecologically healthy, and livable for local people and neighbourhood.

The green infrastructure devices or network model like Water Squares, green streets, connected parks, stream corridors were also used to construct a sustainable GIN. Because of the different weather conditions, the detail designs of these devices were
different to adapt to specific temperature and rainfall conditions in Auckland.

In this procedure, a local area network (LAN) and shared infrastructure were created in GIN in respond to the ‘environmentalist’s paradox’ (Wu, 2014). There were different kinds of recreational spaces and shared facilities in the LAN to add more social benefits to neighbourhood. These spaces were more positive and useful in intensified urban residential or business areas.

To form a more sustainable GIN maintain mode, the stormwater distribution pattern and a new sustainable consumption and maintenance pattern were designed for the whole GIN system. Through creating a siphon system and designing the urban farming gardens to establish a stormwater recycle mechanism within the LAN thus bringing more social and economic benefits to neighbourhood.

The detailed designs showed how to create the GIN in the frame of unitary plan. The urban spaces were redesigned to form a more positive urban spatial mode. The new open spaces had the designed functions of stormwater management, biodiversity protection, beautification of the city and other ecological and hydrological functions. Even if in intensified area like the business area defined in the unitary plan, a proper urban space design based on the GIN offered multiple ecological benefits as well as landscaping benefits to local people.

The ecological, social, and economic benefits of the GIN and LAN are as follows:
The GIN and LAN explore a sustainable urban development paradigm which can help to achieve the urban design objectives of Auckland: constructing the Auckland city as a more livable, environmentally friendly, welcomed city in the future (Auckland Council, 2013). Therefore, it can be used for Auckland Council’s city retrofit plan and projects. Within the frame of the Unitary Plan, the GIN can work well and bring multiple benefits to the whole urban environment. However, the further explore is needed to adapt this GIN to the different topography conditions and special sites in urban Auckland.
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