A landscape architecture of wetland design in the context of sea level rise in eastern Christchurch

A dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Master of Landscape Architecture

at
Lincoln University
by

Zeyu Tan

Lincoln University
2019

Abstract of a dissertation submitted in partial fulfilment of the requirements for the Degree of Master of Landscape Architecture.

A landscape architecture of wetland design in the context of sea level rise in eastern Christchurch

By Zeyu Tan

With sea level rise (SLR), coastal zones will be gradually inundated by sea water and that could significantly damage the existing ecosystem services and affect people's daily life. To mitigate the adverse impacts from SLR, wetlands are identified as not only the potential solution but also an opportunity to generate more value. To do this, the state of knowledge for expressing the productivity of wetlands is first explored through a literature review. Second, best-practice design guidelines, from part of a research placement, are used together with the literature review to generate design patterns for releasing the productivity of wetlands that are easy to apply in a wetland design. Different design patterns serve to increase different values from wetlands through direct expression or integrated expression in design practices. Third, to better harness and categorize the values of wetlands identified in this research or could be investigated, the diagram of productivity in wetland design aims to further open opportunities for releasing more values, as they are developed. These diagrams categorize the wetlands as natural wetlands, constructed wetlands for water purification, and constructed wetlands for food production. Through an investigation into generating design patterns, the integration or junction zones of any two types of the wetlands mentioned, above, are able to generate new values. Fourth, these design patterns are examined in Kaiapoi, eastern Christchurch. Then, in the discussion, a design-based selective system of productive wetlands in SLR is generated to provide an adaptive design framework to assist wetland designers in harnessing the productivity of wetlands under SLR. Since this system is open and expandable, it can be widely applied, adjusted and developed for alternative scenarios in the current uncertain future.

Keywords: Wetland, wetland design, productive wetland, wetland values, design guidelines, design patterns, design framework, scenario development, Christchurch, New Zealand.

Acknowledgements

Special thanks to my supervisor， Mick Abbott, who has been providing valuable feedback and guide me all the time. Special thanks to my mother, who has been so supportive in my study. To my girl friend, who provide me with emotional support. To my friends Tina and Woody, who helps me with moral support and advices.

Table of Contents

List of Figures

List of Tables

Chapter One: Introduction

1.1 Sea Level Rise

Current projections from the National Oceanic and Atmospheric Administration (Sweet et al., 2017) suggests that the sea level will have risen by 0.3-2.5 meter at the end of the 21st century and current research is showing that the speed of SLR has accelerated due to the ongoing Antarctic ice collapse (Rintoul et al., 2018). As a consequence, about 187 million people who live in the coastal zones of the world would find their property and themselves in danger (Nicholls et al., 2011). Based on current research, sea level Rise (SLR) is the main threat to the resilience of a coastal city (Cazenave & Cozannet, 2014) and it will also cause enormous damage in New Zealand, an island nation where all its major cities like Auckland, Wellington and Christchurch are on the coast.

With SLR, More coastal zones will be drowned under the water with more wetlands forming (Passeri et al., 2015). Moreover, the ongoing formation of wetlands under SLR is a natural process that could lead to a significant difference from our existing understanding of wetlands. Therefore, this could be an opportunity to investigate what are the impacts from SLR on different types of wetland and how could they be transformed into opportunities, especially within the scope of mitigating the ongoing adverse effects of SLR.

In addition, SLR will have an enormous impact on people's daily lives. However, the planning and design about these impacts are still dominated by engineering approaches that often neglect the intangible needs of the local communities (Jabareen, 2012). Therefore, there is a need to review and approach the adverse impacts of SLR through the lens of landscape architecture.

1.2 Sea Level Rise in the Wetlands of New Zealand

1.21 Introduction

To explore the potential of wetlands' productivity for mitigating the adverse impacts of SLR through design intervention, a critical review of SLR is essential. The Ministry for the Environment of New Zealand ("Adapting to sea-level rise," 2019) provides a precise introduction on SLR in general terms, stating that the earth is covered with greenhouse gases which serve to trap the heat energy projecting from the sun. These accumulated greenhouse gases will cause global warming, which will lead to SLR. Based on the research from IPCC (Change, 2014), global warming was once a natural process that progressed slowly. However, over the last 150 years, human activities like agriculture, transportation and industry accelerated global warming, thus, the SLR is accelerating accordingly. In addition, current research is showing that the speed of SLR has been further accelerated due to the ongoing melting of Antarctic ice (Rintoul et al., 2018). With SLR, more coastal zones will be drowned under water with more wetlands occurring (Passeri et al., 2015).

Current research shows that wetlands are one type of green infrastructure that carries a strong ability for mitigating the impacts of extreme environmental events, including SLR (Allam & Jones, 2018). Besides, the existing wetlands could adapt to SLR through naturally occurring migration (Enwright, Griffith, & Osland, 2016). Thus, the ongoing formation of wetlands under SLR, as an emerging natural process, could lead to a significant difference in our existing understanding of the wetlands. Therefore, wetlands have the potential for generating strategies for mitigating the adverse effects from SLR, and an examination of wetlands in the scope of landscape architecture is very relevant.

1.22 Definition of Wetlands

Form our current understanding, a wet pond after rain does not necessarily make it a wetland, a wetland is a distinctive ecosystem which is temporarily or permanently inundated by water and supports many aquatic plants. Specifically, a water table that exists long enough to support aquatic plants characterizes a wetland from other landforms (Keddy, 2010). In New Zealand, a definition of a wetland is clearly indicated in the Resource Management Act (1991) Part 1 (2) (Gov, 1991) Interpretation and application, which states a "*Wetland includes permanently or intermittently wet areas, shallow water, and land water* *margins that support a natural ecosystem of plants and animals that are adapted to wet conditions.*"

1.23 Classification of Wetlands

Wetlands occur naturally on every continent, thus, there are many different types of them (Davidson, 2014). Johnson and Gerbeaux divided the wetlands into nine types according to the broad hydrological conditions that include landform setting, salinity and temperature (Johnson & Gerbeaux, 2004). Other classifications of wetlands using different approaches or with a focus on different countries have also been found. However, there are three reasons that make Gerbeaux's wetland classification more applicable in this research. First, their classification and related discussion is focused on the wetlands of New Zealand. Second, their classification is officially recognized and used by the Department of Conservation (DoC) in New Zealand. Third, their classification has considerable relevance to SLR as this classification is based on hydrological conditions. For these reasons this dissertation adopts Johnson and Gerbeaux' classification of wetlands. The nine wetland types based on this classification are: marine, estuarine, riverine, lacustrine, palustrine, inland saline, plutonic, geothermal and nival, as shown below.

Table 1. Wetland classification based on hydrological conditions

Term	**Definition**
Marine	Marine is the saline waters of the sea.
Estuarine	Estuarine is located in the junction zone where land meets the sea and the soil water there is affected by sea water. Some typical estuarine areas are estuaries, coastal lagoons and other tidal reaches of coastal zones. The estuarine classification is also known as coastal wetlands. The dominant functions here are tidal effects and the salinization of soil water.
Riverine	Riverine is connected to water channels like rivers and streams. The dominant function here is the constantly flowing water in the wetland, which keeps running. The hydrosystem of riverine includes both the river bed and its riparian zones ecologically connected to the wetland. Going downstream, the riverine land will eventually merge with the estuarine land. The boundary is usually defined by where the salinity is 0.5%.
Lacustrine	Lacustrine is connected to open water bodies like lakes and large ponds.

	The dominant functions here are wave actions and fluctuating water levels with little water flow. The lakes and large ponds mentioned here generally have a dimension of longer than 500 m.
Palustrine	Palustrine includes all freshwater wetlands that are replenished by surface water, ground water and rain, and do not directly connect to an open water body. The palustrine classification is also known as a marsh, which is the major type of wetlands that consist of a wide range of vegetation types.
Inland saline	The inland saline classification is located close to water resources with a high concentration of soluble salts and a semi-arid climate. Inland saline land is uncommon in New Zealand and is mainly found in the basins of Otago.
Plutonic	Plutonic is generally located underground in caves or underground waterways where little photosynthesis takes place.
Geothermal	Geothermal is located close to geothermal water and most of this land is found in the central North Island in New Zealand.
Nival	Nival is not a generally thought of as a wetland habitat as it is located in glaciers and snowfields. Nival is a habitat for algal communities.

From the classification of wetlands, it can be seen that marine, estuarine, riverine and lacustrine are wetlands that could be directly affected by SLR based on their hydrosystems and dominant functions. Besides, palustrine as the major type of wetlands in New Zealand bears significant ecosystem services. Thus, these five types of wetlands are included in the following discussion and will be applied in the spatial illustration of ongoing SLR in the design stage.

1.3 Investigation on the Potentials of Wetlands in New Zealand

To discuss the potential challenges and opportunities of SLR rises on different types of wetland, it is first useful to explore the ecosystem services wetlands provide. Clarkson has divided these ecosystem services into four groups: provisioning services, regulating services, habitat services and cultural services (Clarkson, Ausseil, & Gerbeaux, 2013), as shown in Table 2.

Table 2. Ecosystem services of wetlands

Types	**Detailed Ecosystem Services**
Provisioning Services	Food, fresh water supplies, raw materials, genetic resources, medicinal resources and ornamental resources.
Regulating Services	Influence air quality, climate regulation, moderation of extreme events, regulate water flows, waste treatment, erosion prevention, maintenance of soil fertility, pollination and biological control.
Habitat Services	Life cycle maintenance and gene pool protection.
Cultural Services	Aesthetic, recreation/tourism, inspiration for cultural, art and design, spiritual experience and cognitive information.

Clarkson also uses predicted economic values to set the "*relative importance*" of the ecosystem services of wetlands, which aims at "*quantifying wetland ecosystem services from around the world*" (Clarkson et al., 2013). Therefore, to investigate the potential of wetlands for further development from a New Zealand perspective, a value-based framework has been created from Clarkson's work and other published papers based on New Zealand's wetlands. This investigation is developed from studies undertaken as part of a research placement in the Lincoln University landscape architecture course LASC 699 (Tan, 2018), as shown in table 3 & Appendix B.

Table 3. Values from wetlands in a New Zealand Perspective

No.	**Categories**	**Values**
1		Remove unwanted nutrients

2	Ecological Values	Provide habitat for wildlife
3		Improve Water quality & Security
4		Increase Biodiversity
5		Defences against flood
6		Regulate water
7		Trap sediment
8		Climate regulator
9		Provide condition for indigenous plants
10		Sinks of carbon
11		Increase resilience of ecological system
12	Economic Values	Generate Income/Reduce Lost
13		Food Production
14		Tourist attraction/services
15	Social Values	Provide Cultural value of Maori
16		Increase Well-being
17		Educational
18		Recreational
19		Aesthetic value
20		International and national significance

In this dissertation, the framework developed in research placement will be adapted and then applied to investigate the productive potential of wetlands in New Zealand under a SLR scenario. Different types of productivity are used to indicate the potential challenges and opportunities of wetlands in relation to sea level rises.

1.4 The Role of Landscape Architect in Sea Level Rise

To mitigate the adverse impacts and reduce the potential losses from SLR, the field of urban planning has identified "resilience" and "adaptation" as relevant conceptual frameworks that aim to mitigate the adverse impacts of SLR (Hill, 2016; Worku, 2017). Therefore, a review on what is "resilience" in relation to coastal zones and to find out what it means in the field of landscape architecture will be useful in revealing the potential of wetlands under SLR. "Resilience" and "adaptation" are emerging terms that people are more likely to use when facing extreme environmental events and ongoing SLR from climate change (Hill, 2016). "*Resilience*" is generally used to describe the ability of a city to recover from a disaster, not on any other incremental trend (Shi, Chu, & Debats, 2015). Then, "adaptation" was created and used to describe the ability of a city to mitigate the adverse impacts from incremental trends like SLR in urban planning (Hill, 2016). Currently, "*adaptation*" is used together with "*Resilience*" to deal with both temporal and incremental adverse impacts from climate change in the US (Botzen, Michel-Kerjan, Kunreuther, de Moel, & Aerts, 2016). Then, how can these concepts of "*resilience*" and "*adaptation*" be applied in the field of landscape architecture?

Nicki Copley (Copley, Bowring, & Abbott, 2015) reviewed the term "r*esilience*" and discussed the term of "a*daptation*" within the scope of landscape architecture. The theoretical framework which she explored with these two terms is insightful for investigating the potential challenges and opportunities generated from SLR (Copley et al., 2015). First, Copley introduced the social-ecological adaptive cycle (Holling & Gunderson, 2002), as shown in Figure 1. There are four phases in this cycle: reorganization phase means "*innovation, experimentation and transformation potential*"; exploitation phase means "*growth and opportunity*"; conservation phase means "*stability, certainty, and control*"; release phase means "*disturbance, disaster leading to creative opportunities for reimagining an alternative state*" (Copley et al., 2015). In my research, ongoing SLR is a new environment that has the possibility of generating potential in the reorganization phase. The research has been undertaken in different fields about SLR is the exploration in the exploitation phase; the different guidelines and frameworks that have been structured are products in the conservation phase and the investigation of this research is in the release phase, which aims to investigate the innovative opportunities and alternative futures for wetlands in New Zealand under the SLR scenario.

Copley then concluded that the role of the landscape architect in assisting a city to become more resilient towards SLR by stating that (as a landscape architect) "*Our research is positioned within the reorganization phase and seeks to grasp this opportunity to develop opportunity and innovation, exploring how landscape architects can be crucial to the imagination of more adaptive and resilient futures."* In Copley's interpretation, the purpose of "Resilience" changed from recovering after a disaster to opening a discourse where values could be released from the landscape in an incremental trend including SLR, through a design-based "adaptation" in the field of landscape architecture. In this research, I will seek to follow her approach while explaining the concepts she developed in the design stage, which aim to express more productivity in wetlands through landscape patterns under the scenario of SLR. Adaptive strategies that could be widely applied in different contexts of coastal zones are generated to mitigate the adverse effects of SLR.

IMAGE REMOVED DUE TO COPYRIGHT

Figure 1. Social-ecological adaptive cycle generated by Copley who adapted it from Holling and Gunderson.

1.5 Challenges and Opportunities of Wetlands in Sea Level Rise

1.51 Introduction

Many impacts from SLR have been found and illustrated (Nicholls & Cazenave, 2010). The aim of this research is to focus on exploring how could the generation of wetlands could, as a consequence of ongoing SLR, be used to mitigate adverse impacts from SLR. Therefore, the following discussion focuses on the adverse impacts with potential to be mitigated by releasing the productivity of wetlands through design intervention. As the generated strategies about SLR will be examined in New Zealand, the following discussion will be discussed in general but also with a focused on New Zealand.

1.52 Increasing Hidden Risk and Cost of Infrastructure Failure

By 2100, without proper adaptation towards SLR, globally half a billion residences in coastal plains will have to relocate to higher ground or live in floating cities (Reise, 2017). About 0.3 – 9.3% of the global gross domestic product will be lost if no adaptation has been successfully implemented (Reise, 2017). In comparison, protecting high-value coastal zones with dykes will pace a much lower financial burden on the local government in the 2100 scenario of SLR (Hinkel et al., 2014). However dykes building is an engineering approach against nature and it is easy to draw serious consequence once the dykes fail (Hinkel et al., 2014). Besides, infrastructure building will involve the distribution of allowances between different zones and this will drag the actors involved into a prolonged debate that will slow down the progress of adaptation towards SLR (Nicholls et al., 2011). Moreover, the New Zealand government officially discourages the building of hard coastal infrastructure like sea walls and advocates to implement a retreating strategy under SLR (Bell et al., 2017). Therefore, the following discussion will be carried out based on a scenario under retreating strategy.

However, there are also some challenges for implementing a retreating strategy. For example, coastal residences today are generally unfamiliar with SLR (Reise, 2017), as sea levels have been relatively constant in human history for a long time until the first signal of SLR that was found in 1970 **(Slangen et al., 2016)**. Besides, coastal residents today generally feel safe as the coastlines have been structured and fortified against storm surges for many years (Reise, 2017). For example, there have been 64 years of no major dyke failures in Netherlands and the people's faith towards the engineered defence has been growing with the years. Besides, scientists are likely to avoid overestimating SLR for their credibility and the risk of dike's defences failing could be further increased (Reise, 2017). Another example is from Holland, a country that used to rely on the building of dykes and coastal barriers as a defence against storm surges. But with the side effects of water control and climate change, the Dutch government turned to find an alternative strategy in 2008. This emphasises a spatial adaptation strategy that integrates the natural dynamics of water and sediments, in other words, it is a retreat and community replacement strategy. This was approved by the Dutch government, but was halted in 2015 after protests by local residents. From the examples, it can be seen that it may take a decade for public debates and another decade for the step change implementation of adjustments in lifestyle (Reise, 2017).

Therefore, coastal residents who were well protected are now vulnerable to the increasing risk of dyke failure due to ongoing SLR. Besides, the sense of safety built into the infrastructure have made coastal residents more likely to accept the inevitable hidden effects rather than to adapt to any changes with a visible cost like community replacement. To help coastal communities adapt to SLR and insightfully manage the related potential risks, it is worthwhile to consider other strategies for innovation in SLR. Besides, increases in public awareness towards the impacts of SLR is another important matter to consider in the field of landscape architecture (Meyer, 2008; Sheppard, 2015). The establishment of the estuarine wetlands are a consequence of ongoing SLR (Passeri et al., 2015) with this natural process able to be perceived by the public as a warning sign. Besides, the time-based approach is a "*trump card*" of for the landscape architect in tackling SLR (Copley et al., 2015; Donald A, 1997) and there is potential for the coastal zone to be developed as a recreational park for mitigating the adverse effects from SLR (Burger, O' Neill, Handel, Hensold, & Ford, 2017). Therefore, this shows the opportunity to develop and design estuarine wetlands for educational purposes as it could increase the awareness of the public towards the consequences, especially the hidden risks from SLR.

1.53 Increasing Demand for Accommodation and Living Spaces

Ongoing SLR will increase the demand on accommodation for two reasons. First, the growth of the human population is constantly accelerating and reached seven billion in 2011 (Worldometers, 2019). In New Zealand, its population has constantly grown from around 3.7 million in 1995 to almost 5 million in 2018 (Worldometers, 2019). This increased population trend will not only transform more land from its original use to residential, industrial and commercial uses but will also create more pressure on the existing ecosystems which increase the input of resources and output of pollution (Ehrlich, 1974). Second, coastal cities are generally densely populated and their population growth rates are higher than in their hinterlands (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015). In particular coastal communities in developing countries are expanding fast and are also comparatively more vulnerable towards SLR, so this will leave not much time for them to have an appropriate adaptation (Jevrejeva, Jackson, Riva, Grinsted, & Moore, 2016). Besides, before 2050, extreme environmental events will double in tropics, destroying coastal cities in low-lying Pacific Island nations (Vitousek et al., 2017). If there is no successful adaptation of SLR to be implemented, the exposure status of coastal cities will generate millions of environmental refugees (Nicholls et al., 2011).

Therefore, not only the increasing population but also incoming climate refugees will require more space for accommodation and living. It is important to plan and prepare for future SLR (Bell et al., 2017). Thus, as landscape architects in facing the challenges from SLR, we need to plan things in advance rather than design afterwards. Therefore, this predicted increasing demand on housing and living spaces will be taken into consideration in this dissertation. While seawater is transforming more coastal zones into wetlands (Passeri et al., 2015), the modern-built houses with their fixed foundations will not be able to meet the needs of residents who then need to relocate to a higher ground in the future (Reise, 2017). However, people have been living in houses surrounded by water for a long time; this can even be traced back to the Bronze Age (Ertl, 2008). A building surrounded by water, and raised above it is called a stilt house. It is raised over the surface of soil or water by piles that primarily protect it against flooding (Bush et al., 2004). Besides, some communities of stilt houses are able to perform economic activities like floating markets where people exchange their products and provide different kinds of service (Geppert & Dufhues, 2005). Therefore, stilt housing opens an opportunity for planning and designing wetlands for accommodation and living purposes.

1.54 Impact on Food Security

SLR will not only reduce living spaces for coastal communities but will also invade arable land. The reduced arable land will affect the food security of a country (Sarwar, 2005). Thus, it could become a challenge for local authorities when more food is required to support the larger population with less arable land available under the impacts from SLR. The Global

Agriculture Towards 2050 report (Alexandratos & Bruinsma, 2012), noted that overall food production needs to be increased by 70 percent from 2005 to feed the predicted 9.1 billion population of the world in 2050. Because of the high population growth rates and low food production efficiencies in developing countries, they will need to double their food production to feed their people (Alexandratos & Bruinsma, 2012).

As a consequence, food prices in the global markets are predicted to increase and this will affect the availability of food to low-income residents and the incoming environmental refugees. Thus, generating more food from the land could contribute to the resilience of coastal communities towards SLR and become a visionary step to adaptation. In New Zealand, harvesting food resources like eels, whitebait, mullet and watercress from wetland is a tradition for Maori ("Maori and wetlands," n.d.; McKerchar, Bowers, Heta, Signal, & Matoe, 2015). Today, wetlands have been found not only have the ability to establish industrialized food production but also to treat the pollution outputs from it (Vymazal, 2017). Therefore, this opens an opportunity to explore how food production in wetlands could be harnessed through design to deal with the food security issue derived from SLR.

1.55 Impact on Coastal Tourism

Coastal tourism, as one of the largest tourism segments (Hall, 2001), has much invested in buildings, such as hotels and vacation homes in the coastal zones (Scott, 2011). Besides the potential loss of coastal properties, there are some other predicted impacts from SLR on the coastal tourism, such as the deprivation of high-value beaches, changes in landscape scenarios and the destruction on coastal infrastructure (Phillips & Jones, 2006). For example, 83% of tourist beaches and 62% of coastal infrastructure in the Caribbean island of Martinique could be severely damaged by SLR (Schleupner, 2008). Therefore, vacation properties and tourist destinations in New Zealand could also be deeply affected by SLR.

Almost every tourism destination needs to adapt to climate change either through minimizing the potential losses or generating new opportunities from the local impacts of climate change (Scott, Gössling, & Hall, 2012). Therefore, a collaborative design that incorporates the ecological and geomorphological structures on the shore can make coastal zones more resilient towards SLR and eco-tourism as one type of productivity from wetlands could be generated from the impacts of SLR (Burger et al., 2017). Then, this opens an opportunity for landscape architects to not only mitigate the adverse effects but also to explore tourism values induced by SLR through planning and designing coastal zones like the estuarine wetlands.

1.56 Conclusion

In conclusion, SLR will cause huge adverse impacts on the community of New Zealand. Compared to the engineering approach of defensive infrastructure building, a combination of adaptation and mitigation on a large scale are required to limit SLR and reduce the severity of its consequences (Nicholls et al., 2007) with considerable opportunity for landscape architecture to generate integrated strategies that pro-actively address SLR (Copley et al., 2015; Donald A, 1997).

1.6 Research question

The literature review in the research context section of this dissertation shows the adverse impacts of SLR on the coastal zones in New Zealand. It also indicates the potential of wetlands for mitigating these impacts. Marine, estuarine, riverine, lacustrine and palustrine wetlands are those which will be most affected by SLR and will be the focus of this research. In addition, it has identified roles for the landscape architect in mitigating the adverse impacts of SLR and the reasons for wetlands being a valuable design component for this purpose. Three challenges of SLR that could be transformed into opportunities through design interventions have been identified: increasing hidden risks and costs of infrastructure failure; increasing demands on accommodation and living spaces and the impacts on food security and coastal tourism. This literature review identified key principles that have potential to generate values from wetlands under SLR scenario. However, the existing guidelines and adaptive strategies for SLR appear general in nature and require more detailed translation into landscape architecture design practice. It is the potential to consider ways that these could be translated into design forms and specifically, designs of different wetland scenarios developed for a common site that offers a strong opportunity for research. Specifically this research asks what range of wetland design forms could be usefully respond to the impacts of SLR? And following this what benefits within the increasingly prevalent issue of SLR could wetlands be harnessed to deliver?

Chapter Two: Methods

2.1 Literature Review

A critical literature review on relevant materials includes the literature and the guidelines that are essential for this research in establishing a strong foundation for identifying and investigating the gap of knowledge in the scope of designing wetlands under sea level rise (SLR) scenario. In table 4, steps 1 to 5 are the questions I want to answer from the literature review in building a firm foundation for this study. A literature review is useful for developing a theoretical model and examining it in a project (Webster & Watson, 2002). In this research, the best-practice design guidelines for wetlands that I developed in research placement and the quadrant evaluation diagram developed by Abbott and Bowring (Abbott & Bowring, 2017) are the two theoretical models examined. Best-practice design patterns for wetlands in SLR and the adaptive strategies generated from it are the new products developed from the literature review.

In Webster and Watson's understanding (Webster & Watson, 2002), there are two types of literature review. First, "*authors could deal with a mature topic where an accumulated body of research exists that needs analysis and synthesis. In this case, they would conduct a thorough literature review and then propose a conceptual model that synthesizes and extends existing research*". Second, "*authors could tackle an emerging issue that would benefit from exposure to potential theoretical foundations. Here, the review of current literature on the emerging topic would, of necessity, be shorter. The author's contribution would arise from the fresh theoretical foundations proposed in developing a conceptual model*". The literature review used in this research included both types, as introduced above. Steps 1 to 3 in table 4 aim to determine what a landscape architect could do to mitigate the adverse impacts of SLR through exploring the potential of wetlands, these steps are from the first type of literature review. Then, steps 4 and 5 in table 1 focus on the emerging topics indicated in the discussion of mature topics in steps 1 to 3. Best-practice design patterns for wetlands in SLR are also developed in the literature review.

2.2 Scenario Development

Scenarios are constructed to inform alternative futures with different potentials and to enable decision-makers to make insightful choices (Nassauer & Corry, 2004). The normative landscape scenario as one type of scenario is effective in exploring the "*potential in both policy and landscape ecology research*" and could be applied to "*an interdisciplinary project that proposed alternative scenarios*" (Nassauer & Corry, 2004). Besides, scenario approaches have also been applied in the field of landscape planning (Ahern, 2011). Therefore, the normative landscape scenario development is applicable to this research, which focuses on revealing the potential of wetlands in SLR.

Based on the understanding of Nassauer and Corry (Nassauer & Corry, 2004), the scenarios should include four parts. The first is "*a description of the present situation*'; the second is "*a number of alternative futures*"; the third is "*possible pathways connecting the present with images of the future*"; and the fourth is "*evaluated and compared*". In this research, the first and second parts of scenario development will be used at step 8 in table 4, which aims to develop a sequential scenario of SLR through overlapping the retreating shorelines of different years in the future. Compare to generate different scenarios in different years, it will be easier to develop an adaptive strategy through reviewing the impacts of SLR in a dynamic and generative view. The adaptive strategies generated for SLR are used to connect the present and the alternative futures at step 9 in table 4. Afterwards, a comparison and an evaluation are also applied in the same section.

The aim of this research is to explore the potential of wetland productivity for mitigating the adverse impacts of sea level rise (SLR) through design intervention. The aim of this research is achieved through following steps:

Table 4. Research Steps with methods

Steps	Chapter	Description	Methods
1.	One	The critical literature review is used to help understand the mechanism of wetlands in New Zealand under the SLR scenario.	Literature Review
2.		The critical literature review is used to investigate the potential of wetlands in New Zealand.	
3.		The critical literature review is used to define the role of the landscape architect in wetland design under SLR.	
4.		The critical literature review is used to explore the potential of wetlands in mitigating the adverse impacts under the SLR scenario.	
5.	Two	The critical literature review is used to produce best-practice design patterns, which are then applied to generate a set of adaptive strategies on different contexts including rural, suburban and city.	
6.	Three	Review best-practice design principles for wetlands	
7.	Four	Generate design patterns for wetlands in SLR	
8.	Five	A sequential scenario for wetland development under SLR in eastern Christchurch is developed for releasing different types of productivity.	Scenario development
9.		An examination of the generated adaptive strategies in the scenario will be used for further discussion and become an exemplar on how the productivity of wetlands can be best harnessed to mitigate the adverse impacts from SLR.	
10.	Six	Conclusion	

Chapter Three: Best-practice Design Principles for Wetlands

3.1 Best-practice Design Principles for Wetlands

This chapter is built on the research placement that identifies the state of knowledge for expressing values of wetlands from New Zealand's perspective through a critical literature review (Tan, 2018), as shown in Appendix B. Besides, it also indicates the research gap in this zone and produces best-practice design guidelines for assisting landscape architects and other related design professionals in wetland design, as shown in table 5. The relevant design guidelines in this research are then transformed into design patterns with the illustrations in the context of sea level rises.

Table 5. Best-practice design principles for wetland developed in research placement

No.	principles
1.	Site selection for wetlands should first consider its soil conditions and, thus, where there used to be wetland is more suitable for the establishment of a wetland
2.	The size and types of wetlands should be considered based on the water resources available
3.	Planning of wetlands should be considered within the larger context
4.	Flexible and mufti-functional design can improve environmental adaptability
5.	Constructed wetland should cover about 1% of the site to maximize its nutrient removal ability
6.	Constructed wetland can deal with storm water directly, as natural wetlands are supposed to only handle the pre-treated storm water
7.	Whether the water levels of wetlands are allowed to change and by much should we expect should be included in the design
8.	The life span of wetlands should be considered in their design, and the designer needs to decide if this wetland design need to be replaced or rejuvenated
9.	Plan routes carefully to avoid external damage to sensitive plants
10.	Hybrid use of different types of constructed wetland can improve nutrient removal ability
11.	Wetlands in critical zones can enhance thr efficiency of nutrient removal while

	controlling the cost
12.	Large wetlands can express more ecological values, but small wetlands could contribute to protecting the endangered species present
13.	Complex topography could generate more vegetation and animal communities
14.	Shallow wetlands have a greater ability for nutrient removal, but fence protection is required
15.	Increasing the use of native plants can enhance indigenous values
16.	Respect and explore indigenous cultural values when designing wetlands
17.	Introduce ornamental plants into wetlands could express more aesthetic and ecological values
18.	Developing wetland tourism could contribute to public awareness of wetland protection, especially with the assistance of visitor centre and guiding services
19.	Simple-constructed and easy-operated designs can reduce the cost of implementation
20.	Easy-maintained designs of wetlands can reduce cost for maintenance
21.	Designs should go along with the owner's personal and business goals to make it happen
22.	Plan and design wetlands to prepare for anticipated climate change and its impacts
23.	Integrating food production into wetland systems could contribute to the balance the watershed ecosystem and economic development
24.	Integrate wetlands with a green infrastructure could mitigate the effects of floods

In this research, the relevant design guidelines to this research and some other useful findings that relate to the expression of productivity from wetlands will be transformed into design patterns through my design-based interpretation within the scope of landscape architecture. These design patterns will be integrated into several adaptive strategies for the expression of productivity in the scenario of SLR in coastal zones.

3.2 Evaluation Method

To effectively categorizing the wetland design patterns and undertaking valuable discussions, a design-directed tool employed by landscape architectural researchers, Mick Abbott and Jacky Bowring, shows great potential to meet the need. This tool is "*a quadrant approach based on intersecting axes, ... [which] can similarly be both analytical and generational, where the two axes set out a field of possibility*" (Abbott & Bowring, 2017). They then also describe the purpose of the tool is for "*crowd-sourced design critique*" (Abbott & Bowring, 2017) and this is useful in categorizing the design appraoch. Therefore, I applied the quadrant diagram for this research and popularized the axes with the resilience and productivity; planning and designing, as shown in figure 2. The reason I chose these axes is because they enable me to express the productivity of wetlands in an environmental-friendly way at the two stages in which landscape architects are generally involved in, planning and designing. Each design pattern generated will be categorized into one of the four quadrants, like productivity-planning. Then the design approaches are able to be located in one of the four quadrants in the form of black dots, as shown in figure 2. Therefore, what design approaches have been taken or have not been taken are identified in the diagram.

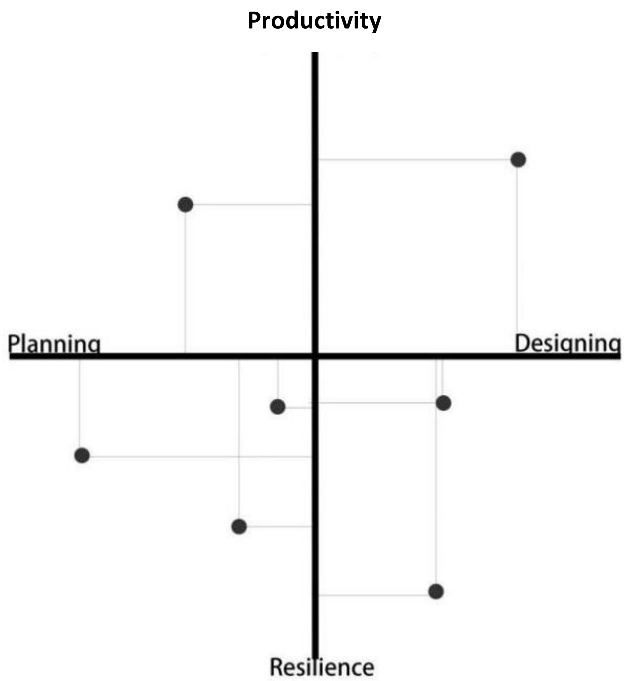


Figure 2. Quadrant diagram for categorizing design approaches of wetlands

3.3 Review on Design

3.31 Introduction

To consider best-practice design principles for wetlands and the quadrant diagram in design practice, the major design of my undergraduate project at Lincoln University in 2017 is used as an example. The chosen location of my major design is on the lacustrine wetland of Te Waihora/Lake Ellesmere in the Selwyn District of the Canterbury Region in New Zealand. Lake Ellesmere has been found to been taken more pressure from the constant and cumulative human activities like intensifying agricultural practices. This leads to an ongoing degradation of water quality. Therefore, I set my primary target to improve water quality of Te Waihora/Lake Ellesmere in major design.

3.32 Case Study

In my research, an exemplar of QianDao Lake in China inspired me. QiaoDao Lake is a man-made lake, made in 1959, as part of the Xin'an River hydroelectric station. With the transformation of the local farming fabric by introducing aquaculture to deal with the ecological crisis in 2004, Qiandao Lake became well-known for not only its aquacultural products and beautiful views but also its consistency in providing clean water to the surrounding cities. Therefore, I found that environmental challenges could be transformed into opportunities with systemic thinking. I then changed my target to transform the water quality issues of Te Waihora/Lake Ellesmere into opportunities that could benefit the local community.

In addition, there were two strategies I have learnt from the exemplar of QianDao Lake; bio-manipulation in aquaculture and incorporating with other industries. Bio-manipulation is the deliberate alteration of an ecosystem by adding or removing species. With human intervention, more environmental services could be explored and enhanced, such as water purification, population control of certain species and even making a profit to benefit the local community. However, there is a limitation on the contribution from a certain industries, but by incorporating different sectors from other industries, a lot more interest could be made by society and for society. Therefore, as landscape architects, we need to consider how to build a win-win mechanism using systemic thinking. From what I learnt from this study, different design approaches that have been conducted in major design are discussed below.

3.33 Systemic Analysis

To redesign a mechanism, it is necessary to review the existing one. Figure 3 is the attempt I have made to shows how do the nutrients released from dairy industries affects the water quality in Te Waihora/Lake Ellesmere. Some turning points of the current situation were found through unfolding the existing system. The turning points were: planting of riparian plants; restoration of wetland plants and introducing aquaculture from omnivorous (mixed-feed) fish. The amplifying version of figure 3 is shown in appendix A.

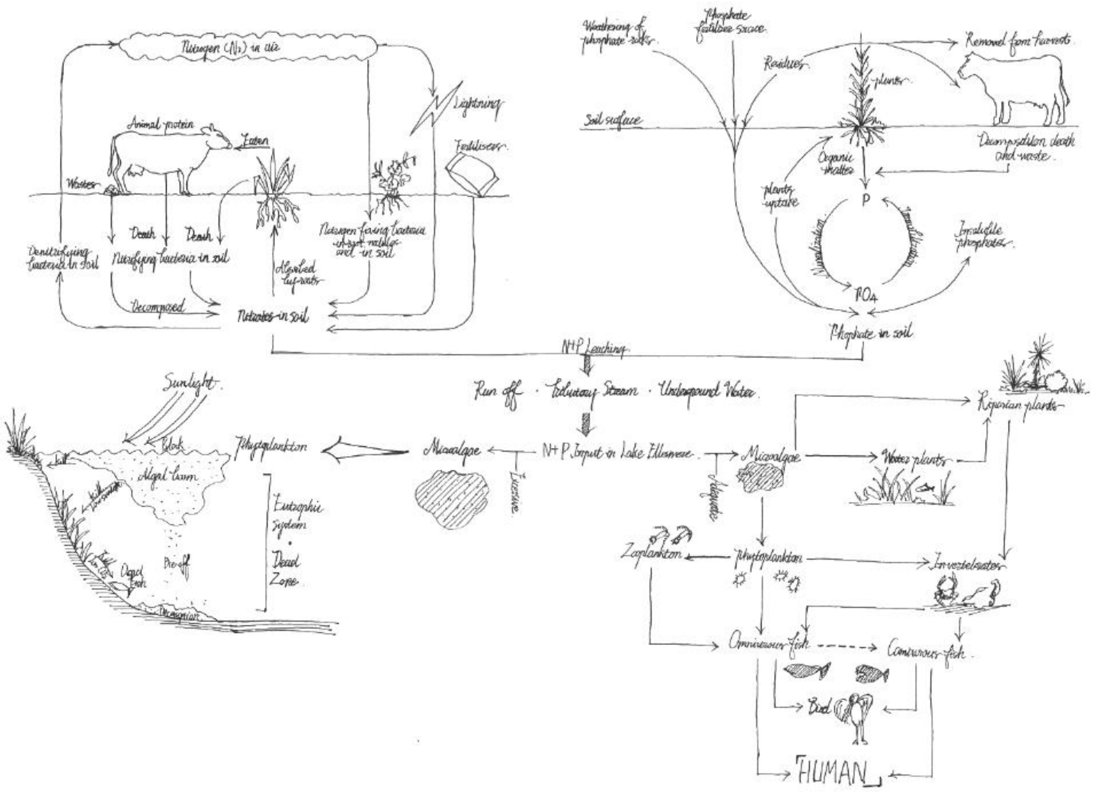


Figure 3. Nutrients leaching patterns on dairy farms developed on major design

After a systemic analysis, figure 4 was produced and illustrated how the nutrients inside the Selwyn River and Te Waihora/Lake Ellesmere could be used for different industries which will finally increase the welfare of the local community. The colours changes in figure 4 means: dark blue to blue represent water quality improved; blue to green represent the water is used for irrigation; blue/green to yellow means the welfare of community is improved.

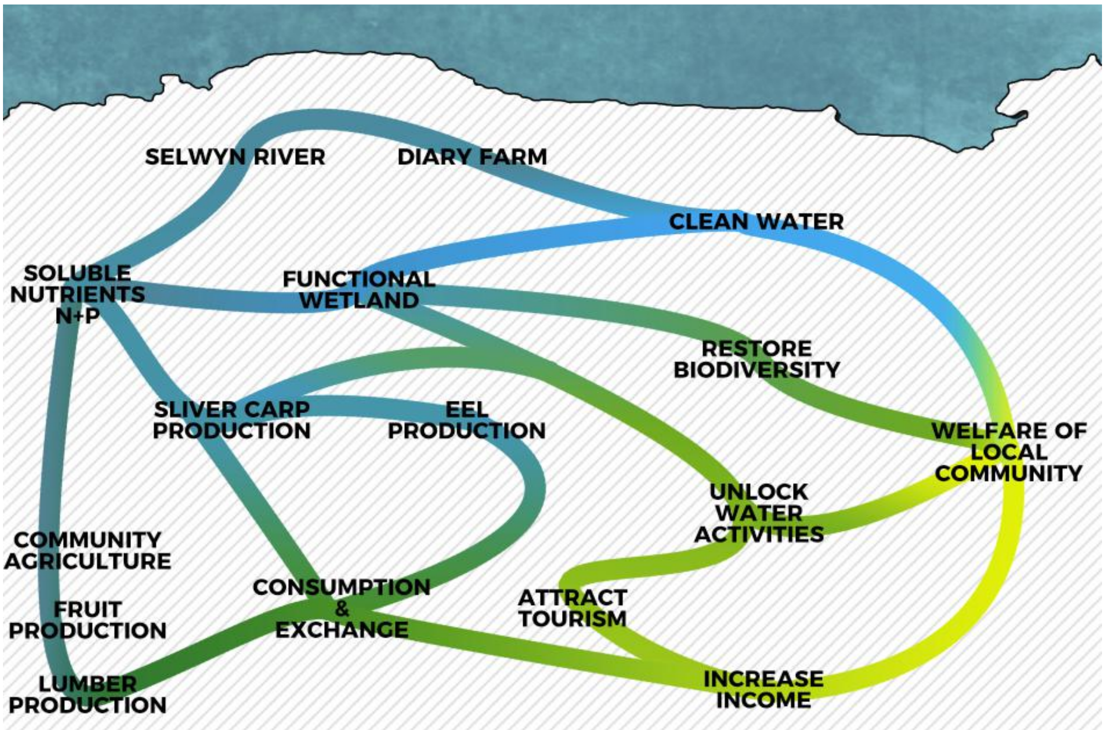


Figure 4. System for transforming leached nutrients to the welfare of local communities

3.34 Anticipation about Climate

Afterwards, I looked closely at the site to discover how the sea level rises change the coastal lines of Te Waihora/Lake Ellesmere, as shown in figure 5.

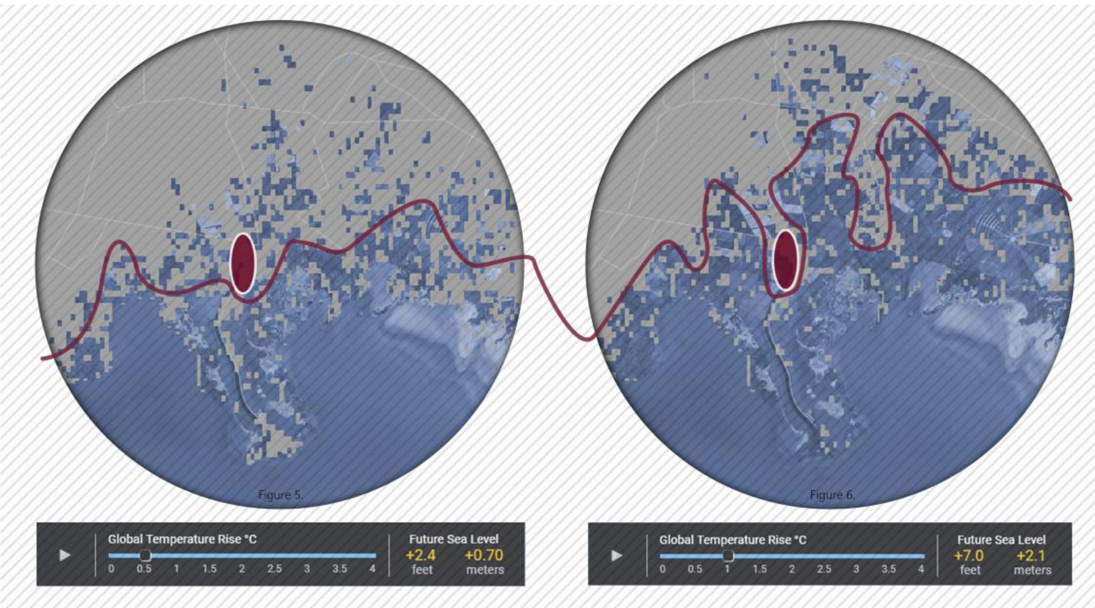


Figure 5. Change of coastal lines in Lake Ellesmere

3.35 Systemic Spatial Planning

With an understanding of the productive systems and following the coastal line changes from SLR, I designed figure 6. Different ecosystem services that could be provided are labelled and classified into three different systems. The food system consists of agriculture, fruit production and aquaculture, for improving food security; the house system consists of re-located 3-storey high ground houses, riparian silted houses and upturned-boat floating houses, for providing accommodation. The water system consists of river channels, estuarine wetlands, palustrine wetlands and fish farms, for improving the water quality in the Selwyn River and Te Waihora/Lake Ellesmere.

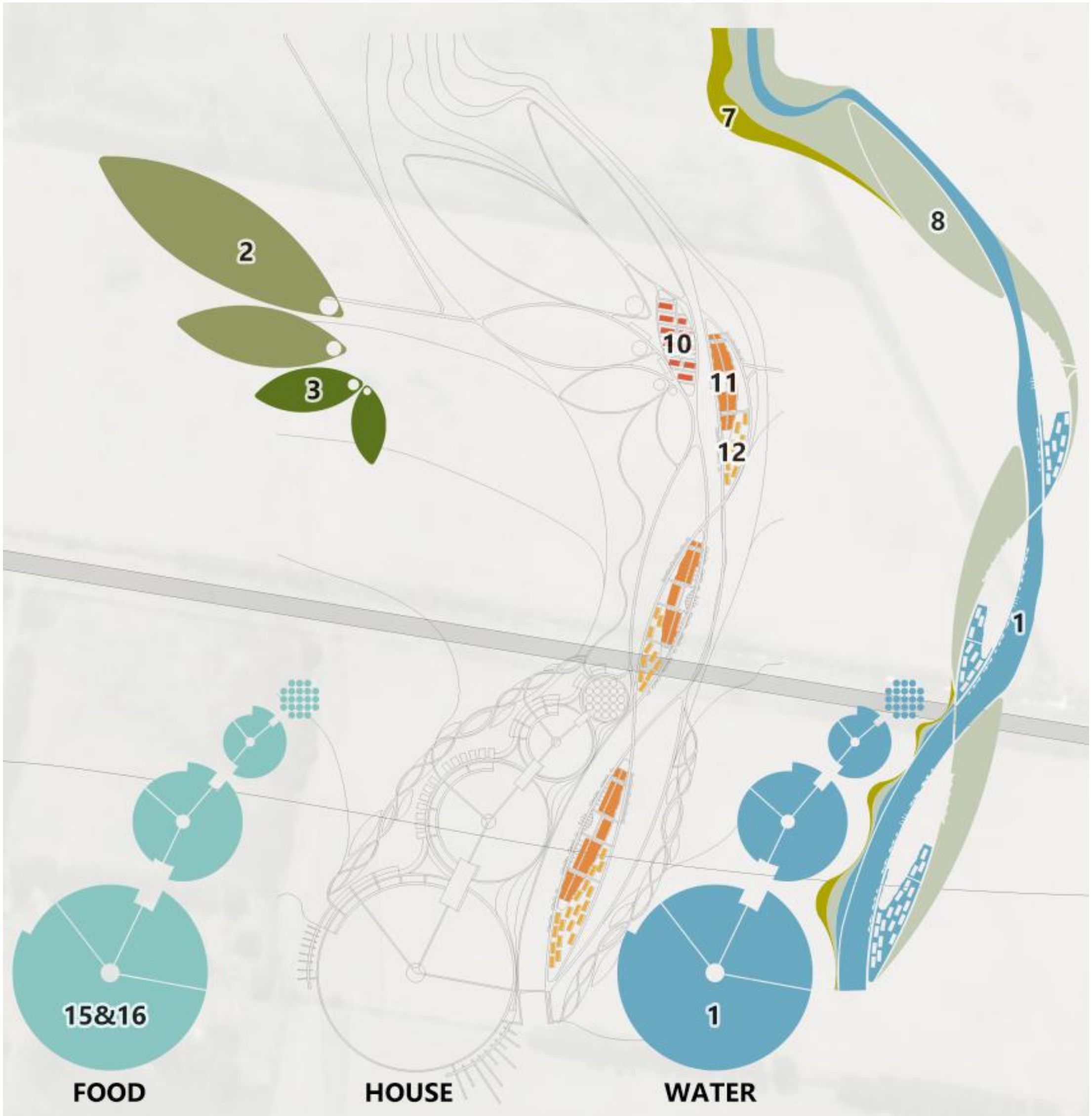


Figure 6. Three layers of systems that benefit the local community

3.36 Time-based Planning

To make my design adapt to SLR, four scenarios are generated and different components of the three systems are located according to their original characteristics and the predicted impacts from SLR, as shown in figure 7.

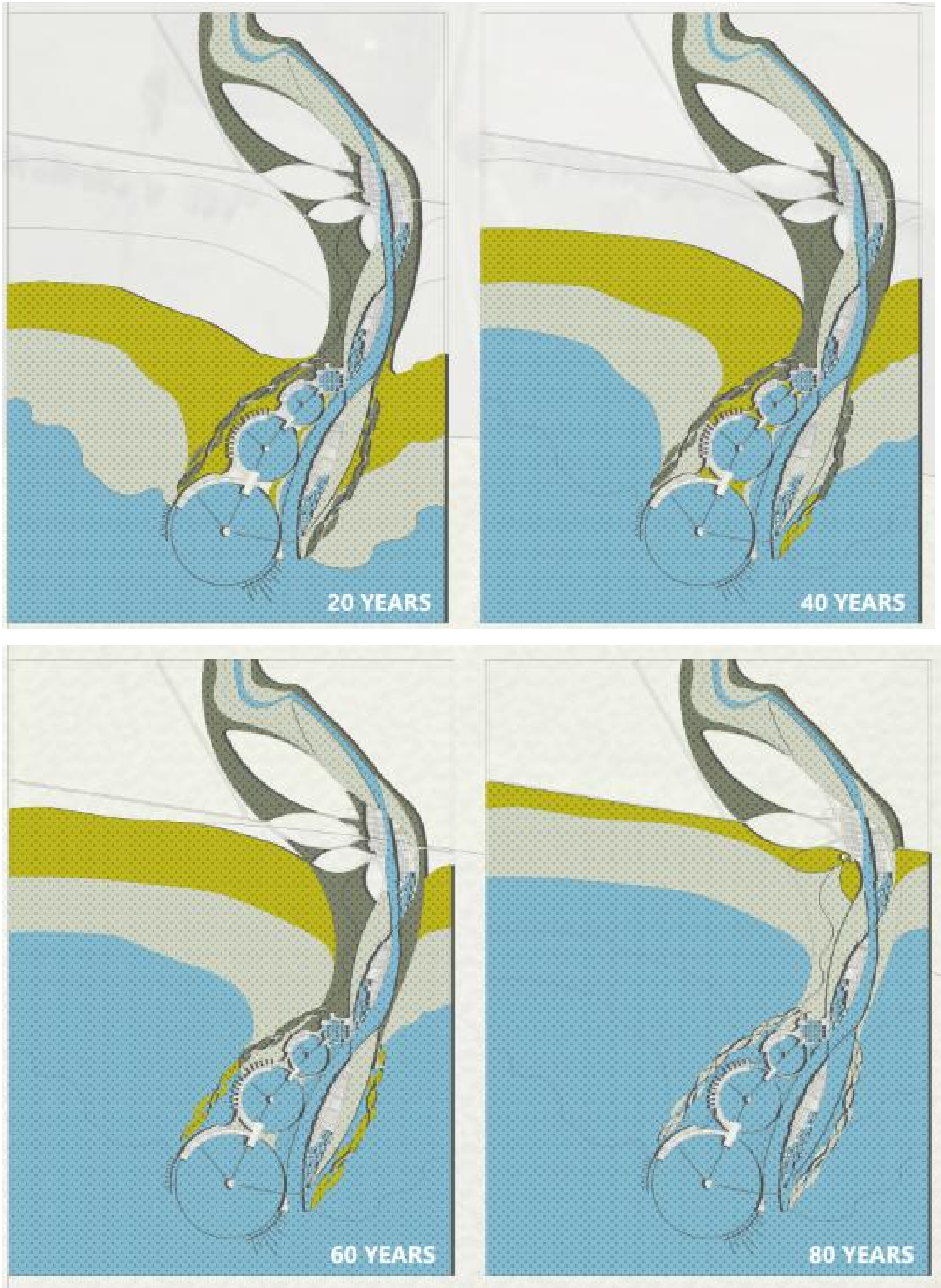


Figure 7. Four scenarios of sea level rise in Lake Ellesmere

Time-based planting are applied to the planting strategy of my major design as well and there are four stages in it, as shown in figure 8.

STAGE ONE (1-5years): In five years, most native shrubs could grow to close to their mature forms. At this stage, the ecosystem of the under-story level could be fully established, and be able to attract some insects and small animals back. In this way, the foundation is complete for transforming into a higher class of ecosystem.

STAGE TWO (5-10years): In ten years, all shrubs should be fully grown and start to expand to fill the empty spaces. Lumber trees are supposed to be half grown by this stage, which can perform a canopy effect to protect the lower shrubs. In addition, fruit trees will be able to produce fruit from year to year, attract not only people but also wild animals.

STAGE THREE (10-20years): In twenty years, the lumber trees are ready to be harvested and transformed into living materials of market value, which will be used to further develop the local community.

STAGE FOUR (20-30years): In thirty years, the lumber trees are harvested, where these where will be left and occupied by native wetland plants. At this stage, the water of Te Waihora/Lake Ellesmere should occupy half of the zone from the rising water caused by global warming.

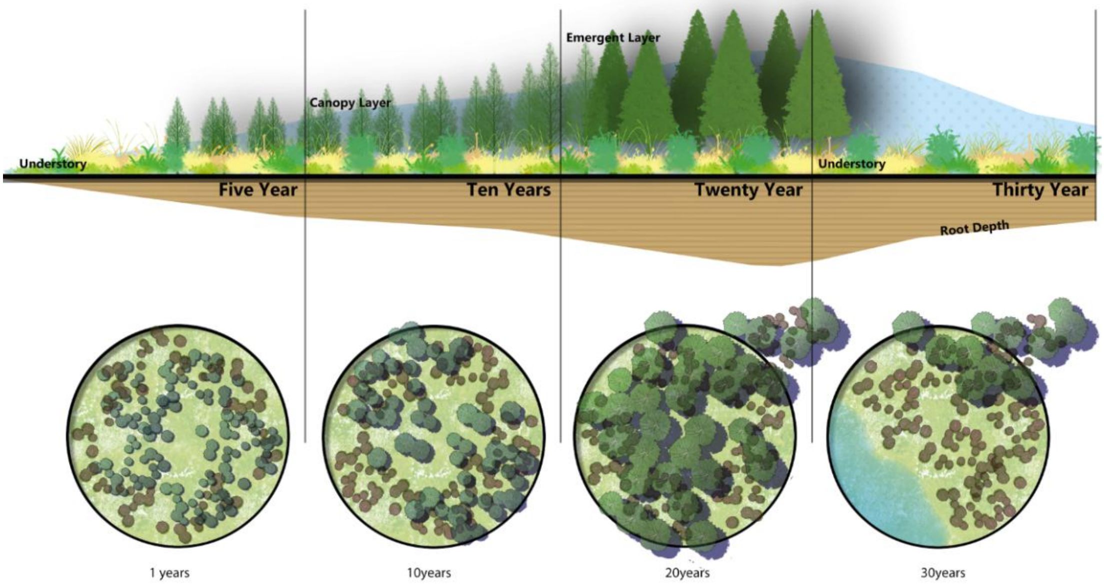


Figure 8. Time-based design of planting strategies

3.37 Discussion

After a brief review of my major design, best-practice design guidelines and quadrant diagram are examined in evaluating my major design. Among them, best-practice design guidelines could be used to evaluate the wetland designs in the form of a check boxes. In using my design as an example, I have meet most of the principles and only failed to meet principle 6, which indicated that the constructed wetlands can deal with storm water directly, but natural wetlands are supposed to only handle pre-treated storm water. In my design, there is one patch of vegetation planting zone that directly connects to the restored riverine wetland. I should connect the vegetation planting zone to a purifying-functioning artificial wetland or other facilities with similar purposes before connecting to the restored natural wetlands. From this result, it can be seen that my major design is complying quite well with the best-practice design principles for wetlands. This is because I had already started to review the literature during the design stage and most of the literature I reviewed at that time was used afterwards to construct the best-design principles for wetlands. Therefore, these design guidelines should be more useful for other wetland designers.

Quadrant diagram adapted in figure 2, is used to identify and localize the design approaches I have taken in major design, as shown in figure 9.

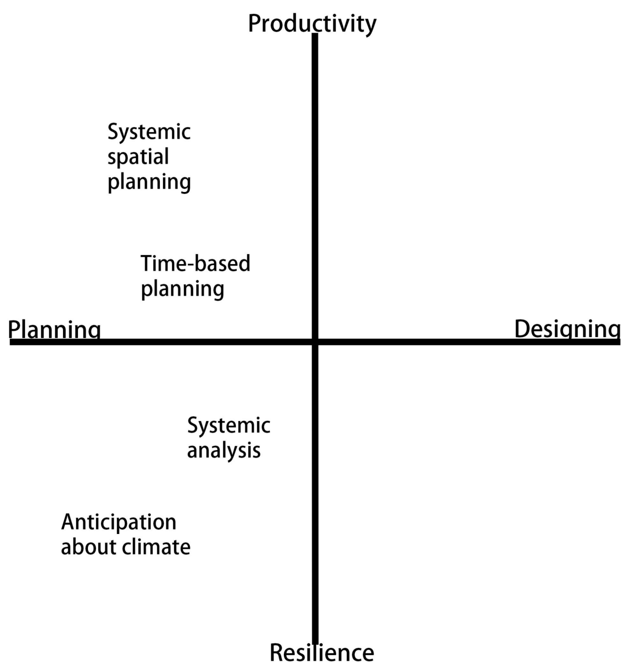


Figure 9. Evaluate the design approaches has taken in major design

From figure 9, it could be seen that there are four major design approaches I have taken in major design, includes systemic spatial planning, time-based planing, systemic analysis and anticipation about climate. Among them, systemic spatial planning and time-based planning are localized in the quadrant of productivity and planning, systemic analysis and anticipation about climate are localized in the quadrant of resilience and planning. Compare to this two quadrants, the quadrant of design are left empty. This means, the design approaches has been taken in MD are more focus in planning and less strong in assisting designing. Therefore, for harnessing the values expressed from wetlands under SLR from not only planning but also designing. The best-practice design patterns for wetlands in SLR are developed in chapter 4, which seeks to structure a design-based tool for wetlands design under SLR.

The four approaches have been taken in major design will also be used in the following chapters. The approach of systemic spatial planning will be conducted in a closer scale in the form of design patterns in chapter 4. The approach of systemic analysis will be conducted in the form of productive system in chapter 4. Anticipation about climate and time-based design will be combined into the approach of scenario development of SLR that will be used in chapter 5.

Chapter Four: Design Patterns for Wetlands in Sea Level Rise

4.1 Introduction

To discuss the best-practice design patterns for wetlands in SLR effectively, the location used to examine these design patterns needs to be confirmed in advance. After comparing different coastal zones in New Zealand, I found eastern Christchurch is a good choice of site selection for three reasons.

First, the earthquake on 22 February 2011 had significant impacts on both the local population and infrastructure, such as widespread building damage, liquefaction and landslides in the city of Christchurch (Kaiser et al., 2012). These changes in the landscape made a large area become void where are now unable to bear heavy structures (Van Ballegooy et al., 2014). Besides, Christchurch is vulnerable from the combined challenges from the earthquake and ongoing SLR (Risken, Fraser, Rutter, & Gadsby, 2015). However, the adverse impacts induced by the earthquake are also opportunities for landscape architects to review the context and look for alternative futures for this landscape in facing SLR (Copley et al., 2015). For example, these void zones could be used to increase the resilience of the city (Roggema, 2018), in this research, the void zones could be used for wetland restoration and development. Therefore, Christchurch not only has an urgent need to be prepared for SLR but also to undertake opportunities to implement innovative approaches in mitigating the adverse impacts of SLR.

Second, the 2011 earthquake severely damaged the economy of Christchurch (Parker & Steenkamp, 2012), and thus it will be impractical for the its city council to build expensive engineering defence to SLR. Besides, the New Zealand government discourages building hard engineering structures to defend against SLR, instead, it encourages alternative approaches including a retreating strategy (Bell et al., 2017). Therefore, it is more possible and practical for Christchurch city to implement wetland design as part of its retreating strategy to SLR.

Third, Christchurch is close to Selwyn District where are many intensified agricultural practices like dairy farming, which are responsible for leaching nutrients into water bodies

(Tait & Cullen, 2006). It has been found that these nutrients have a positive link to the productivity of wetlands (Ponnamperuma, 1984). Therefore, Christchurch is a good location for implementing productive wetland designs.

The key principles of wetland design under the SLR scenario are indicated through the literature review and then categorized into the two key aspects of wetlands design: resilience and productivity. Each of these key aspects is embodied with many terms, like "size" in resilience and the "food production" in productivity. Most of these terms are translated into design patterns to facilitate future designs of wetlands.

4.2 Resilient Wetlands

4.21 Introduction

The quadrant diagram for categorizing the key principles of resilient wetlands design includes four parts: size, depth, quantity and connectivity. This section provides suggestions on some general questions about wetlands design or how to design a resilient wetland.

4.22 Size

Water depth and space coverage of a wetland depends on the inputs and outputs of water resources (Zedler, 2000). It can be deduced that a larger wetland requires more water to sustain its hydrological condition and; thus, it will be good for designers to decide the size and depth of a wetland according to the existing water resources available, to achieve a self-sustaining wetland design, as shown in figure 10. Beside the existing water resources, the local evaporation rates of water should also be taken into consideration in the planning stage. For example, Christchurch is an arid city and its evaporation rate for water is high (McGann, 1983). Thus, the wetland design in Christchurch should involve calculating the water inputs and outputs to decide on the water depth and space coverage of a future wetland. However, since the invading sea water will transform coastal land, riverine wetlands and lacustrine wetlands into marine wetlands and estuarine wetlands that could directly use the sea as a water resource. Therefore, the water balance of the marine and estuarine wetlands is not a limitation for their size.

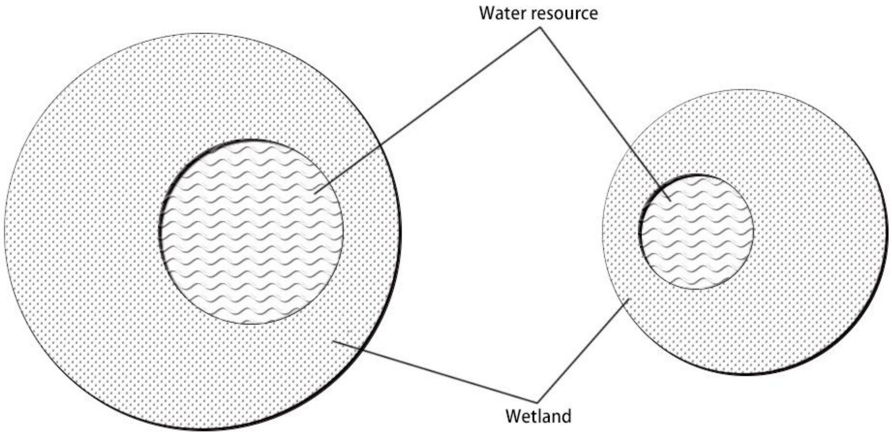


Figure 10. A large wetland requires more water input

Moreover, open water surfaces have a higher evaporation rate than vegetated wetlands (Mohamed, Bastiaanssen, Savenije, Van den Hurk, & Finlayson, 2012). So, instead of limiting the entire size of a wetland, water outputs from evaporation can also be controlled through replacing open water spaces by vegetated wetland surfaces, as shown in figure 11.

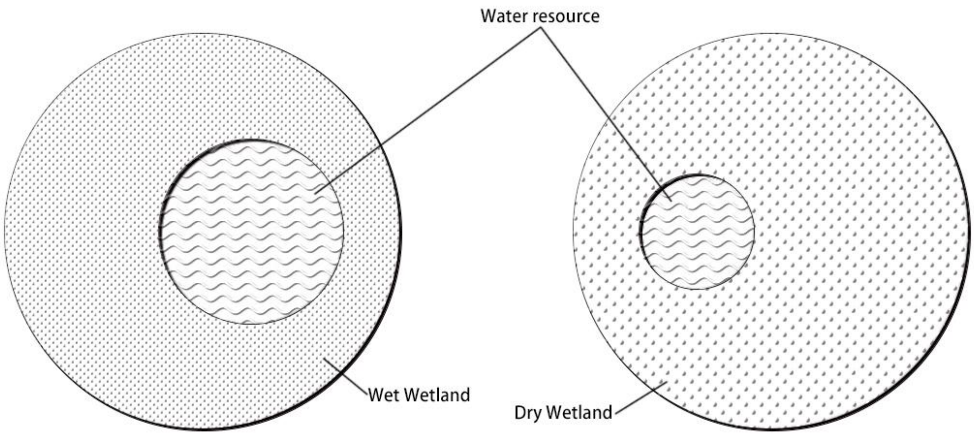


Figure 11. More water exposed space increases the need of water resources

Constructed wetland of 1% of the total catchment area of a farm can greatly cut down its nitrogen output (C. Tanner, Nguyen, & Sukias, 2005). This was mentioned by Vymazal who stated that more than 1% of constructed wetland in a catchment farm will not increase its nitrogen removal ability significantly (Vymazal, 2017), as shown in figure 12. This means constructed wetlands should be controlled within the most effective percentage of a farm, and the nutrient inputs and outputs should be calculated to achieve effective nutrient management.

Therefore, for wetland design, the space saved from having excessive constructed wetlands for purification can be developed to express other types of productivity like tourism and food production. Unlike a farm, the leached nutrients, waste-water or storm water in coastal zones of Christchurch, are hard to measure. Thus, this pattern is more useful for palustrine wetlands, especially for those focusing on food production and should not be applied on wetlands but into a larger hydrological system like marine, estuarine and riverine wetlands.

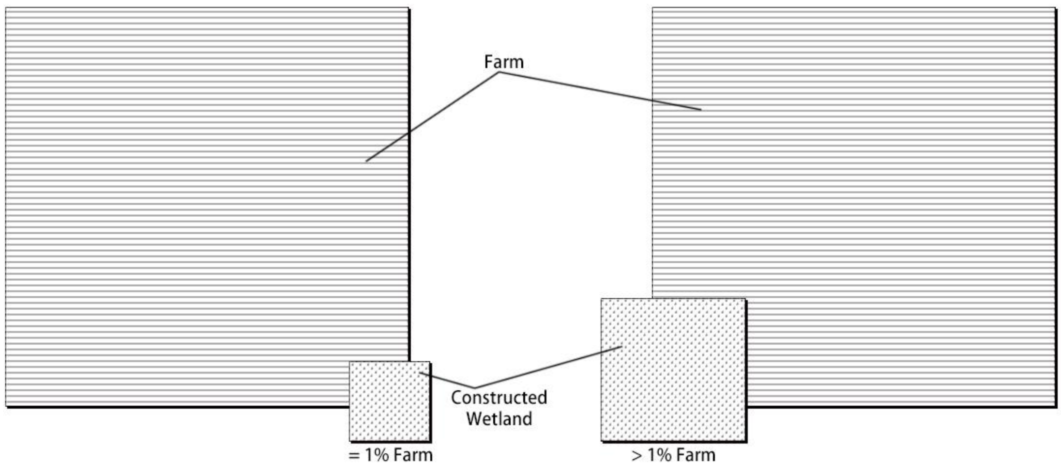


Figure 12. Percentage of constructed wetland for effective nutrient removal

4.23 Depth

Shallow soil (2.5-7.5 and 7.5-15 cm) has higher phosphorus absorption and higher phosphorus buffering capacity, thus the subsoil is critical in managing phosphorus release (Aye, Nguyen, Bolan, & Hedley, 2010). However, shallow wetlands are vulnerable to herding animals and a fence around a wetland is necessary (Robertson & Suggate, 2012). This idea is supported by (McKergow, Matheson, & Quinn, 2016) who highlighted that riparian planting and fencing are currently the best solution for protecting water quality and habitat restoration from herd animals. He then added that 96% of cows had been excluded from shallow water (>1 m and >30 cm) on dairy farms during the milking season (McKergow et al., 2016). In contrast with shallow wetland, deep wetlands (up to 2 m) could greatly reduce damage from herding animals, as stated by (Hughes, Tanner, McKergow, & Sukias, 2016), who further stated that a fence seems unlikely to neither protect cows from trampling in wetlands or improving downstream water quality in deep wetlands. Therefore, in shallow wetlands where close to herd animals, fences are required in the design, as shown in figure 13.

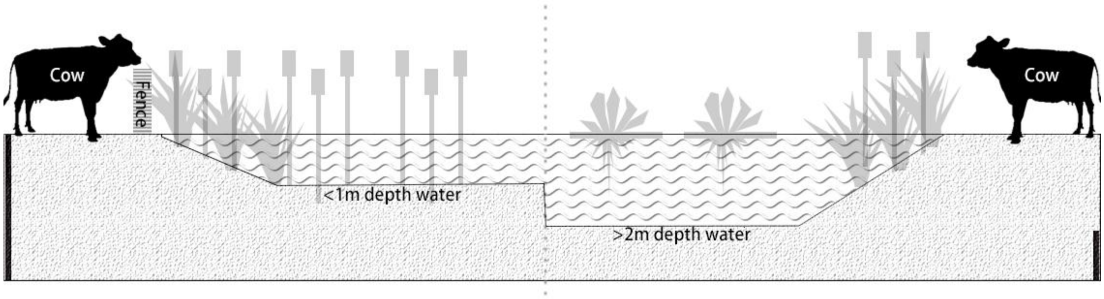


Figure 13. Shallow wetlands need to be fenced up from herding animals

Wetlands with changing water levels are fundamentally different from wetlands with stable water levels (Zedler, 2000). Thus, the hydrological regime needs to be confirmed in advance and the landscape architect needs to understand the transitional sequence of wetlands, that are responsible for the drier state of wetlands through accumulating residues, as shown in figure 14. This transitional sequence is likely to be accelerated in agricultural and urban areas with more nutrient outputs (Zedler, 2000). In addition, it also generates a different type of wetland where it provides various habitats that breed a diversity of animal communities, but the induced water level change is one of the most critical threats to these habitats (Zedler, 2000).

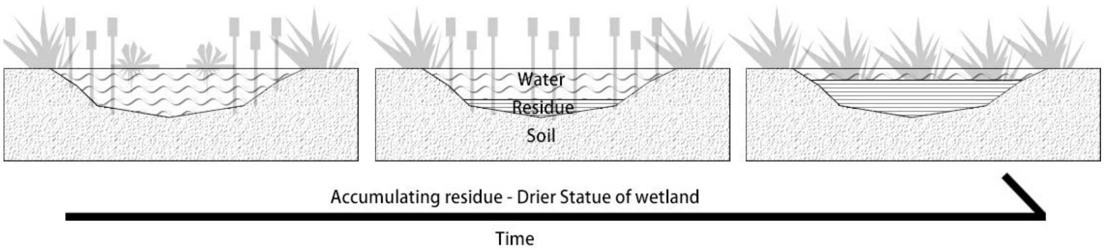


Figure 14. Transitional sequence of wetlands

Therefore, for wetlands with rare or endangered species, water level changes should be reduced to a minimum. To achieve this, first, the restoration of wetlands with high ecological values should be located on higher ground or in the hinterland to reduce water level changes induced by SLR. Second, design a deep wetland for having a longer life span.

4.24 Quantity

The conservation of wetlands should focus on large wetlands that provide many types of ecosystem services (McGlone, 2009). Besides, a large wetland usually contains multiple wetland types that carry more ecological value (Ausseil, Lindsay Chadderton, Gerbeaux, Theo Stephens, & Leathwick, 2011). Therefore, a large wetland could release more ecological ecosystem services than the same area of small divided wetlands, as shown in figure 15.

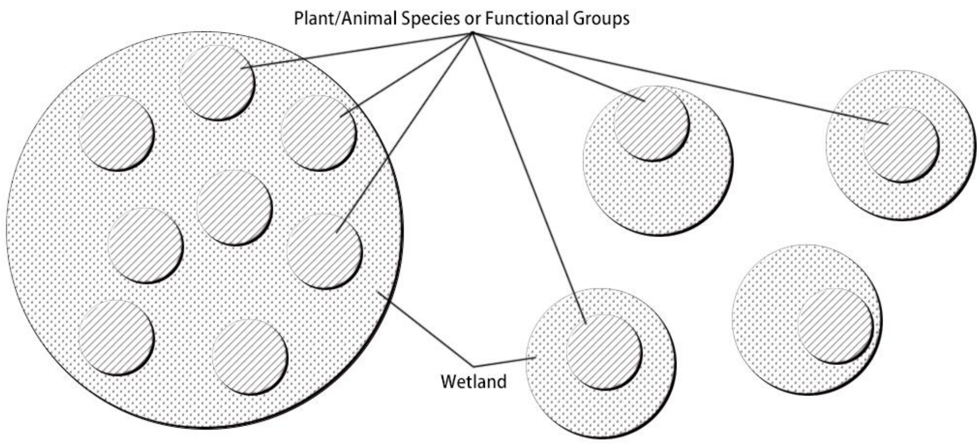


Figure 15. Large wetlands release more value than small wetlands combined in same space

4.25 Connectivity

However, a small wetland is valuable in protecting rare and threatened plant species (J. et al., 2015) and; thus, the unique ecosystem services of a small wetland should also be protected and enhanced. Because there is no official guideline to categorize a wetland as large or small, we should focus on the connectivity between wetlands. For example, many connected small wetlands could also contribute significantly to ecological ecosystem services (Bornette, Amoros, & Lamouroux, 1998). Moreover, the connectivity of wetlands is also important in mitigating the adverse impacts from floods (Karim, Kinsey - Henderson, Wallace, Arthington, & Pearson, 2012); improving nutrient removal ability (Racchetti et al., 2011) and increasing inshore fishery yields (Meynecke, Lee, & Duke, 2008). Therefore, the connectivity of wetlands is important for a wetland design to be more resilient and productive, as shown in figure 16.

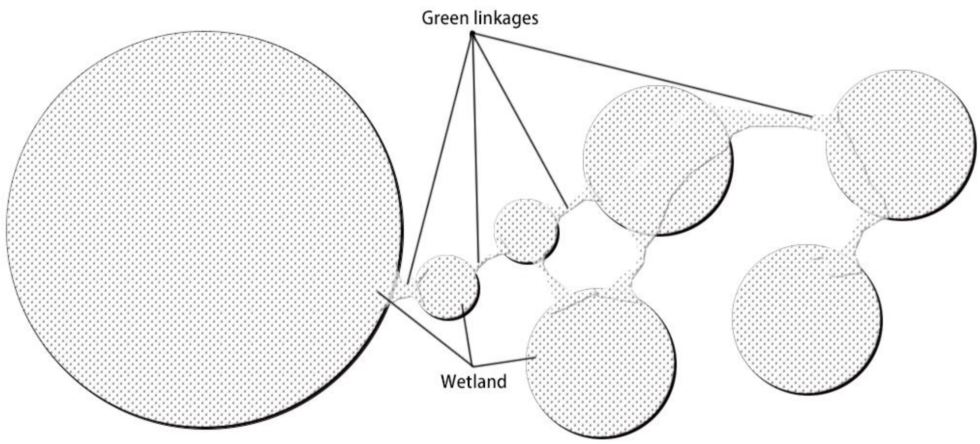


Figure 16. Connected wetlands release more ecosystem services than divided wetlands

Flexible and multi-functional wetland design could be adapted to different environments (C. C. Tanner & Kloosterman, 1997). This principle was primarily generated for the design of constructed wetlands, but it has the potential to be implemented within an urban context. This is because the urban zones are complex in nature and are more likely to provide many fragmented patches instead of a large patch (Salata & Yiannakou, 2016). To make effective use of these fragmented patches, the connectivity of wetlands is, thus, is very important for releasing the ecosystem services of wetlands into the urban fabric. Therefore, fragmented patches have the potential to be developed as connected wetlands for releasing more ecosystem services, as shown in figure 17.

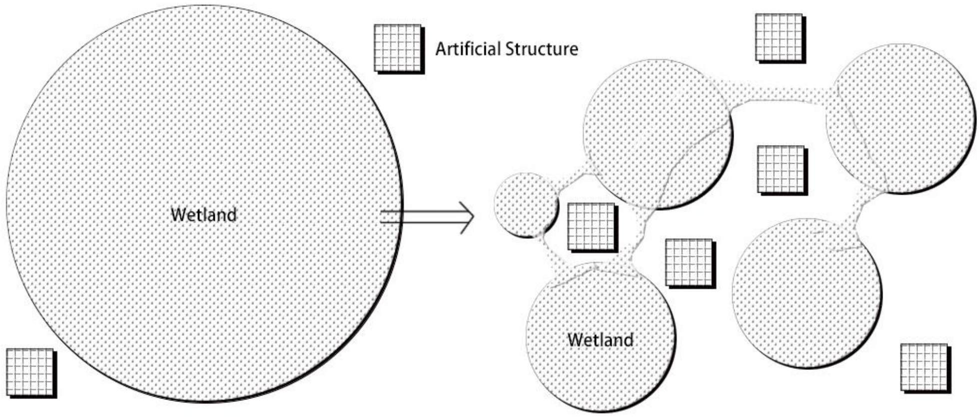


Figure 17. Connected fragmented wetlands are adaptive towards SLR

4.26 Migration

The magnitude of the change on shorelines under SLR depends on the existing morphology of the landscape. For example, a shoreline with a steep slope could be more resilient to SLR than that with a gentle slope (Runting, Lovelock, Beyer, & Rhodes, 2017). As one consequence of the interaction between a gentle shoreline and the ongoing SLR, estuarine wetlands will gradually migrate landwards (Passeri et al., 2015), as shown in figure 18. However, the development of coastal zones, like the extension of a coastal city, may hinder the migration of estuarine wetlands (Runting et al., 2017).

Therefore, the void space or corridor with a lower elevation or gentle slope is necessary for the landward migration of estuarine wetlands. In Christchurch, the void/empty zones generated by the 2011 earthquake and the riparian zones of the Avon River have great potential to be designed for the migration of estuarine wetlands.

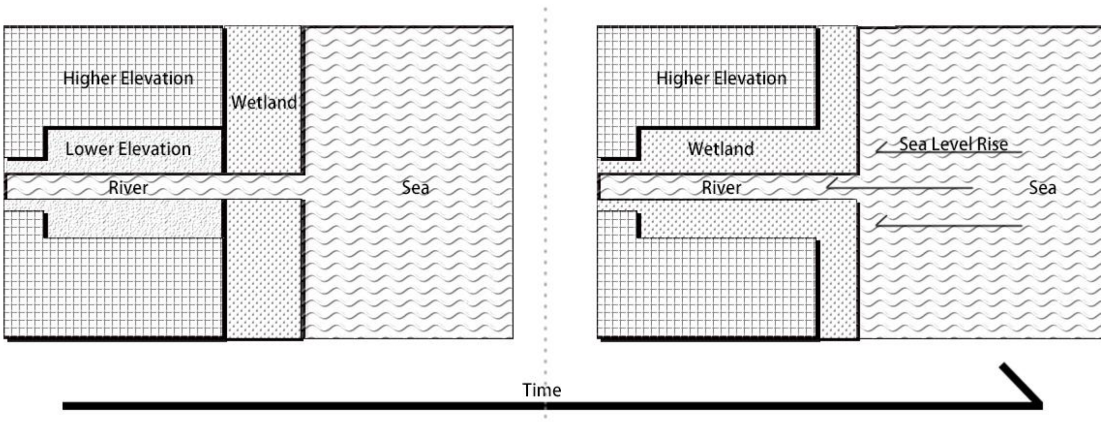


Figure 18. Migration of estuarine wetlands

SLR has a significant impact on the living organisms in wetlands (Nichols, 1989). The migration of estuarine wetlands could result in the replacement of the major plant species due to changes in the supply chain of ecosystems caused by the changing macro climatic conditions (Osland et al., 2016). Besides, the replacement of plant species in estuarine wetlands increases the decomposition rates of the soil organic matter (Mueller, Jensen, & Megonigal, 2016). Therefore, the estuarine wetland is not suitable for expressing ecological ecosystem services, instead, it is more suitable to be developed for nutrient removal purposes.

A mangrove forest, is one type of valuable estuarine wetlands grown in the tropics and subtropics, provides various ecosystem services like food, storm protection, carbon sequestration and storage (Ewel, Twilley, & Ong, 1998). It has the ability to keep pace with most of the predictions made on surface elevation changes caused by SLR (Sasmito, Murdiyarso, Friess, & Kurnianto, 2015). However, mangrove forests are threatened by human activities like coastal development and, thus its hydro-geomorphological setting may prove to be influential in the resilience of mangrove forest to SLR (Sasmito et al., 2015). For example, a basin mangrove forest with its more land-building ability is more resilient to SLR compared to the fringe of mangrove forests (Sasmito et al., 2015), as shown in figure 19.

The differences between basin mangroves and fringe mangroves for migration are helpful for other types of estuarine wetlands and, thus, the migration corridors of estuarine wetlands are better to be localized in the middle than at the rear.

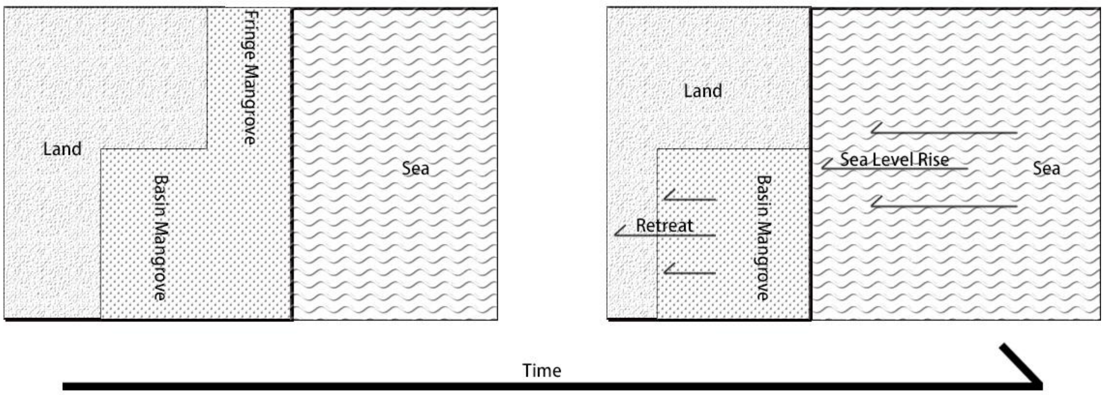


Figure 19. Basin wetlands are more adaptive for migration

In addition, ornamental plants growing on the landward edge of estuarine wetlands may also impede the migration process as they cannot migrate landward (Field, Gjerdrum, & Elphick, 2016), as shown in figure 20. However, ornamental plant species are also useful in wetland design for releasing more aesthetic and ecological values (Calheiros et al., 2015). Therefore, ornamental plants could be used in the inland wetlands, including riverine, lacustrine and palustrine wetlands, that will not impede the migration of estuarine wetlands.

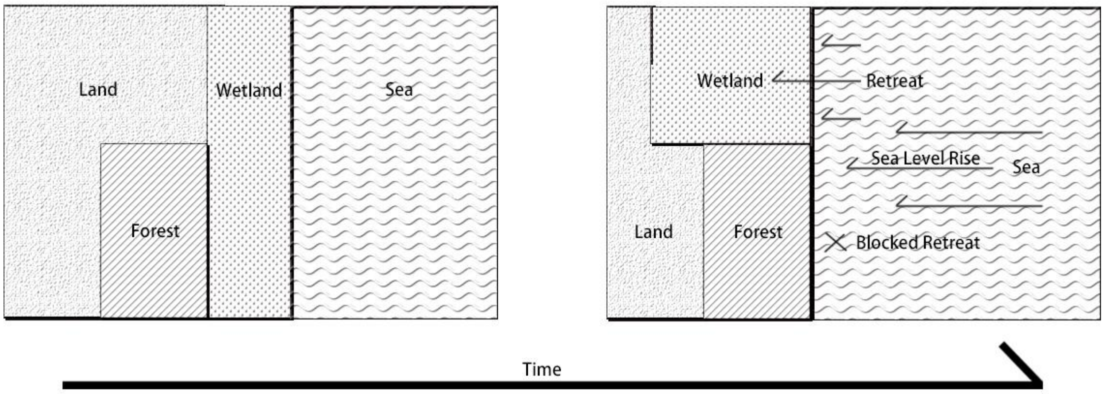


Figure 20. Forests could hinder the migration of estuarine wetlands

The substrate conditions are vital for the colonisation and development of a wetland (Zedler, 2000) and, thus, this should be examined as a priority in the planning stage. Moreover, a location that used to be a wetland generally has a suitable condition to be restored or developed as a wetland (Zedler, 2000).

Therefore, Christchurch as a coastal city, which was developed on a wetland, has great opportunities for wetland development under an SLR scenario. Specifically, coastal zones like eastern Christchurch are a good location for wetland development, as shown in figure 21.

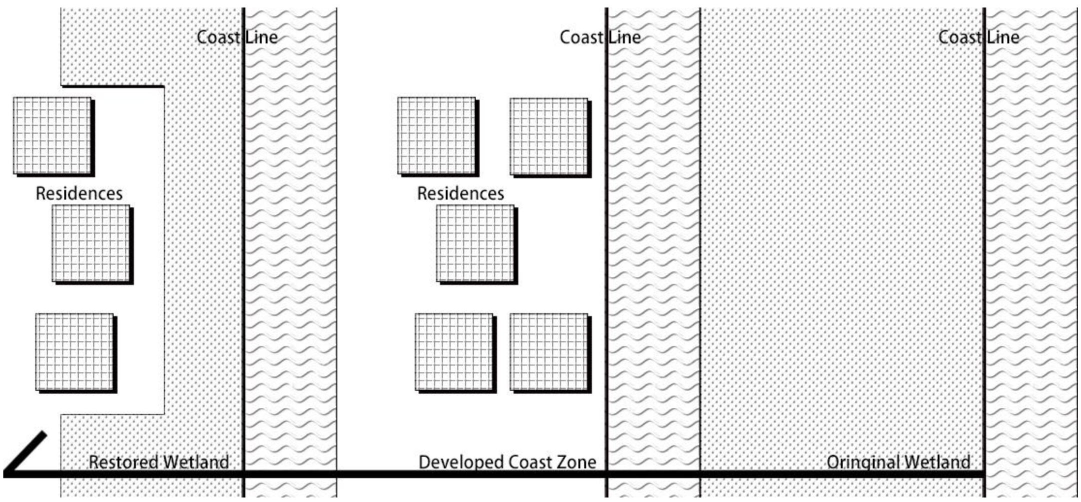


Figure 21. Historical opportunity for restoring wetland

4.27 Barriers

Storm surges induced by dynamic SLR are sensitive to the transformation of a coastal landscape that has the ability to amplify storm surges by over 80%, and decrease the level of storm surges by over 100% under the SLR scenario (Bilskie, Hagen, Medeiros, & Passeri, 2014). Particular, barrier islands could modify the flow direction of a storm surge, but do not significantly change the total amount of inundated area (Bilskie et al., 2014). Therefore, the construction of a barrier island is an effective way to mitigate the potential damage of storm surges induced by SLR, as shown in figure 22. Thus, this is very important to protect high-value coastal zones like the existing urban zones and the potential productive wetlands development in the future.

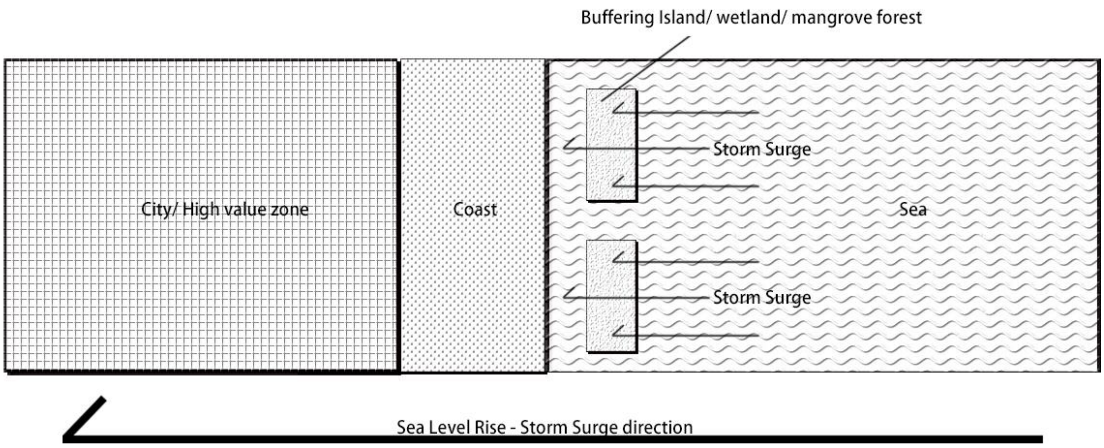


Figure 22.Barrier islands for amplifying storm surge

4.28 Bio-reactor

The protection, restoration and management of a wetland should review the wetland in a wider context to achieve a sustainable design and development (Zedler, 2000). For example, a riverine wetland usually plays the role of a bio-reactor between upstream and downstream, such as the pollution from the upper river could be absorbed by a riverine wetland (Fink & Mitsch, 2007), as shown in figure 23. In general, the riverine wetlands deal with the induced changes from upstream like pollution and storm water but, with SLR, the induced changes from downstream, like the increase on water level and salinity, also affects the functions of a riverine wetland (Bhuiyan & Dutta, 2012).

The design of a riverine wetland should consider both influence from upstream and downstream, and the function of the wetland should be planned in this big context. For Christchurch, Avon River is connecting the city from west to east and links to the sea. This makes the Avon river provides major locations for potential development of riverine wetlands.

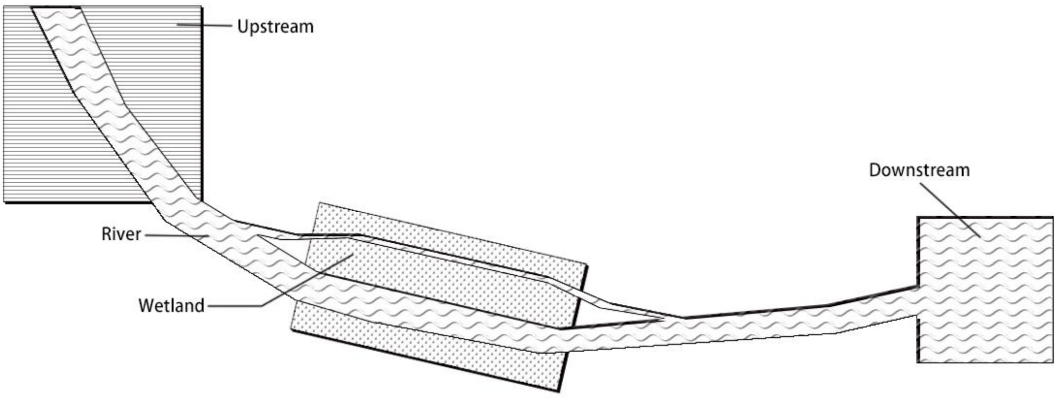


Figure 23. Riverine wetland as a bio-reactor between upstream and downstream

In addition, Semlitsch and Bodie (Semlitsch & Bodie, 2003) indicated that the zones surrounding wetlands are the core habitats for many semi-aquatic species. The core terrestrial habitat for amphibians ranged from 159 to 290 m and, for reptiles, ranged from 127 to 289 m from wetlands (Semlitsch & Bodie, 2003). Therefore, a transitional buffer between the riverine wetlands and residential zones would be useful to make the wetlands more resilient in performing habitat services for semi-aquatic species, as shown in figure 24.

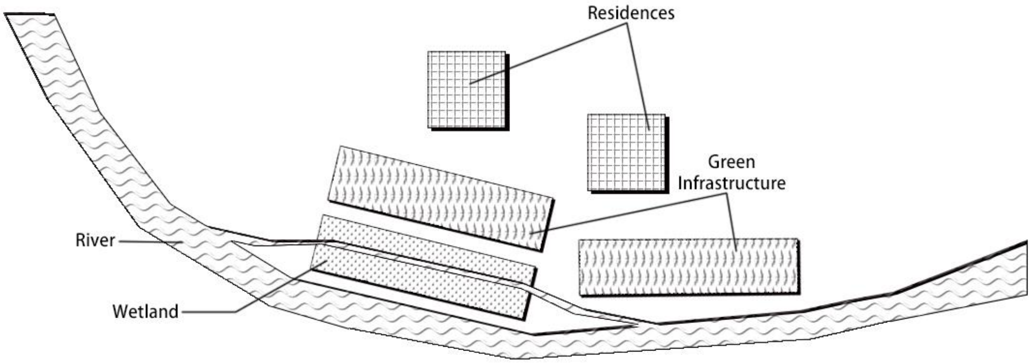


Figure 24. Transitional buff or improving ecological resilience

4.29 Floating Wetland (FTW)

A floating wetland (FTW) is a type of wetland design that has the most flexibility (Sukias, Yates, & Tanner, 2010). FTW not only could tolerate water level changes in slow-flowing water bodies (C. C. Tanner, Sukias, Park, Yates, & Headley, 2011) but also have a good ability in nutrient removal, especially for Cu and Zn (Borne, Fassman-Beck, & Tanner, 2014), as shown in figure 25. Therefore, a FTW could adapt to the migration of estuarine wetlands and the extension of marine wetlands caused by SLR. The FTW could be a supplementary method to improve the total ecosystem services of wetlands under a SLR scenario.

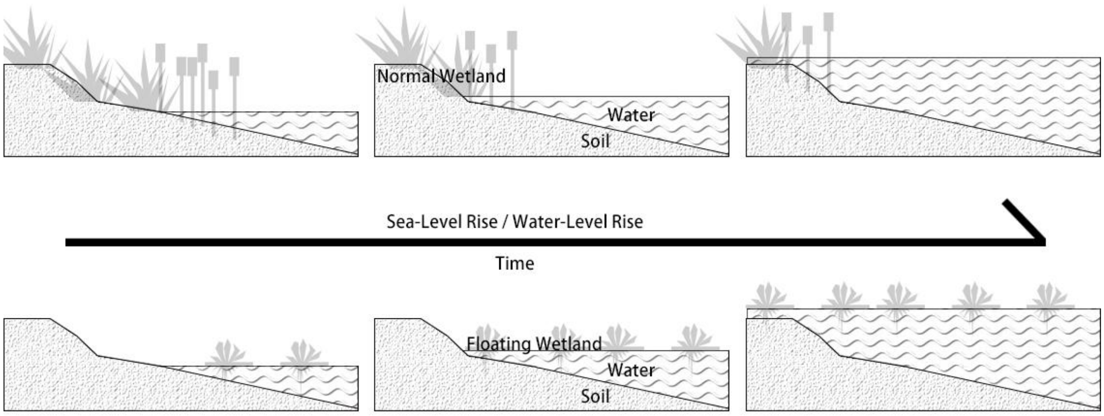


Figure 25. Floating wetland (FTW) is adaptive to sea-level rise

4.3 Productive Wetlands

4.31 Introduction

The quadrant diagram for categorizing key principles of productive wetlands design includes four parts: water purification, food production, tourism and housing. This section aims to provide suggestions about how to improve the productivity of wetlands under SLR in the planning stage. To improve the awareness of the public in protecting wetlands, economic incentives and financial compensation are required (Jones, Cocklin, & Cutting, 1995). This is supported by Whitby (Whitby, 2018) who states that the farmers are much more motivated to create wetlands that can earn income. Therefore, productive wetlands that could bring visible welfare are welcomed by the community.

4.32 Water Purification

The Waterways, Wetlands and Drainage guide from the Christchurch City Council (*CCC Web Waterways, wetlands and drainage guide*, 2018) indicated that constructed wetlands could treat storm water directly, but natural wetlands could only deal with pre-treated storm water. This idea was supported by Tanner (C. C. Tanner & Kloosterman, 1997) who highlighted that high diversity, low nutrients, pristine wetlands or wetlands with significant conservation values should not directly deal with the disposal of waste water. In addition, most wetlands in agricultural landscapes generally carry a relatively high nutrient level and this makes the wetlands there become more capable in treating waste water (C. C. Tanner & Kloosterman, 1997). Therefore, wetlands should play the main role in treating waste water and the nutrient removal ability of natural wetlands needs to evaluated for effective protection.

Constructed wetlands are very effective in water purification for nutrient removal and this ability could be further strengthened by placing different types of constructed wetlands together (Vymazal, 2010). Therefore, different types of constructed wetlands like the vertical constructed wetland, horizontal constructed wetland and floating constructed wetland could be used to enhance the total efficiency of nutrient removal according to the existing landscape, as shown in figure 26.

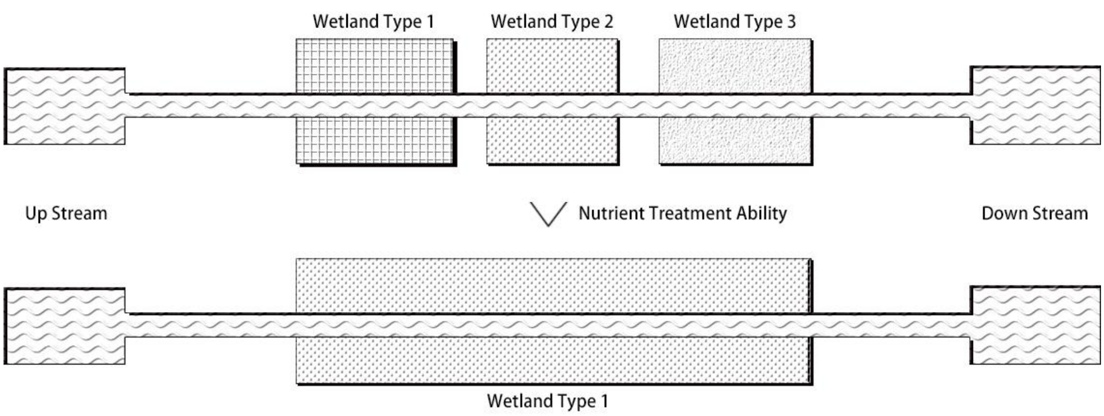


Figure 26. Different types of constructed wetlands combined have better nutrients removal efficiency than a single type of wetlands with same space

A simple system that integrates natural wetlands with denitrifying bioreactors could greatly improve nutrient removal ability with relatively low energy inputs (C. C. Tanner, Sukias, Headley, Yates, & Stott, 2012), as shown in figure 27. The nutrient removal ability could be further enhanced by integrating a pre-treatment component into the constructed wetland, but also with a higher energy input, suitable for treating high effluent waste water (Lin et al., 2015). Therefore, a constructed wetland could be applied in a natural wetland to improve its nutrient removal efficiency and the combination of pre-treatment components, constructed wetlands and natural wetlands could greatly improve its nutrient removal ability.

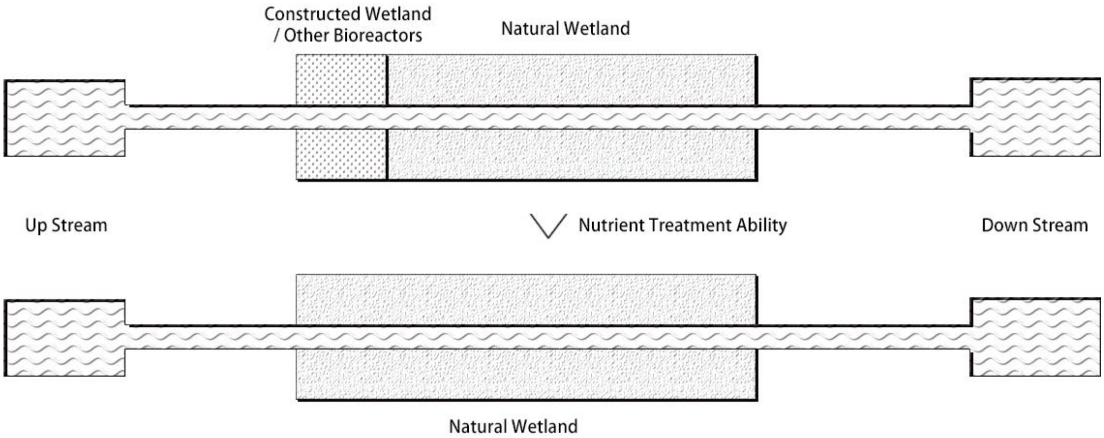


Figure 27. Combination of natural wetland with bioreactors could enhance nutrients removal ability with a relatively low energy input

The economic efficiency in nutrient removal could be greatly improved by managing the critical pollution sources (R. McDowell et al., 2014), as shown in figure 28. This was supported by Uuemaa, who further indicated that putting a small seepage wetland in the headwater of a stream was an effective way for nutrient removal (Uuemaa, Palliser, Hughes, & Tanner, 2018), as shown in figure 29. Therefore, the site selection of a wetland for water purification should be close to the sources of pollution to achieve a higher efficiency.

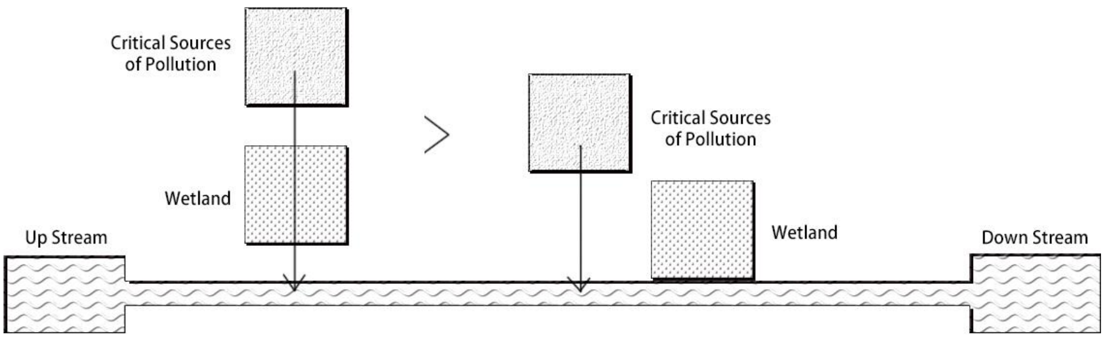


Figure 28. Manage pollution sources could improve the efficiency of nutrients removal

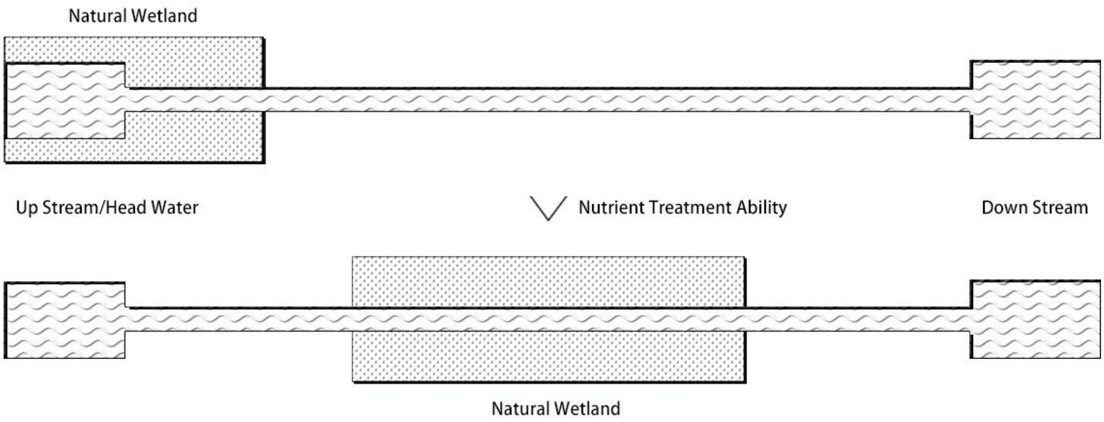


Figure 29. Seepage wetland in the head water is effective in nutrients removal

In addition, It will be more cost-effective and faster to focus on one specific nutrient rather than take all nutrients as removal targets (R. W. McDowell et al., 2017). But, then, they added that the co-benefits of nutrient removal for non-target nutrients or other pollution will be limited in this practice.

4.33 Food Production

Camacho-Valdez indicated that in their study, a 14% area decrease in salt marsh and a 12% area increase in shrimp ponds increased the annual value of the flow by 9% from $215 to $233 million (2007 USD) over ten years (Camacho-Valdez, Ruiz-Luna, Ghermandi, Berlanga-Robles, & Nunes, 2014). Moreover, aquaculture was proven to have a win-win relationship with the constructed wetlands by Turcios who further highlighted that constructed wetlands could cost-effectively treat waste water and support in recirculating aquaculture systems (Turcios & Papenbrock, 2014). This was supported by Ni who noted that constructed wetlands were a good way to balance the watershed ecosystem and economic development, and then release more value from wetlands as a whole (Ni, Xu, & Zhang, 2016).

Also, rice paddies as one type of constructed wetland could integrate with agriculture in releasing more productivity while controlling pests (Berg, Söderholm, Söderström, & Tam, 2017) and this has created a win-win relationship with aquaculture (Frei & Becker, 2005). The local community could also benefit from this practice in many aspects like the economy, health and environment (Berg et al., 2017). Moreover, Walton added that aquaculture could be used to mitigate the loss of wetlands for historical reasons and generate more ecosystem services (Walton, Vilas, Cañavate, et al., 2015). Therefore, an integrated wetland system, including natural wetlands, constructed wetlands, aquaculture and agriculture, has the potential to improve the economic benefits, food resilience, public health and ecological resilience of a local community.

Turcios introduced two profitable system “Fish–phytoplankton–shellfish systems convert the fish waste into bivalves, which have a large global market value” and “Fish–seaweed–macroalgivore systems have a choice of marketing either the seaweed or the macroalgivore, while they use less land than the fish–phytoplankton–shellfish systems and maintain a more stable water quality” (Turcios & Papenbrock, 2014), as shown in figure 30. These two aquaculture practices could generate extra income from the water with no extra cost. Therefore, the ecosystem system of species in aquaculture practices is important for generating more economic value, effectively and ecologically. Different classes of these species should be reviewed and designed within this entire system.

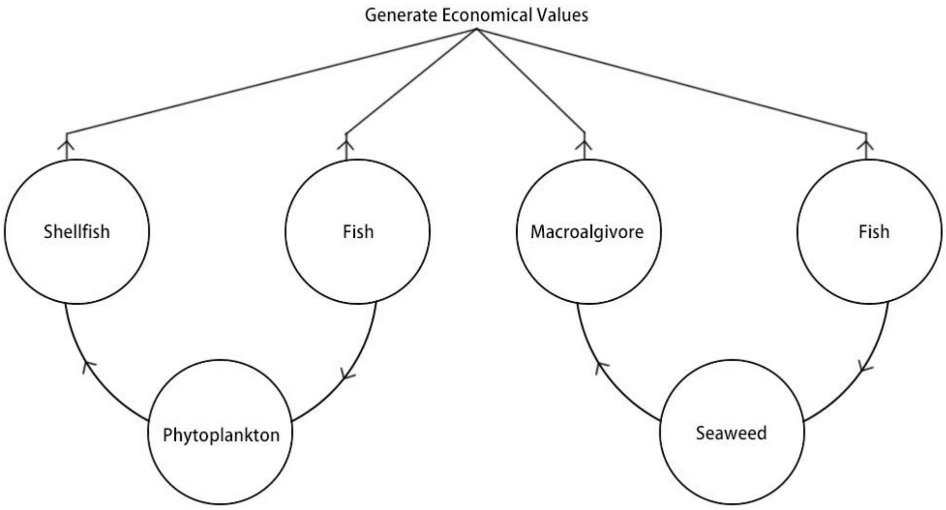


Figure 30. Fish-seaweed-macroalgivore systems and fish-phytoplankton-shellfish systems

For the selection of aquaculture species, Lin undertook research showing that the total income from aquaculture could be greatly increased by switching from low-priced species to high-priced species (Lin et al., 2015). In a six-year observation, the annual income become 2.6 times greater from a lower annual fish yield and the clarity of water greatly improved from 61 cm to 111 cm (Lin et al., 2015). Therefore, the selection of high-value species in aquaculture could be expressed in more productivity from wetlands with a lower pollution output, as shown in figure 31.

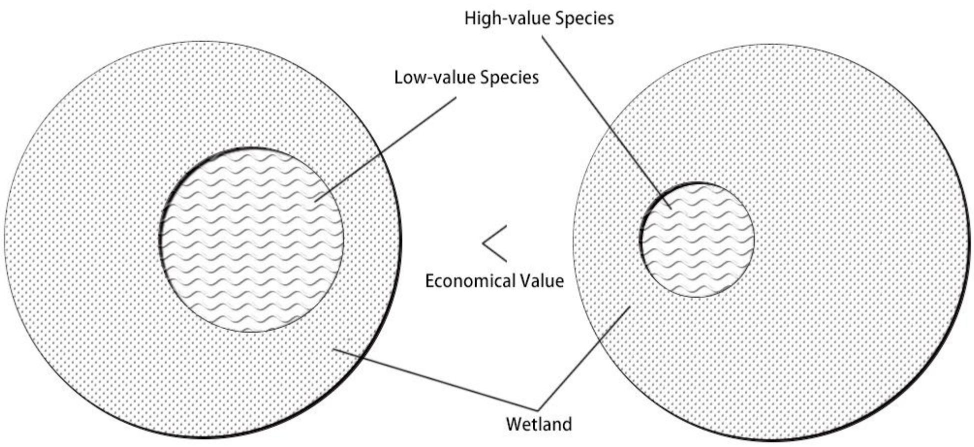


Figure 31. High-priced agricultural species could better balance the productivity and resilience of a wetland

In addition, Walton added that a higher water exchange could result in a higher productivity in extensive aquaculture practices (Walton, Vilas, Coccia, et al., 2015). Therefore, flowing water is good for aquaculture production and, thus, natural constantly flowing water bodies like rivers and the sea could be used to increase the water exchange rate through design interventions like landform design or water flow regulation.

The Paddy Eco-ditch and Wetland System (PEDWS) was designed for rice production while controlling the leaching of nutrients like nitrogen and phosphorus (Xiong, Peng, Luo, Xu, & Yang, 2015), as shown in figure 32. In their design, the infrastructure is easy to build, no energy input is required and most of the leaching nutrients are collected in wetlands. Even if rice production is not suitable for Christchurch, the pattern of PEDWS could still be used for wetland design.

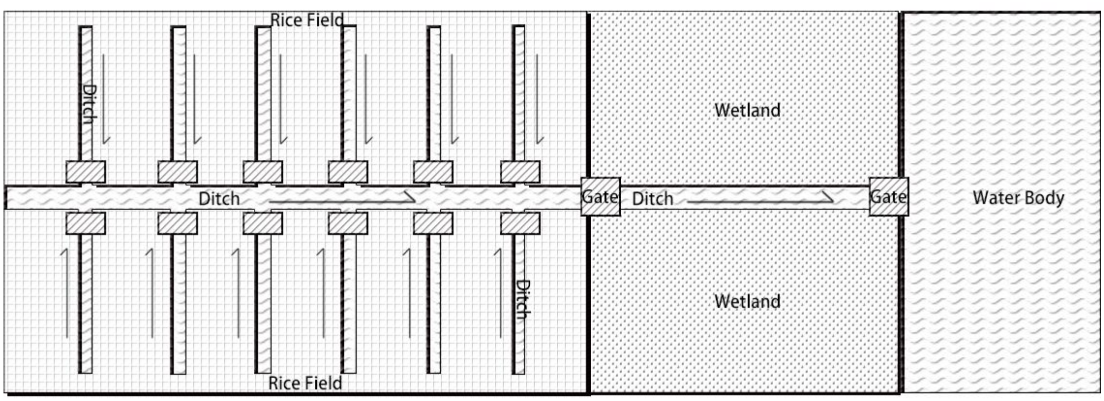


Figure 32. Paddy Eco-ditch and Wetland System (PEDWS)

4.34 Tourist Attraction

Wetland tourism could play an important role in increasing the awareness of wetland protection (Do, Kim, Kim, & Joo, 2015). It is necessary to properly plan and manage wetland tourism to make it succeed and widely benefit the local community (Sharma, Rasul, & Chettri, 2015). In Khoshkam's research, the distance away from tourist destinations, residency length of the tourists and the size of local families were found to positively relate to the attitudes towards the economic impacts of wetland tourism development (Khoshkam, Marzuki, & Al-Mulali, 2016). Therefore, the residential zones of local communities should be separated from the tourist zones of wetland tourism.

The SLR will increase the frequency of coastal storms that will cause huge damage on the coastal transport infrastructure (Dawson, Shaw, & Roland Gehrels, 2016). Besides, many ecosystems of wetlands are also vulnerable to anthropogenic disturbance (Ellison & Farnsworth, 1996). Therefore, tourist infrastructures should be planned carefully to mitigate the adverse impacts of SLR and tourist development. There are some suggestions on the pedestrian trail of wetlands from The <Waterways, wetlands and drainage guide> from Christchurch City Council (*CCC Web Waterways, wetlands and drainage guide*, 2018):

1) Signage and interpretation: clearly outline the desirable and expected behaviour.
2) Formed tracks and boardwalks: locate these away from sensitive areas.
3) Fences: simple post and wire fences can effectively isolate sensitive areas.
4) Shrub planting: densely planted shrub associations provide shelter and screening for wildlife islands and moats: these provide both refuges and nesting sites for wildlife. Note that some predators are not deterred by water.

4.35 House Development

As identified earlier stilt houses are a common and enduring building form that people have used to allow them to leave in and near wetlands. However, since house development is not a common focus in the field of landscape architecture, house development will not be a primary focus in this research into the productivity of wetlands. Therefore, it is applied as a supplementary component in the generation of adaptive strategies to SLR.

4.4 Systems of Productive Wetlands

In this section, design patterns of “productivity” are integrated into systems that release the following types of productivity: purifying water, producing food and generating tourism value. These systems will then be used with the design patterns of “resilience” in the generation of scenario-driven adaptive strategies. The three systems discussed in this section are all developed from the design patterns for wetlands under SLR, but they are also applicable to fresh water bodies with a few minor changes, as indicated.

The system of food production in productive wetlands is shown in figure 33. The leached nutrients from both aquaculture in fresh water and agriculture are channelled to the bio-reactor with food production ability. For example, the organic wastes from eel production and the leached nutrients from traditional agricultural practices like farming and herding could be used to fertilize the paddies for rice production or algae for feeding shrimp, and crabs and omnivorous fish, to transfer the excessive nutrients into food for humans. For the selection of aquaculture species, in one part “Aquaculture in fresh water” should be chosen based on their economic value and in the another part a “bio-reactor” should be chosen primarily based on their water purification ability. In addition, the bio-reactor should be planned to be larger than the current need to adapt to the uncertain future. The pre-treated waste water from the bio-reactor and aquaculture will, then, be channelled into the constructed wetlands for further purification before flowing into the sea or other type of water bodies. The aquaculture species in the part “Aquaculture in salt water” should be chosen based on their economic value and market performance. Since a constructed wetland is flexible, the detailed design of it should consider the size of site and the amount of effluent output to achieve the desired water quality. Moreover, this system could also be applied in a complete fresh water body by removing the part “Aquaculture in salt water”.

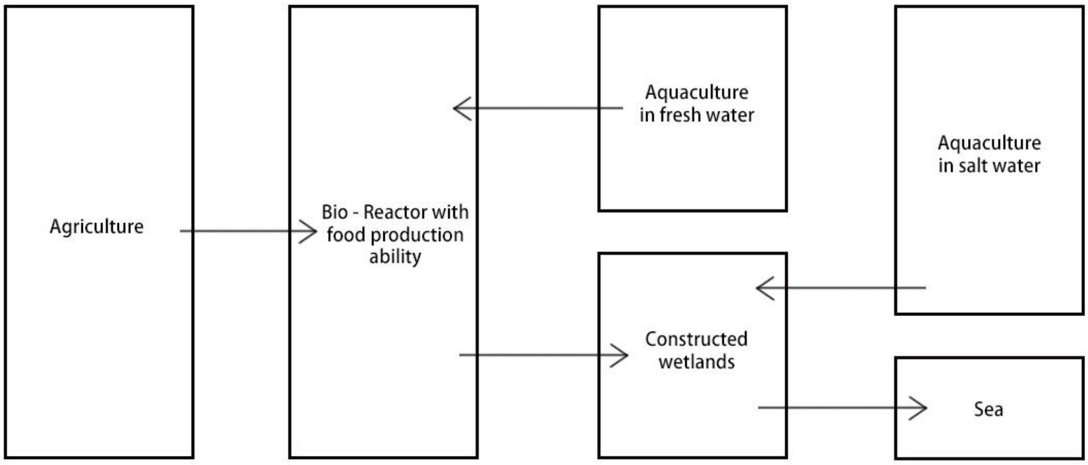


Figure 33. Productive system of wetlands - food production

The system of water purification in productive wetlands is shown in figure 34. The water input into the wetland zone will first be purified in the seepage wetlands in the upper stream and then channelled into the river/water channel of the riparian wetlands. The non-point pollution from residential and commercial users will also flow into riparian wetlands before entering the river/water channel. In addition, tree plantations are used here to divide the residential/commercial zones and the wetlands to protect their ecological values from anthropogenic disturbance. Significant pollution sources should be indicated and the constructed wetlands then used to treat the waste water generated from them, possibly, at a close range. Finally, all water flowing through the riparian wetlands will be channelled into the constructed wetlands before flowing into the sea or another water body, to control the water quality.

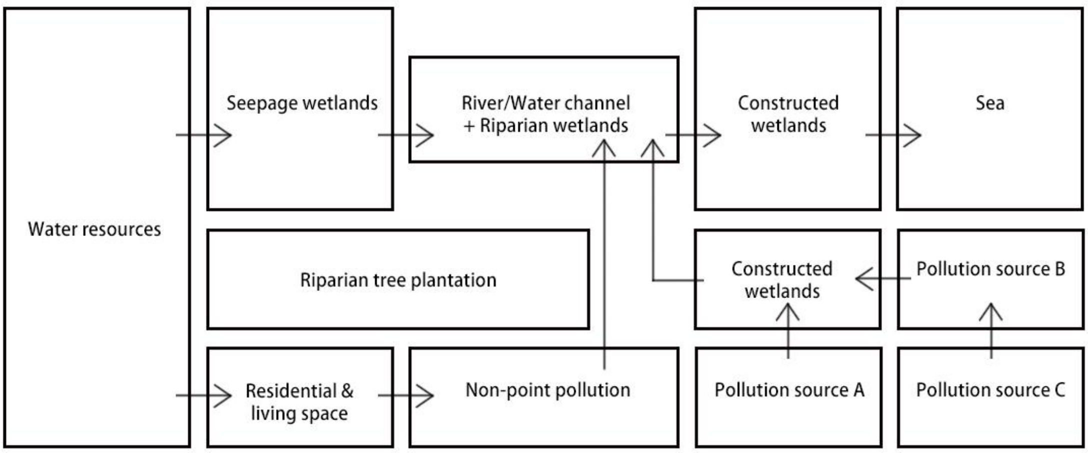


Figure 34. Productive system of wetlands - water purification

The system of tourism attractions in productive wetlands is shown in figure 35. The residential zones of the local community should be separated from the tourist zone to improve residents' attitudes towards the impacts of wetland tourism development. The waste-water from the two types of zones, above, will be connected to constructed wetlands before entering the sea or another type of water body.

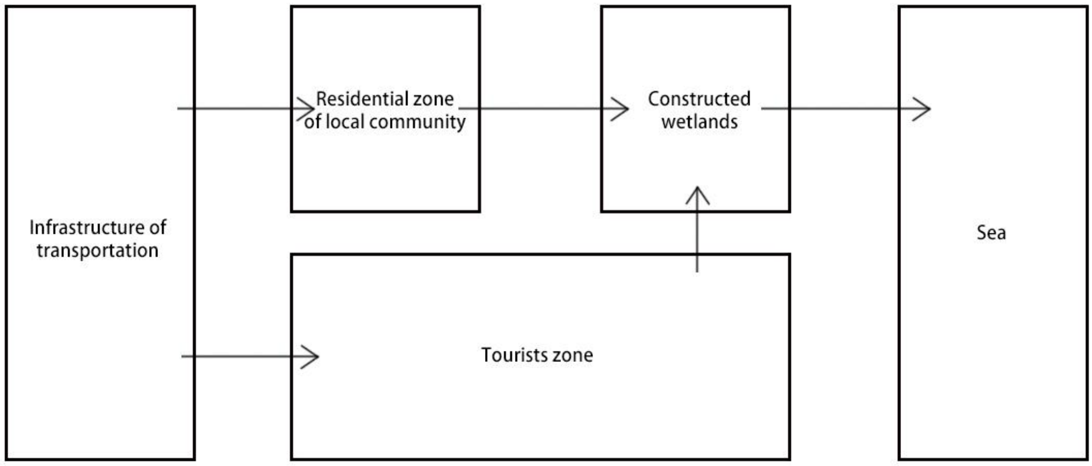


Figure 35. Productive system of wetlands - tourism

4.5 Conclusions

In this chapter, the design patterns of productive and resilient wetlands are transformed from best-practice design guidelines and other relevant resources from the literature review. Among them, the design patterns of productive wetlands are integrated into productive systems that could be more effectively included in the design. Both resilient design patterns and productive wetland systems will be examined on eastern Christchurch to generate adaptive strategies for wetlands under a SLR scenario.

Constructed wetlands are simplified versions of the natural wetlands used to purify water (C. C. Tanner, Kloosterman, & Champion, 2006) but could also be used for food production, such as using leaching nutrients for the production of rice (Li et al., 2002; Zhou & Hosomi, 2008). In recent years, food-producing wetlands have also been recognized as a type of constructed wetlands (Watanabe, 2018; Yang & Zhu, 2013). Therefore, for identifying different types of productivity that could be expressed, the approaches to wetland design are categorized into natural wetlands, constructed wetlands for food production and constructed wetlands for water purification. Among them, natural wetlands are coloured green, constructed wetlands for water purification, coloured blue, and constructed wetlands for food production coloured red, as shown in figure 36.

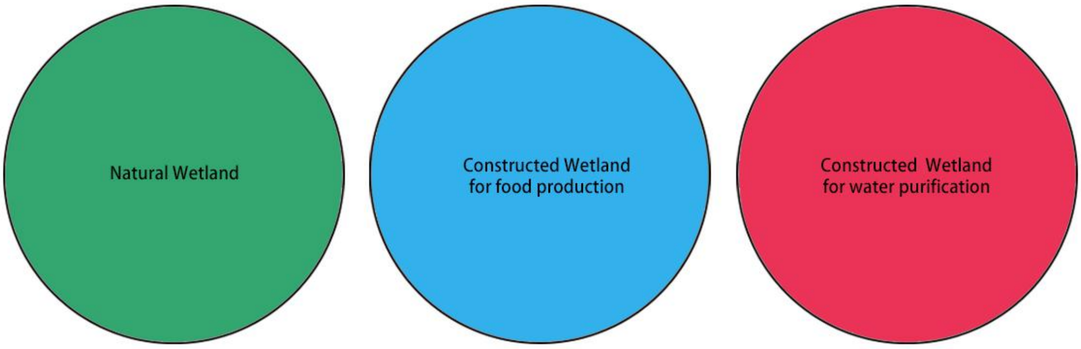


Figure 36. Three types of productivity that could be released from wetlands

Besides the values that could directly be expressed from each type of wetland, the junction zone between any two types of wetlands reveals opportunities for releasing different values including economic, ecological and social values that have been concluded in research placement (Tan, 2018), as shown in Appendix B.

The junction zone of constructed wetlands for food production and water purification show great potential for releasing economic value through practices, such as by using constructed wetlands to treat the leaching nutrients generated from intensified agriculture and aquaculture (C. Tanner et al., 2005; Turcios & Papenbrock, 2014), as shown in figure 37.

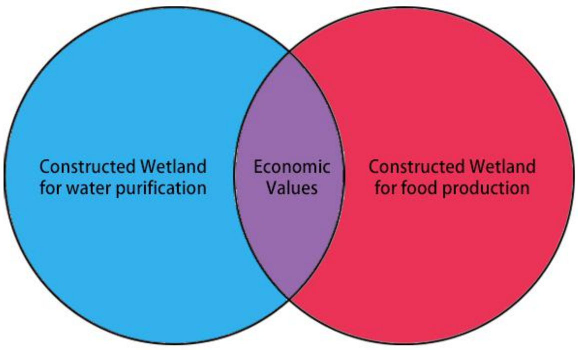


Figure 37. Junction zone of wetlands for releasing economic values

The junction zone of the constructed wetlands for water purification and natural wetlands show great potential for releasing ecological values though practices like restoring a native wetland while using constructed wetlands to treat the waste water generated from the living spaces of humans (Hammer, 1989; Stottmeister et al., 2003), as shown in figure 38.

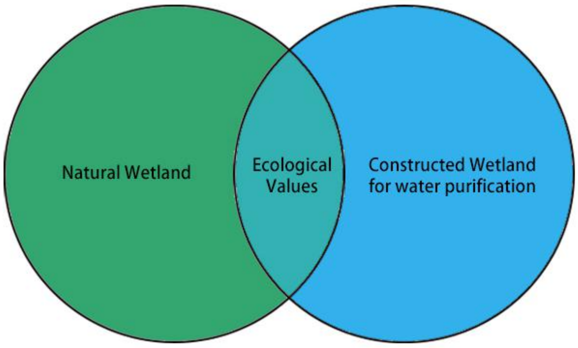


Figure 38. Junction zone of wetlands for releasing ecological values

The junction zone of constructed wetlands for food production and natural wetlands show a great potential for releasing social values through practices, such as, restoring the traditional methods of food gathering like cultural harvesting by Maori (Robb, 2014; Wehi & Lord, 2017), as shown in figure 39.

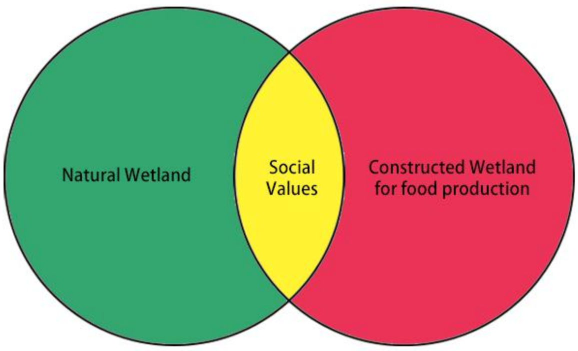


Figure 39. Junction zone of wetlands for releasing social values

There are more examples of practices that could express values from the junction zones of different types of wetlands and they will be indicated in the next chapter. However, from the literature review and the research placement (Tan, 2018), as shown in Appendix B, it can be seen that most of the study's focus is on releasing economic and ecological values, rather than social values. The reason is that social values are hard to be engineered or measured, and many of them are built on the foundation of economic values or ecological values. In a design sense, social values could only be released after a deep exploration of the tangible values. In other words, with more exploration of the economic and ecological values, more social values could be revealed and then released through design practices, as shown in figure 40.

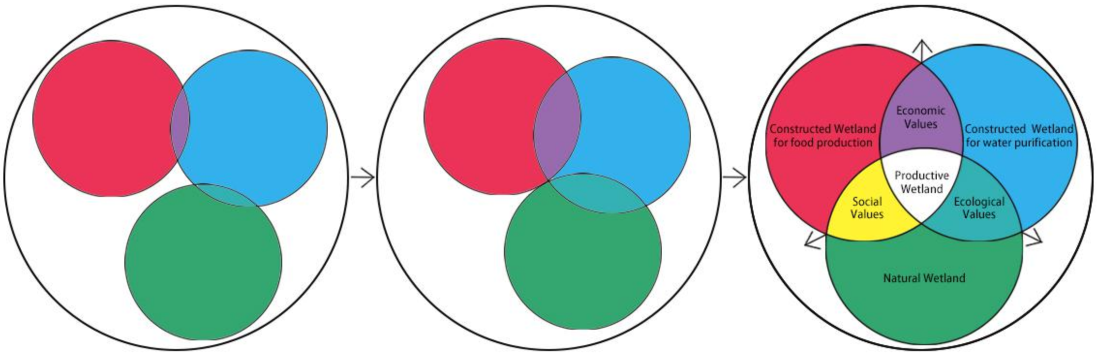


Figure 40. Identifying more values through overlapping different productive wetlands

The final diagram to conclude the findings, above, is shown in figure 41. The three types of values generated from the junction zones in this diagram are used in generating adaptive strategies for SLR in the next chapter.

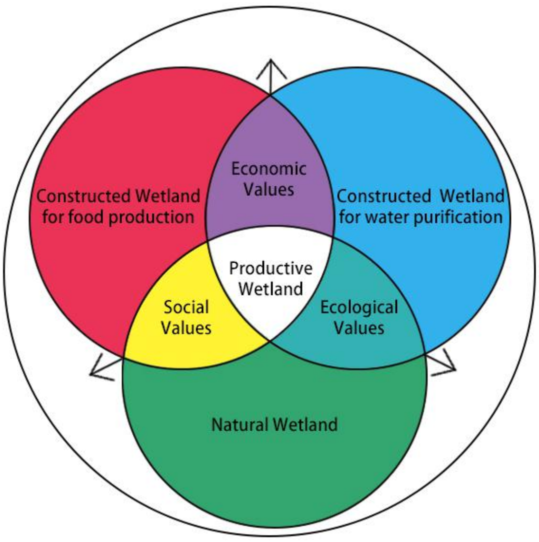


Figure 41. Diagram for identifying the values that could be expressed in wetlands design

Chapter Five: Scenario-driven Adaptive Strategies for Wetlands in Sea Level Rise

5.1 Introduction

The existing guidelines and adaptive strategies for SLR appear general in nature and require more detailed translation into landscape architecture design practice. This chapter aims to translate the key principles reviewed and the generated design patterns to adaptive strategies from the perspective of landscape architecture. More particularly, designs with different focus were developed for a common site (eastern Christchurch) in a sequential scenario to ask what range of design forms for wetlands could be generated to mitigate the adverse effects of SLR through design interventions. The systems of productive wetlands and the design patterns of resilient wetlands are applied in this section to generate adaptive strategies for wetlands in SLR through scenario development. There are three steps to achieve this goal:

1. Select a study zone within eastern Christchurch.
2. Investigate the site with analytical maps.
3. Generate adaptive strategies with different focus on the sequential scenario.

5.2 Site Selection in Eastern Christchurch

Aligning with Copley’s work (2015) Eastern Christchurch is also chosen as the site for generating adaptive strategies for wetlands under SLR. Three sites are considered: Kaiapoi, Bottle Lake Forest Park and New Brighton. There are four categories of site selection among them. The first category is a low elevation, so the impacts of sea level rise can be more effectively demonstrated. The second category is the presence of an existing wetland, so how can the existing wetlands be integrated into the new wetland design could be discussed. The third category is diverse contexts, so the combination and transformation between different contexts can be illustrated further. The fourth category is cultural values, which can be used to develop other values. The above categories of site selection are used to examine the three sites in eastern Christchurch, as shown in table 6.

Table 6. Category of Site Selection

No.	Category of Site Selection	Kaiapoi	Bottle Lake Forest Park	New Brighton
1.	Low elevation	√		√
2.	Existing wetlands	√		√
3.	Diversity of contexts	√	√	
4.	Cultural values	√		√

Based on the results of above the categories, Kaiapoi in eastern Christchurch is selected, as shown in figure 42. First, the site is located at a low elevation and; thus, the impacts of SLR are more significant. Second, the site has existing natural wetlands and a constructed wetland, that could be used to show how to incorporate the existing wetlands within the proposed wetland system. Third, the site is located in the junction zone of sub-urban and rural contexts and, thus, this site is referenced to both contexts. Fourth, the site carries cultural significance for Maori so that reveals opportunities for releasing social values.

Figure 42. Site Selection in eastern Christchurch for examining design approaches

5.3 Analytical Maps

5.31 Introduction

To investigate future opportunities in a landscape under a SLR scenario, a comprehensive understanding of the existing context, existing challenges and future challenges is necessary. Among different kinds of information, six types of analytical maps show strong relevance for releasing productivity of the wetlands under SLR.

The existing context in this research consists of district plans and an existing aerial and underground wetland map that shows the patterns of human activities. In the district plan, as shown in figure 43, the public open spaces coloured green are suitable for wetland development; special purpose zones are coloured grey, were created after the Christchurch Earthquakes in 2011. These zones are not suitable for founded housing development; rural zones coloured blue are for conducting intensified agricultural practices, which generally leach nutrients; residential zones are coloured red, where the community needs to be replaced under the scenario of SLR; business zones are coloured yellow, which generally carry a high economic value that make them expensive to be replaced.

5.32 District Plan

From figure 43, it can be seen that the existing public open spaces are connected from Bottle Lake to Brooklands and from the Brooklands Spit where the surrounding existing estuarine wetland, to the riparian zones of Waimakariri River that leads to the hinterland. Thus, the public green space could be used for wetland development, restoration or retreat. Besides, the special purpose zones created by the earthquakes are adjacent to the public open spaces and, thus, could also be incorporated into the wetland design with public open space. The main residential zones are located in Kaiapoi, Bottle Lake, Kainga, the Pines Beach and Kairaki. Among them, the communities in Kairaki, the Pines Beach and Bottle Lake are close to the sea and are more likely to be inundated by sea water that could lead to community replacement or transformation. The two major business zones are located at Chaneys and the centre of Kaiapoi, which are relatively distant from the coast; thus, they are less concerned in this design practice.

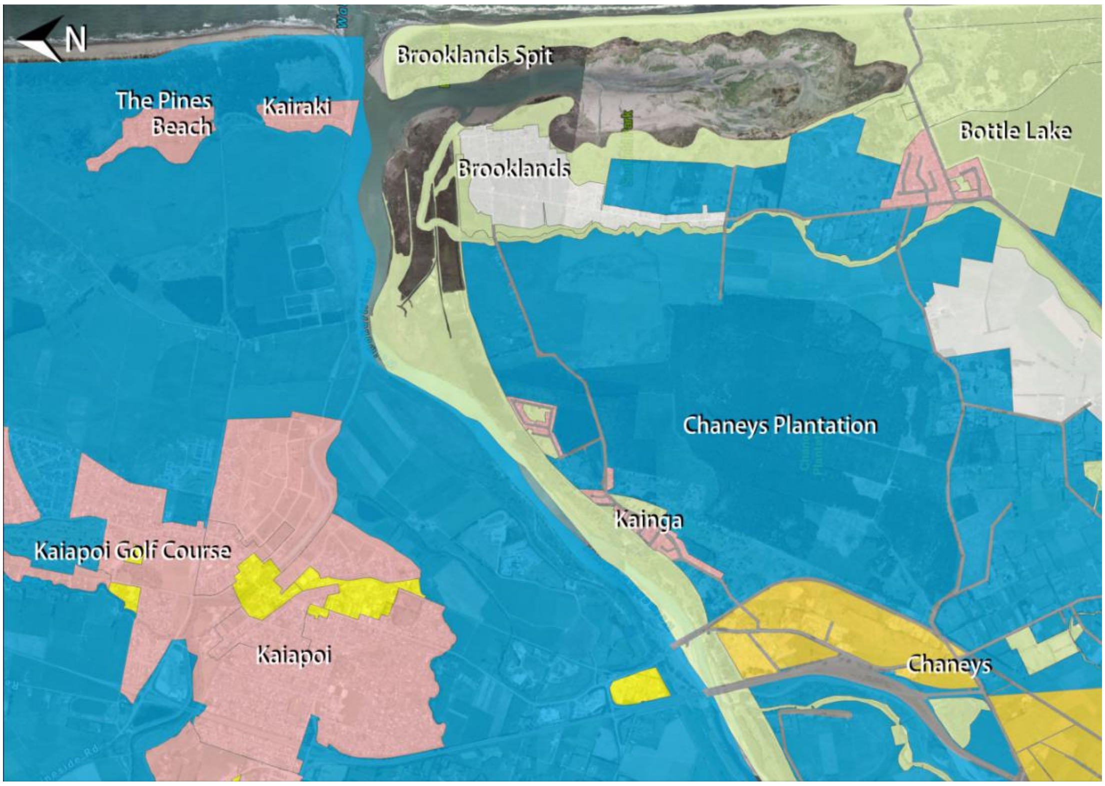


Figure 43. Diagram of district plan on Kaiapoi

5.33 Existing Aerial and Underground Wetlands

In figure 44, the existing aerial wetlands are coloured light blue, while the underground wetlands are coloured dark blue. It can be seen that the existing wetlands are mostly aerial wetlands that extend from Bottle Lake to the Pines Beach, and from Brooklands Spit to the riparian zones of Waimakariri River in the hinterland. Most of these wetlands are adjacent to the Waimakariri River and its tributary rivers, thus wetland development in this landscape should focus on the inundated zones of SLR and the riparian zones of the Waimakariri River. Besides, the wetlands in the Pines Beach and Brooklands Spit have been indicated to have cultural significance to the Maori community so that could be used for releasing more social values.

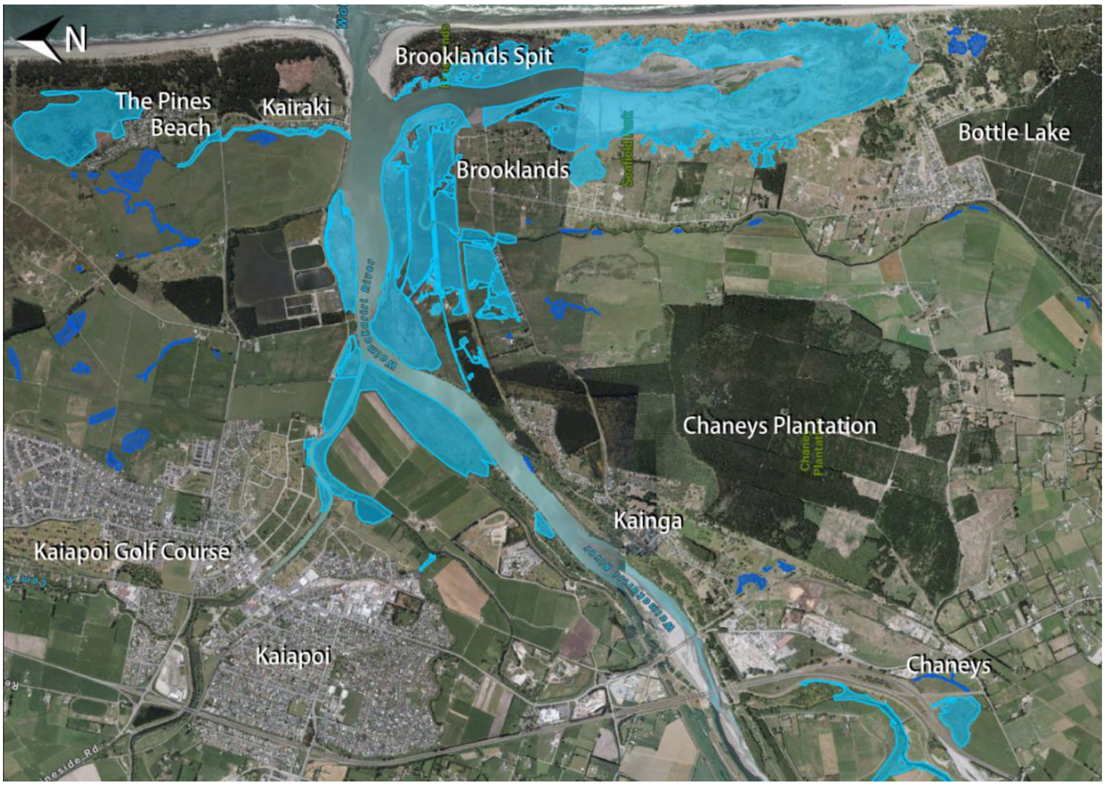


Figure 44. Diagram of existing aerial and underground wetlands on Kaiapoi

5.34 Liquification Zone

Existing challenges in this research are revealed through the maps of the liquification zone and tsunami zone that reveal the existing threats to the resilience of the site, as shown in figure 45. In general, liquification zones are not suitable for development with heavy structures, like founded houses, shopping malls or factories. From figure 45, it could be seen that the existing liquification zones coloured red are located in Brooklands, Brooklands Spit, Kairaki, the Pines Beach, Bottle Lake, Chaneys and the riparian zones of the Waimakariri River. The liquification zones cover most of the existing wetlands or the zones have the potential for wetland development; thus, wetland development is not suitable to be incorporated with heavy-structured buildings here like founded houses. Therefore, the existing founded houses are required to be replaced or transformed into an adaptive form, like stilt and floating houses.

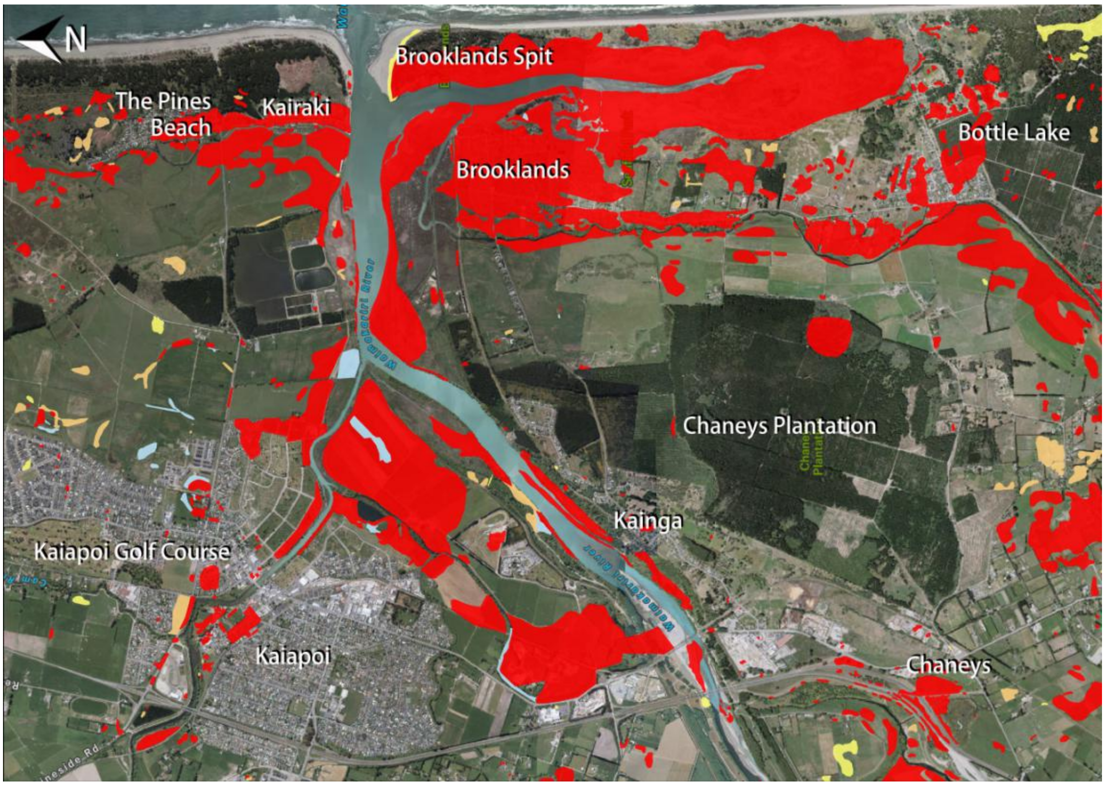


Figure 45. Diagram of liquification zone on Kaiapoi

5.35 Tsunami Zone

A tsunami zone is where it has a high chance to be damaged from tsunami activities. Considering the increasing numbers of extreme weather events induced by climate change, the future development of this zone needs to be well prepared. In figure 46, the zones will be affected by tsunami activities are coloured, and the severity of the impacts decrease from red to orange to yellow. Therefore, it can be seen that the heavy impact zones are in the riparian zones of Waimakariri River; the moderate impact zones are located in the Pines Beach, Kairaki, Brooklands Spit, Brooklands and Bottle Lake where they are adjacent to the sea or the tributary water channels of the Waimakariri River; the lightly impacted zones are located further back from the coast. The heavy impact zones of tsunami are mostly covered by the existing wetlands or the potential zones for wetland development; thus, the wetland development in these zones should have the ability to adapt to temporary inundation by sea water and the increased salinity it brings.

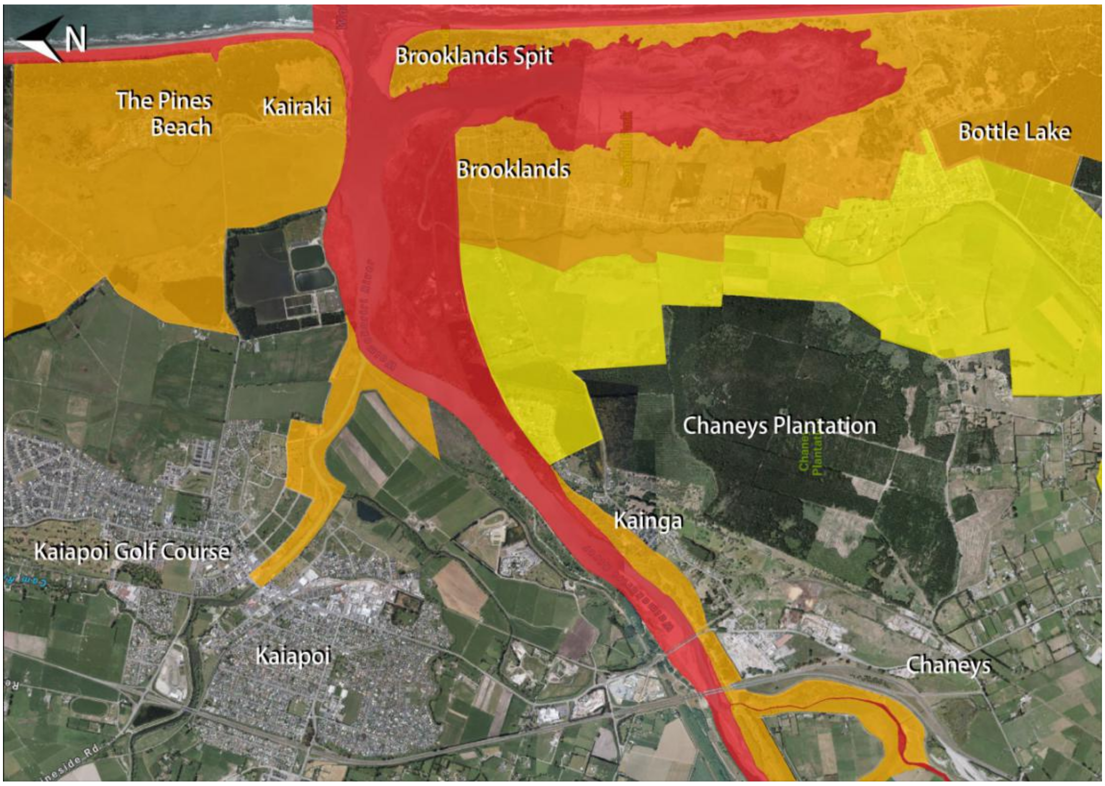


Figure 46. Diagram of tsunami zone on Kaiapoi

5.36 Retreating Shorelines

Future challenges in this research are revealed through the maps of retreating shorelines and soil moisture that inform the spatial progress of SLR on the site and indicates the potential zones for wetland development, restoration or retreat. The retreating shorelines are drafted based on the scenario of a 0.5-degree global temperature increase with a 0.7 metre SLR, 1-degree global temperature increase with a 2.1 metre SLR and a 1.5-degree global temperature increase with a 2.9 metre SLR, as shown in figure 47. This diagram is structured based on the information provided by Benjamin Strauss in Before The Flood. From the map, it can be seen that the western part of Brooklands and the zone between the Pines Beach and the Kaiapoi golf course are first to be inundated by sea water. These zones mostly belong to intensified agriculture; thus, food production will be severely interrupted by the intrusion of sea water. Brooklands and the riparian zones are second to be inundated by sea water where they also mostly have intensified agriculture with liquefied sub-urban zones. The north side of Kaiapoi is the third area to be inundated by sea water where it consists both intensified agriculture and sub-urban contexts. Overall, the existing patterns of food production and a few sub-urban communities will be significantly interrupted by the SLR.

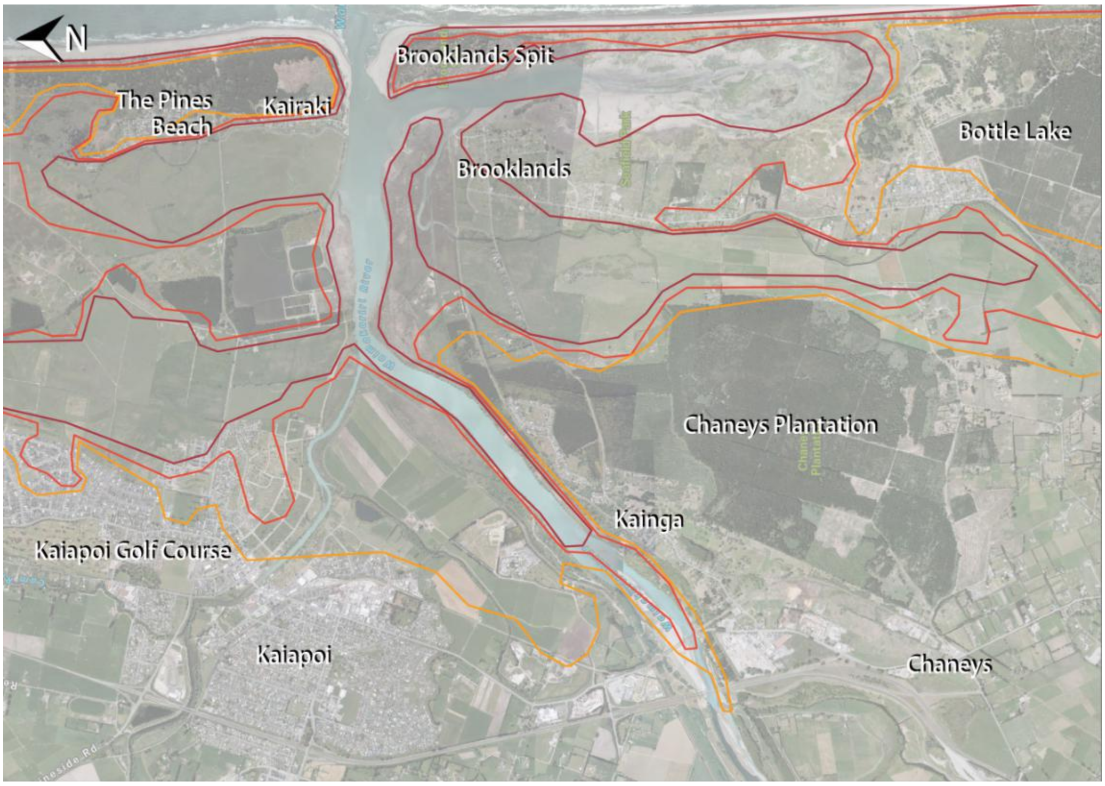


Figure 47. Diagram of retreating shorelines on Kaiapoi

5.37 Soil Moisture

The soil moisture is indicated in figure 48, and the moisture of soil is differentiated by colour. Dark blue means very moist, blue means moist, yellow means dry and orange means very dry. From the map, it can be seen that the Pines Beach, Kairaki, Brooklands Spit, Brooklands and the northern part of Bottle Lake are very dry. The southern part of Bottle Lake, Chaneys Plantation, Kainga and the Kaiapoi golf course are dry. These zones are not suitable for wetland development or restoration if there is no additional water input. The rest of the zones that are mostly moist or very moist are suitable for wetland development, restoration and so making a landward retreat of these estuarine wetlands becomes possible. However, the wetland development of coastal zones and riparian zones are not limited to the existing condition of soil moisture; thus, the sea water induced by SLR could greatly affect the form of wetland design in the future.

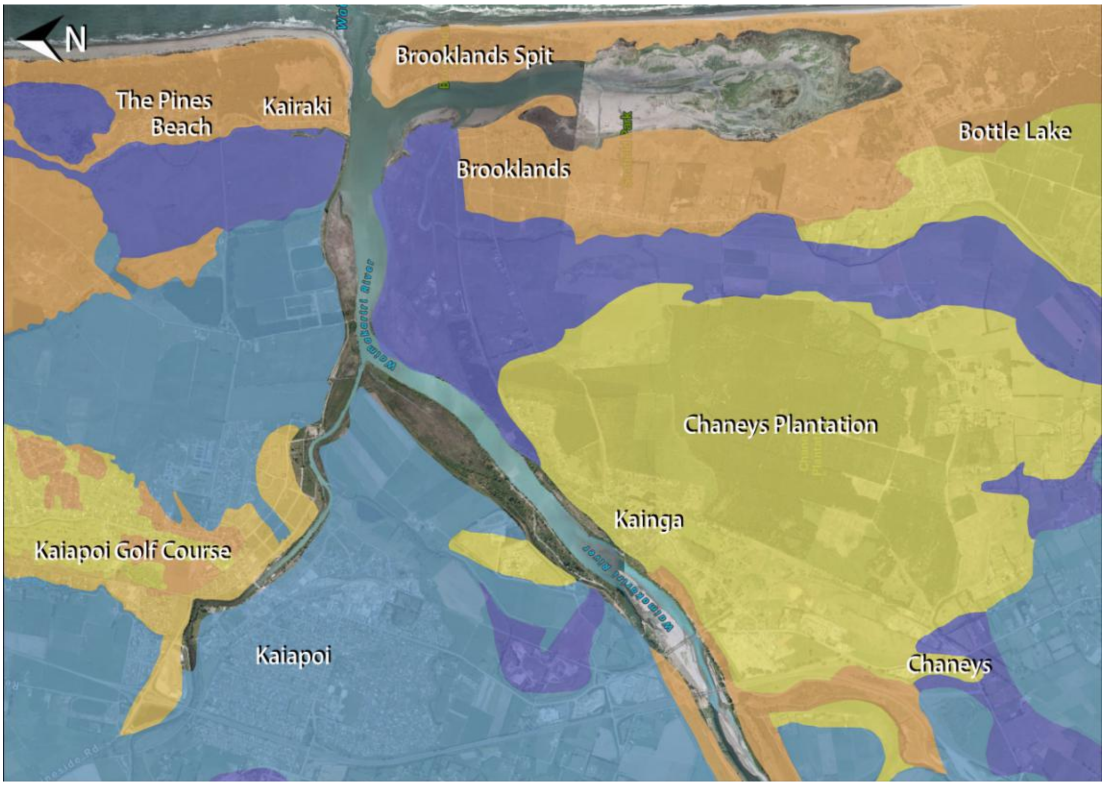


Figure 48. Diagram of soil moisture on Kaiapoi

5.38 Conclusions

In conclusion, SLR will significantly interrupt the existing patterns of food production, sub-urban communities and existing wetlands with cultural values. Not only the economic and ecological values but also the social values in Kaiapoi will be greatly damaged as the result. But the existing intensified agricultural practices in the hinterland and the riparian zones of rivers still opens opportunities for productive wetland designs in mitigating these lost values or even enhancing them in the sequential scenario of SLR. Therefore, the different types of values that could be released through wetland design under a SLR scenario are examined and discussed in the next section. Based on the requirement to more explicitly explore and examine the diagram of productivity in wetland design, as shown in figure 41, there will be two focuses. Focus one is located in the junction zone between the constructed wetlands for food production and water purification that aims to release economic values, focus two is located in the junction zone between the constructed wetlands for water purification and the natural wetlands, and these aim to release ecological values. Since both designs in the two focuses are developed from analytical maps generated in section 5.3, how does these analytical maps could be used in the wetlands design will be illustrated at first.

5.4 Productive Wetland for Releasing Economic Values

5.41 Spatial Design

To release the economic values of wetlands in SLR, a productive system for food production generated from the design patterns, as shown in figure 33, is applied in Kaiapoi along with other productive components, as shown in figure 49.

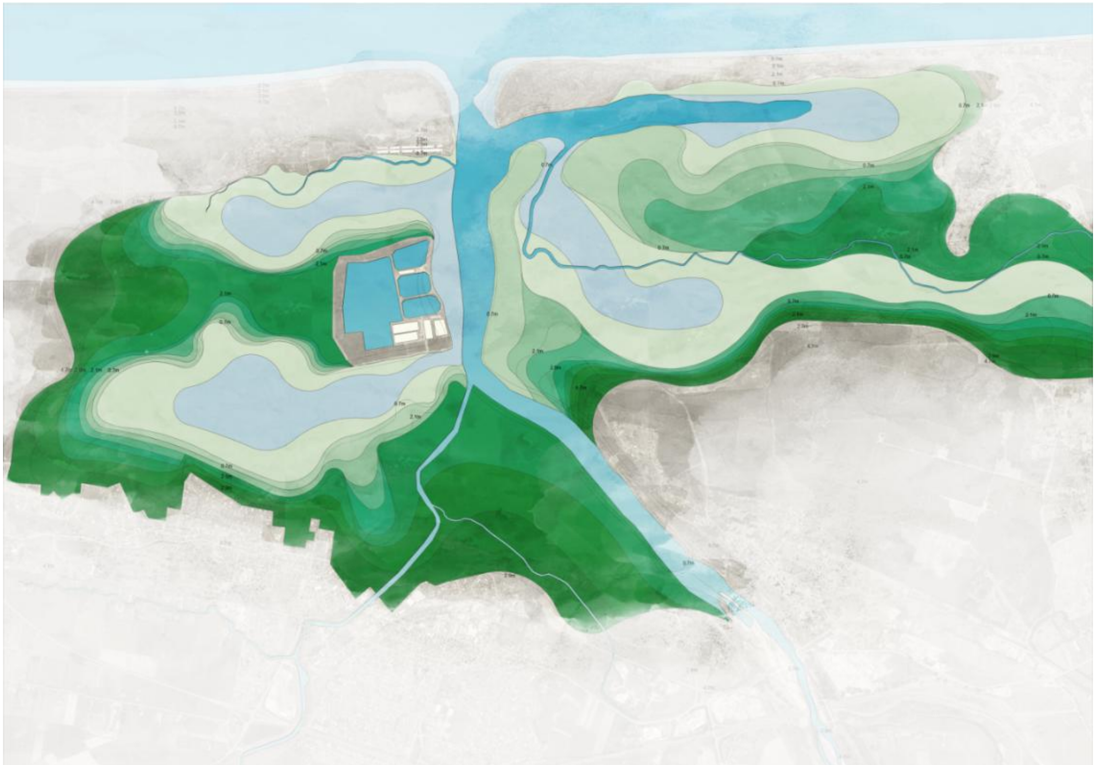


Figure 49. Productive wetlands for releasing economic values on Kaiapoi

In figure 50, the existing wetlands are overlapped on the regional plan map to show the existing context of Kaiapoi, then the wetland design is placed on top to show the relationship between the existing contexts and the wetland design for releasing economic values. From figure 50, it can be seen that the major development of wetlands is on the rural zones and there are three reasons for this. First, the rural lands are closer to the sea and they are soon to be invaded by seawater. Second, compared to residential zones or business zones, rural zones are easier to be replaced or redeveloped. Third, the leached nutrients from adjacent intensified agricultural practices in the hinterland could be used in the wetlands for food production like rice paddies or aquaculture. The special purpose zones created by the earthquakes could also easily be used for wetland development and;

thus, they are corporately used by rural zones and public open spaces in this design. The existing natural wetland is not very relevant for food production, but the existing wetland used for water purification could be incorporated into the productive wetland design to deal with waste-water or to treat excessive nutrients.

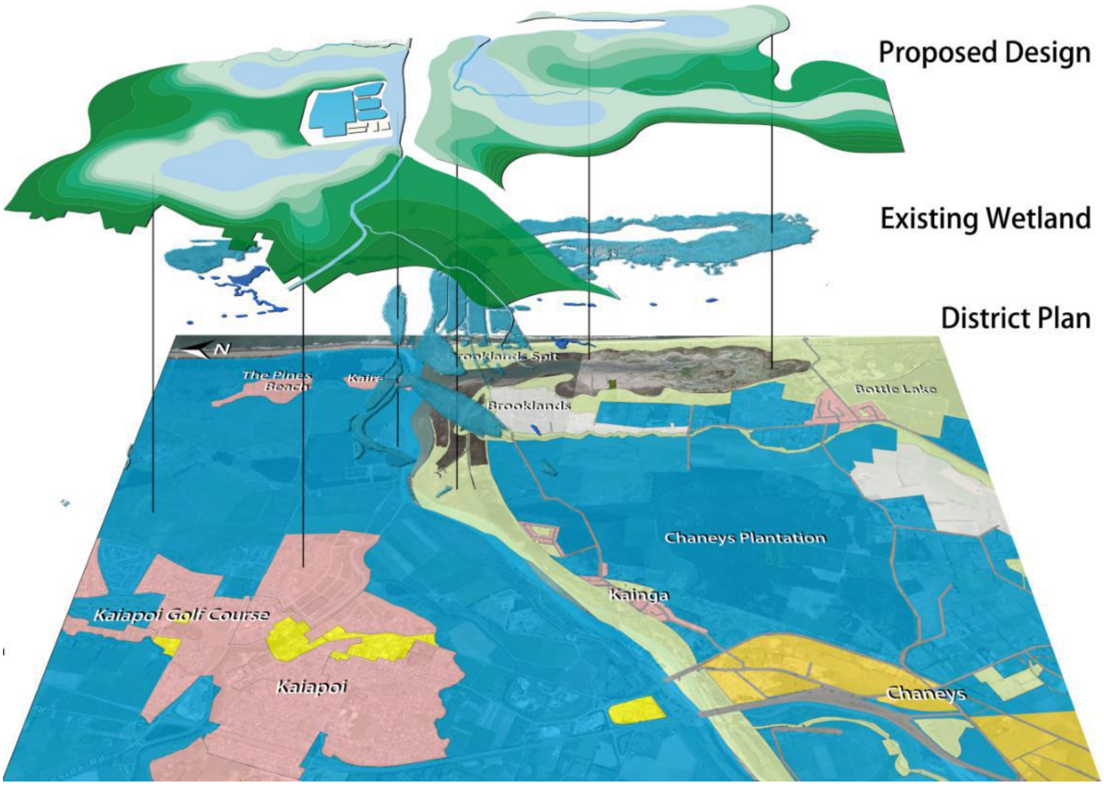


Figure 50. The impacts of existing contexts on wetlands for releasing economic value

In figure 51, the liquification zone is overlapped on the tsunami zone to show the existing challenges of Kaiapoi, while the wetland design is on top to show the relationship between the existing challenges and the wetland design for releasing economic value. From figure 55, it can be seen that the tsunami zones are mostly covered by the wetland design and that serves for two purposes. First, the wetlands could effectively mitigate the adverse impacts from tsunami activities. Second, the wetlands could be used as a buffer zone to allow mental preparation about these changes for the local community. To deal with the increased salinity brought by the tsunami activities, the wetland is designed based on retreating shorelines. From the high elevation to the low elevation, crops with ascending salinity-tolerance are planted. Liquification zones are unable to bear heavy structures and; thus, no grounded houses or industries are proposed in this wetland for generating economic value.

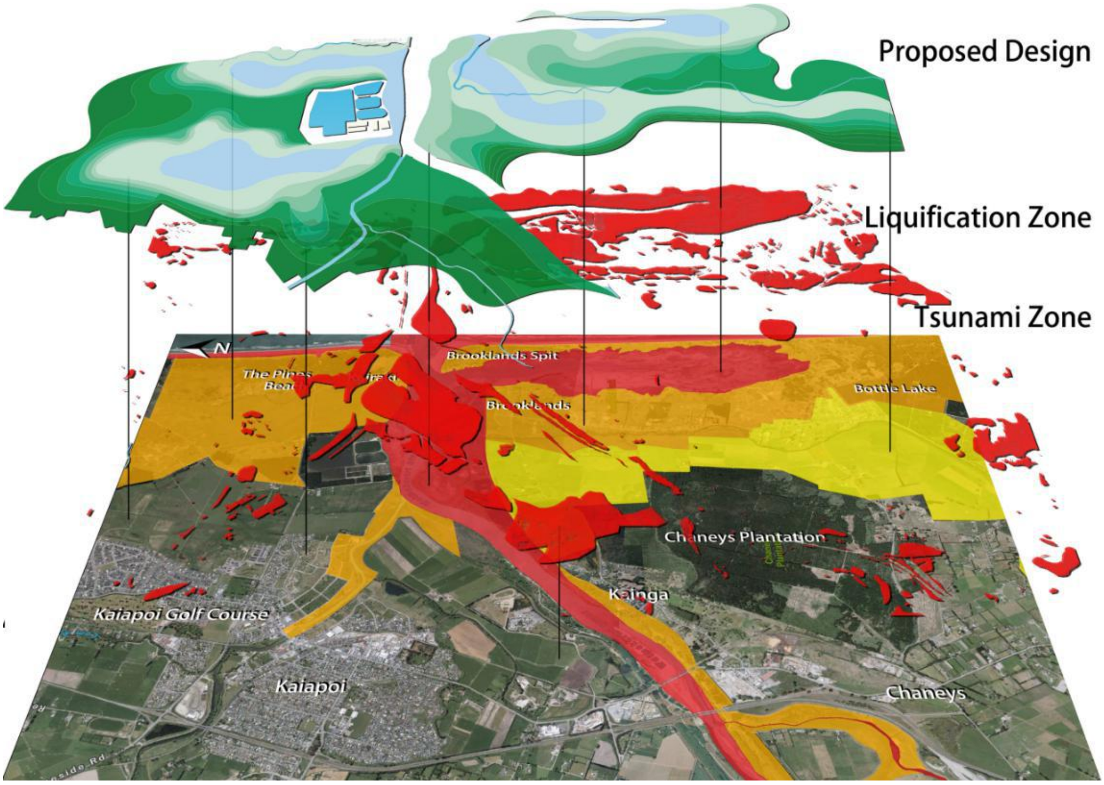


Figure 51. The impacts of existing challenges on wetlands for releasing economic value

In figure 52, retreating shorelines are overlapped on the map of soil moisture to show future challenges of Kaiapoi, wetland design is on top of them to show the relationship between the future challenges and the wetland design for releasing economic values. From figure 52, it could be seen that linear patches of wetland design follows the existing soil moisture. The difference are in Brooklands, The Pines Beaches and Kairaki, where are adjacent to the sea. This is because even these zones have dry soils, but the salt-water from the sea could be directly used to irrigate the wetland crops like high saline-alkali tolerant rice or other crops alike. The retreating shorelines indicates the routes of salt-water invasion, and thus the form of wetland design are responding to the dynamic changes on the shorelines.

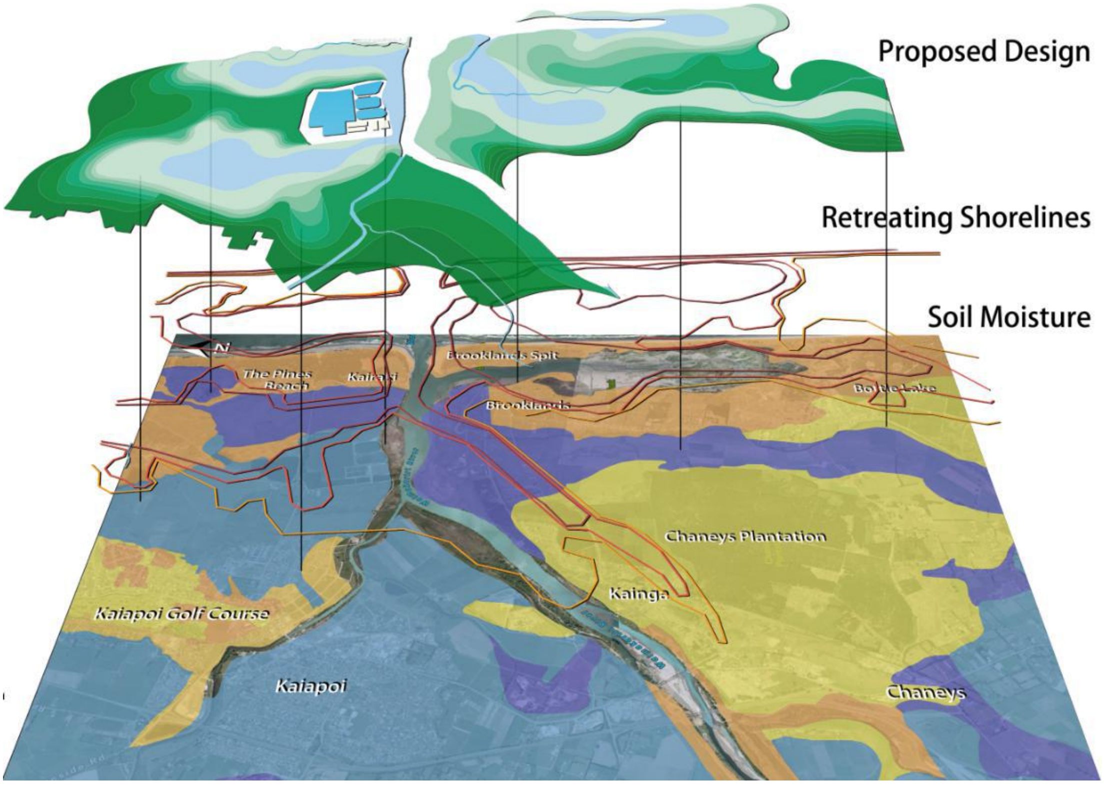


Figure 52. The impacts of future challenges on wetlands for releasing economic value

In the design practice for productive wetlands in this research, I found “form” is the first thing the designer needs to consider before structuring the productive system. The forms here are not based on aesthetic values but, more importantly, the form of the wetlands that could enhance the overall productivity and be adaptive to SLR is what matters. To do this, I found the existing topography of a landscape became one of the most important considerations for wetland design under the SLR scenario. Thus, I outlined the retreating shorelines with a 0.3 metre elevation change, as shown in figure 53. In design practice, I found that the linear patches between two adjacent retreating shorelines could be easily used to put productive components inside and to make them resilient under the SLR scenarios.

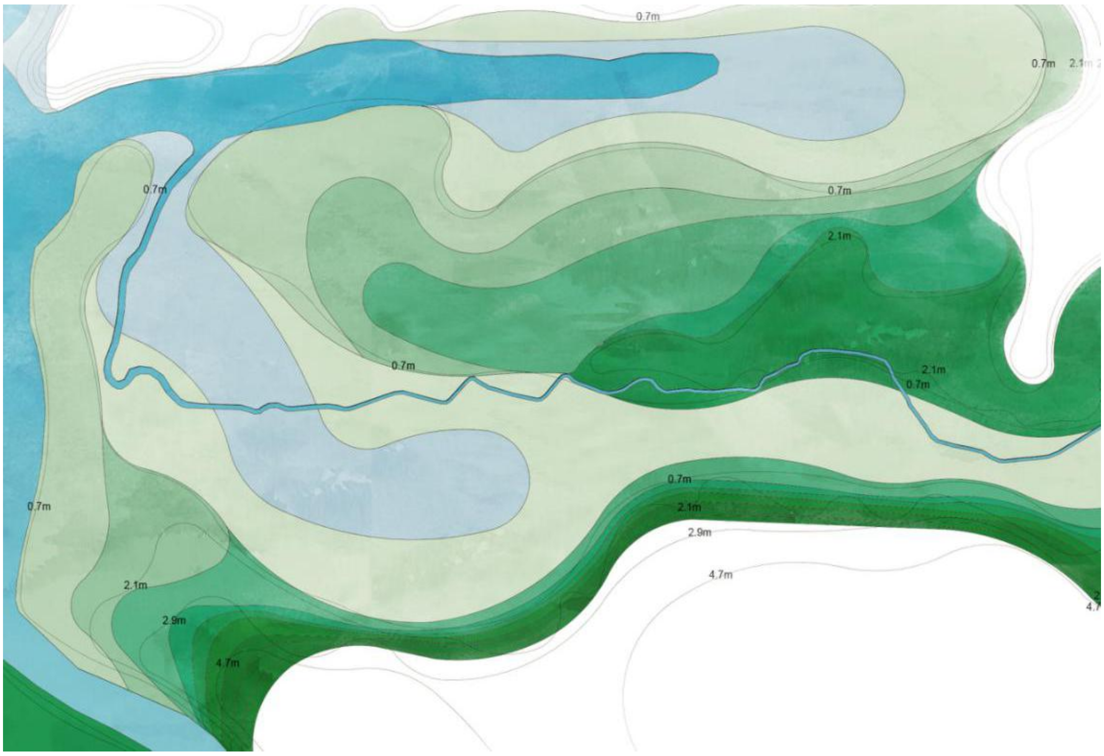


Figure 53. Design details for releasing economic values on Kaiapoi under SLR

5.42 Productive Components

All the productive components used here are arranged by the differences in elevation towards SLR. From a low elevation to a high elevation (left to right), the components are: salt-water aquaculture, productive wetland with standing water, productive wetland with temporary flooding, productive wetland with infrequent floods, intensified agriculture and fruit farms, as shown in figure 54.

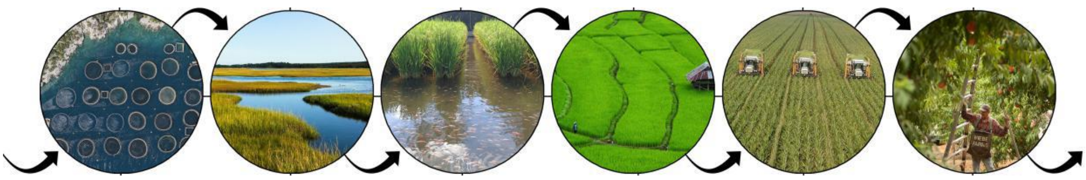


Figure 54. Productive components for releasing economic values in SLR - A

Each of the productive components could encompass a different type of approach. Fruit farms like plums and peaches, and intensified agriculture like dairy farming, are common in the Canterbury region of New Zealand. Productive wetlands with infrequent floods allow crops that are saline-tolerant, like barley, rice, pearl millet, maize, sorghum, alfalfa (Ashraf & Wu, 1994). Besides, this component could also encompass freshwater aquaculture and especially carp, that could effectively consume the algae grown from the leaching nutrients to purify the water (Knösche, Schreckenbach, Pfeifer, & Weissenbach, 2000). In addition, the combination of rice production and aquaculture is able to ecologically generate more food from lower nutrient inputs (Berg, 2002; Frei & Becker, 2005); thus, these two types of approaches could also be integrated for better productivity. Productive wetlands with temporary flooding and with standing water also allow saline-tolerant crops to grow, besides, salt production could also be conducted here through natural evaporation. Salt water aquaculture with cod, halibut, and bluefin tuna could be conducted in the coastal waters (Naylor & Burke, 2005).

Among these six types of productive components, intensified agriculture generally has the most nutrient inputs that could easily leach into the water system. But in the descending nutrients required level, as shown in figure 55, the leached nutrients from practices with high nutrient demand could be effectively used by the productive wetlands with descending nutrients requirements going towards the sea. In other words, the leached nutrients in a relatively high concentration could be used to fertilize the crops in a relatively low concentration. If the overall nutrients are too high to be consumed, carp breeding or other constructed wetlands for water purification could also be used as a bio-reactor to consume the leached nutrients.

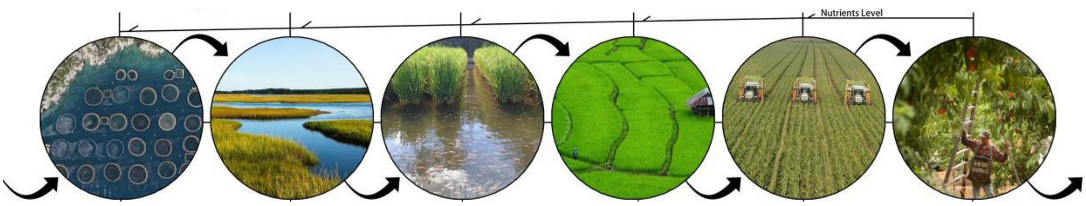


Figure 55. Productive components for releasing economic values in SLR - B

The Canterbury region of New Zealand, including Kaiapoi, is famous for its food production and; therefore, the productive wetlands in this system not only deal with the leached nutrients from the proposed design but also from the broader intensified agricultural practices in the hinterlands of the Canterbury region. In addition, the intensified agricultural practices and fruit farms are not a core part of this productive wetland system. In design practice, there will be no need to put them into the linear patches if there are existing agricultural practices that could be contributing to the leached nutrients. More importantly, this system allows more intensified agricultural practices to be conducted in the hinterland since most of these will be used in the productive wetlands system.

This productive wetland system for releasing ecological values is created based on elevation changes and; thus, is adaptable to the dynamics of SLR, as shown in figure 56. Linear patches are formed between different elevations of the existing topography and the boundaries between different linear patches are piled up like the soil ridges in between paddy fields, and serve to control the water flow. The piled boundaries here are not serving to stop water from flowing in, but to create a stable environment for productive wetlands to function.

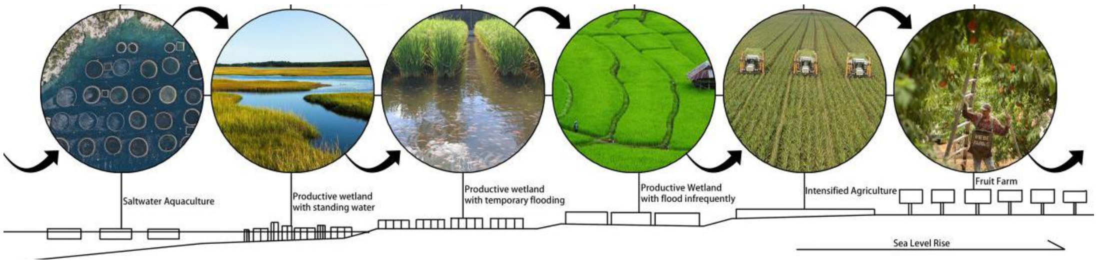


Figure 56. Productive components for releasing economic values in SLR - C

For example, the productive wetland with temporary flooding is expected to be naturally invaded by sea water in a large storms or tsunami activities, the crops there are also selected to be with saline-tolerant and capable of surviving inundated by water for some time. But on ordinary days, the water level of the productive wetlands will be controlled to maximize the efficiency of food production. The height between the boundary piles here are decided based on tidal changes. Whether salt-water brought by the high tide is allowed to flow into the productive wetland with temporary flooding is; therefore, controllable and decided by the actual needs for food production.

In addition, the productive wetland components for releasing economic value could be easily shifted landwards to respond to the dynamic changes of SLR. For example, when productive wetlands with temporary flooding are permanently inundated by sea water, they will then be replaced by the linear patches that used to be productive wetlands with infrequent flooding. The complete productive wetlands design of Kaiapoi for releasing economic value on the regional scale is shown in figure 57. How the productive components could be spatially arranged on the linear patches of productive wetlands are indicated on this diagram.

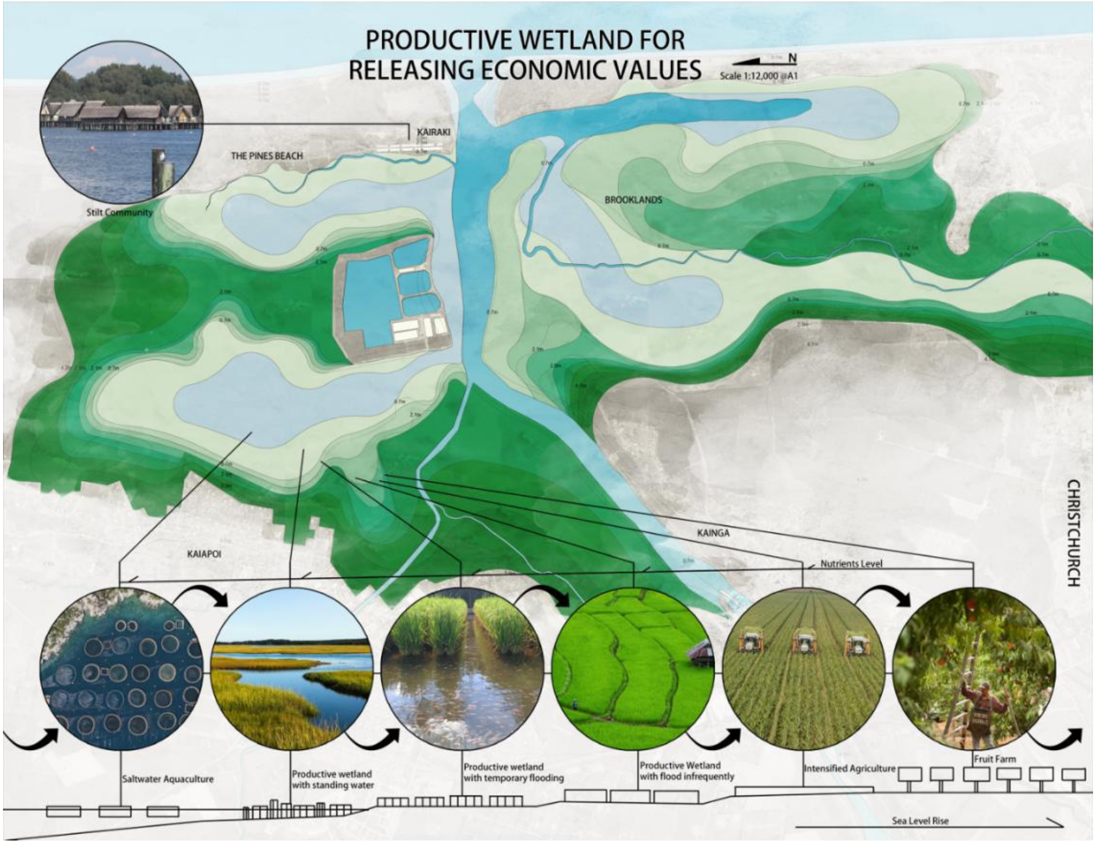


Figure 57. Productive wetlands for releasing economic values with productive components

In chapter 1.5, four aspects of the challenges induced by SLR, include: 1) increasing hidden risks and costs of infrastructure failure; 2) increasing demand for accommodation and living spaces; 3) impacts of food security; and 4) impacts on coastal tourism. In the productive wetlands, for releasing economic values, the productive wetland first creates a large buffer zone between the coast and the traditional communities. No founded buildings or engineering defensive structures are proposed, only stilt housing are applied at small scales. Therefore, the risk and cost of infrastructure failure is reduced to a minimum. Second, stilt housing is built to provide accommodation and living spaces for the workers in local food production, but the stilt houses and floating housing also have the potential to be applied on a larger scale. Third, a large coastal zone is transformed for different types of food production that could even be further integrated for higher efficiency in food production. Therefore, food production will not be undermined much from SLR, but could also be enhanced with more investment input. Fourth, agricultural and foodie tourism could be generated from productive wetlands that could mitigate or generated opportunities for tourism.

5.5 Productive Wetland for Releasing Ecological Values

5.51 Spatial Design

To release the ecological values of wetlands in SLR, a productive system of water purification that generated from the design patterns as shown in figure 34, is applied here with other productive components, as shown in figure 58.

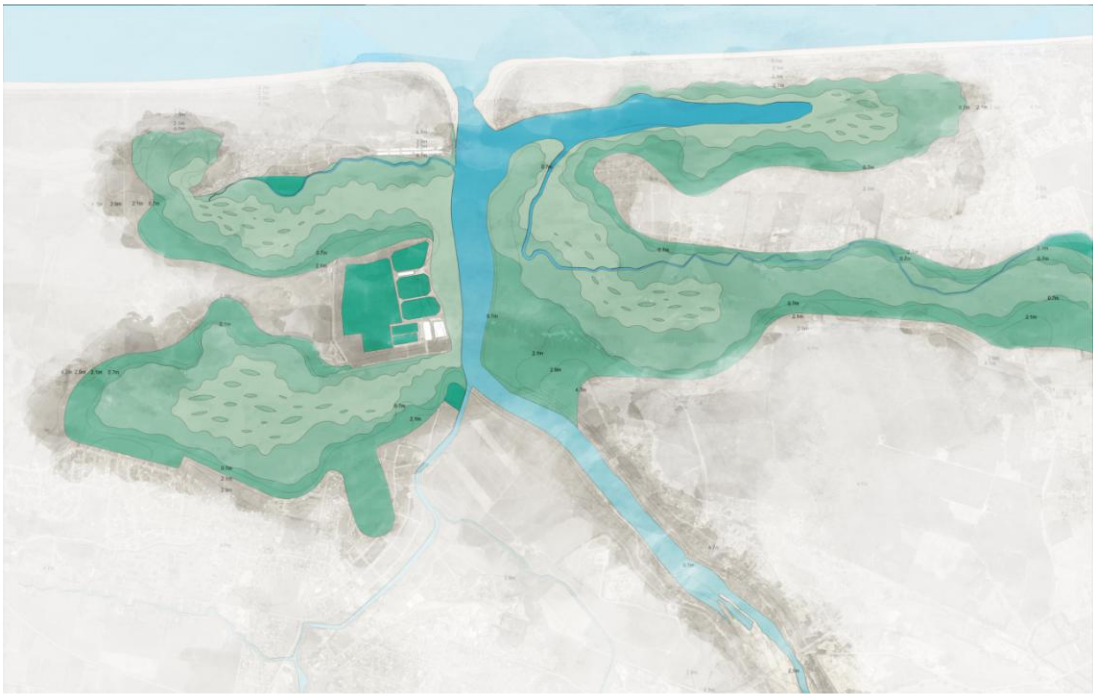


Figure 58. Productive wetlands for releasing ecological values on Kaiapoi

In figure 59, the existing wetlands are overlapped on the regional plan to show the existing context of Kaiapoi. The wetland design is placed above these to show the relationship between the existing context and the wetland design for releasing ecological values. From figure 59, it can be seen that the major restoration of the wetlands is in the rural zone and open public spaces. Besides the fact they are close to the coast, both are also close to, or connected to, an existing water system like the Waimakariri River and its tributaries. This is very important as self-sustainability is generally what the designer wants to achieve in wetland restoration, to maximize the ecological values with minimum human input. Special purpose zones that were created after the earthquakes could also be used for wetland restoration, but since the soil of these zones has been disturbed by human construction over a considerable time, soil evaluation and tilling might be required before replanting. The existing natural wetlands carry high ecological value, especially the estuarine wetlands.

Therefore, the proposed restored wetland in this design not only enhanced the existing natural wetlands but also constructed a corridor for wetland retreat under SLR. The existing constructed wetland is incorporated into this design as well to pre-treat the waste-water and storm water before they enter the natural wetlands to protect the high ecological values within.

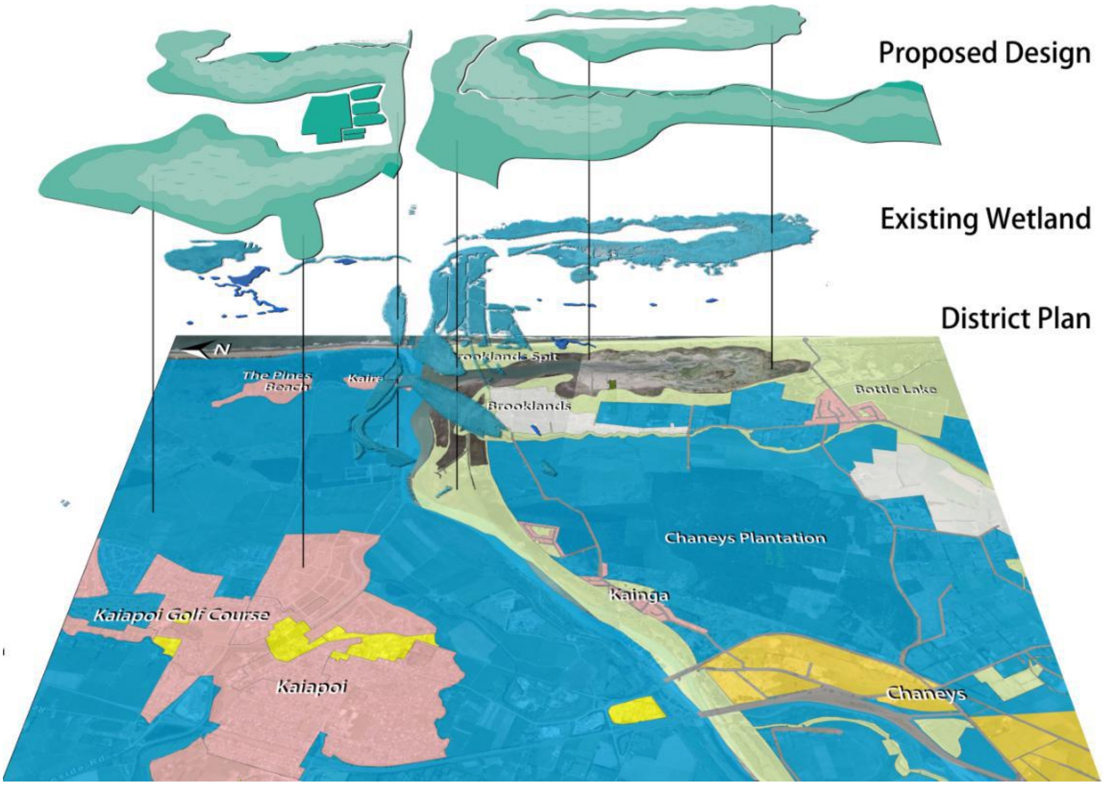


Figure 59. The impacts of existing contexts on wetlands for releasing ecological values

In figure 60, the liquification zone is overlapped by the tsunami zone to show the existing challenges of Kaiapoi. The wetland design is placed above to show the relationship between the existing challenges and the wetland design for releasing ecological values. From figure 60, it can be seen that the tsunami zones are mostly covered by the wetland design that serves the same purpose as the wetland design for releasing ecological values. First, the wetland could effectively mitigate the adverse impacts from tsunami activities. Second, the wetland could be used as a buffer zone to allow for mental preparation by the local community to changes because of SLR. To respond to the temporary tidal change and constant SLR, the wetland is designed in linear patches. From the high elevation to a low elevation native plants are chosen: native trees and shrubs with infrequent floods; native shrubs with temporary flooding; and native shrubs with standing water. The liquification zones are not relevant in this design since no heavy structures were found to contribute to releasing ecological value.

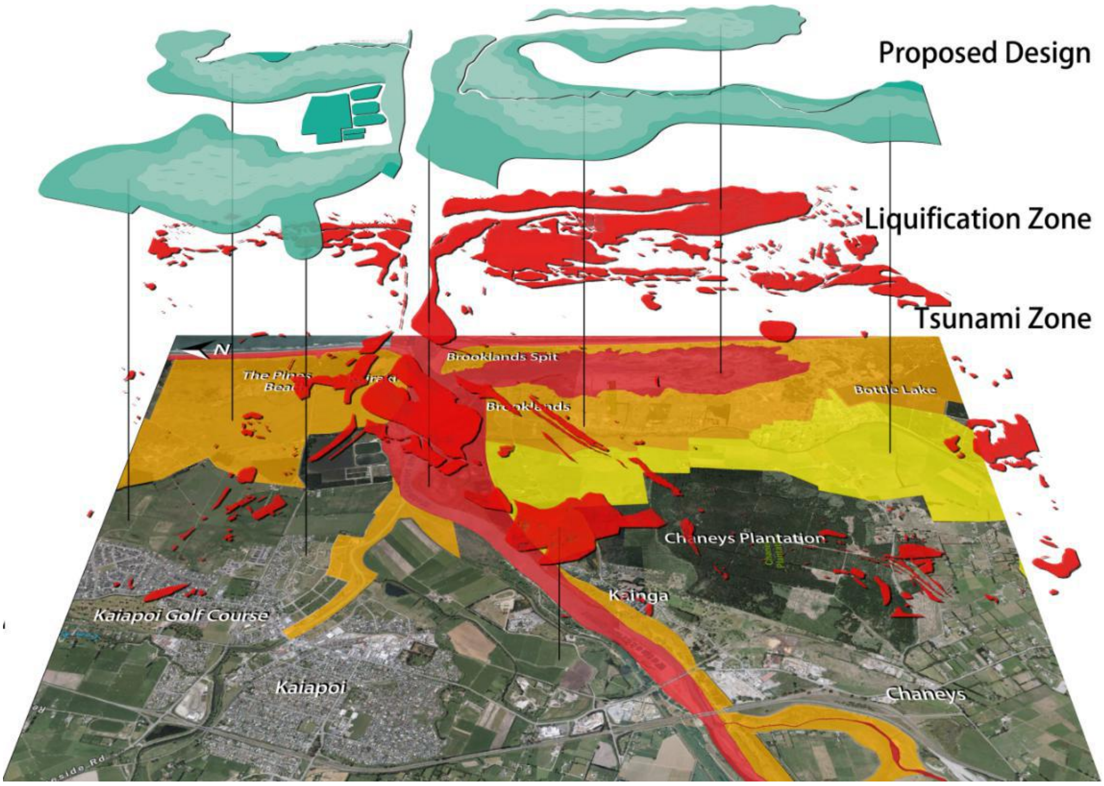


Figure 60. The impacts of existing challenges on wetlands for releasing ecological values

In figure 61, the retreating shorelines are overlapped on the map of soil moisture to show future challenges for Kaiapoi. The wetland design is placed above to show the relationship between the future challenges and the wetland design for releasing ecological values. From figure 61, it can be seen that the linear patches of wetland design more strictly follow the existing soil moisture, since the existing water resources are more important in wetland design for releasing ecological values than economic values. This is because wetlands for releasing ecological values are designed to be more self-sustaining and the ecological values could also be enhanced with less human intervention. The differences are at Brooklands, the Pines Beach and Kairaki, where they are adjacent to the sea. This is because even these zones have dry soils but they still can use the salt water. The retreating shorelines indicated highlight the corridors for the retreat of natural wetlands.

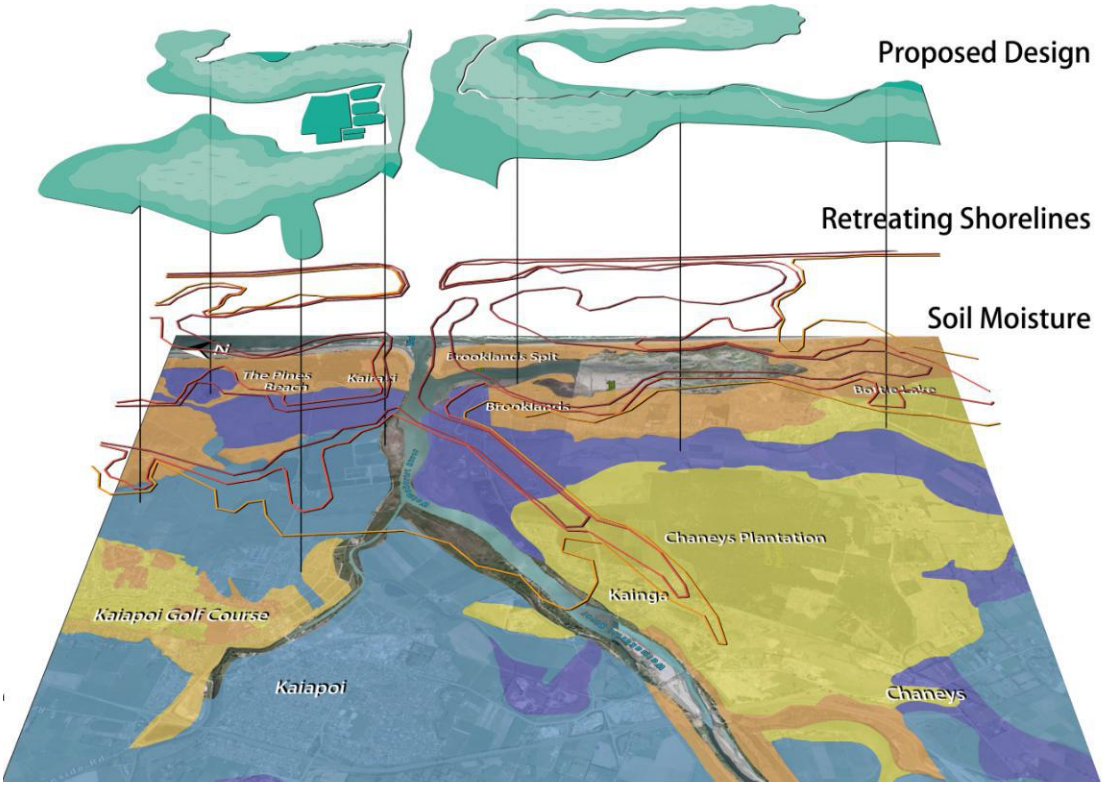


Figure 61. The impacts of future challenges on wetlands for releasing ecological values

SLR has a significant impact on the ecosystem of estuarine wetlands (Osland et al., 2016); thus, the existing topography is also the most important factor for releasing ecological value from a wetland design. Therefore, the components of productive wetlands for releasing ecological values are also designed to be able to fit into the linear patches between the predicted retreating shorelines, as shown in figure 62. Different from constructed wetlands, restored natural wetlands are generally aimed to be self-sustaining with little or no maintenance. To achieve this, the minimum width of the restored wetland is 5 metres, but only wetlands wider than 15 metres are likely to be self-sustaining (Parkyn, Shaw, & Eades, 2000). There is another difference from the constructed wetland design, the edge of the natural wetland is designed to be curved to enhance the biodiversity (Dramstad, Olson, & Forman, 1996). In addition, the isolated wetlands here are what will naturally happen based on existing topography and this serves to protect endangered species (J. et al., 2015).

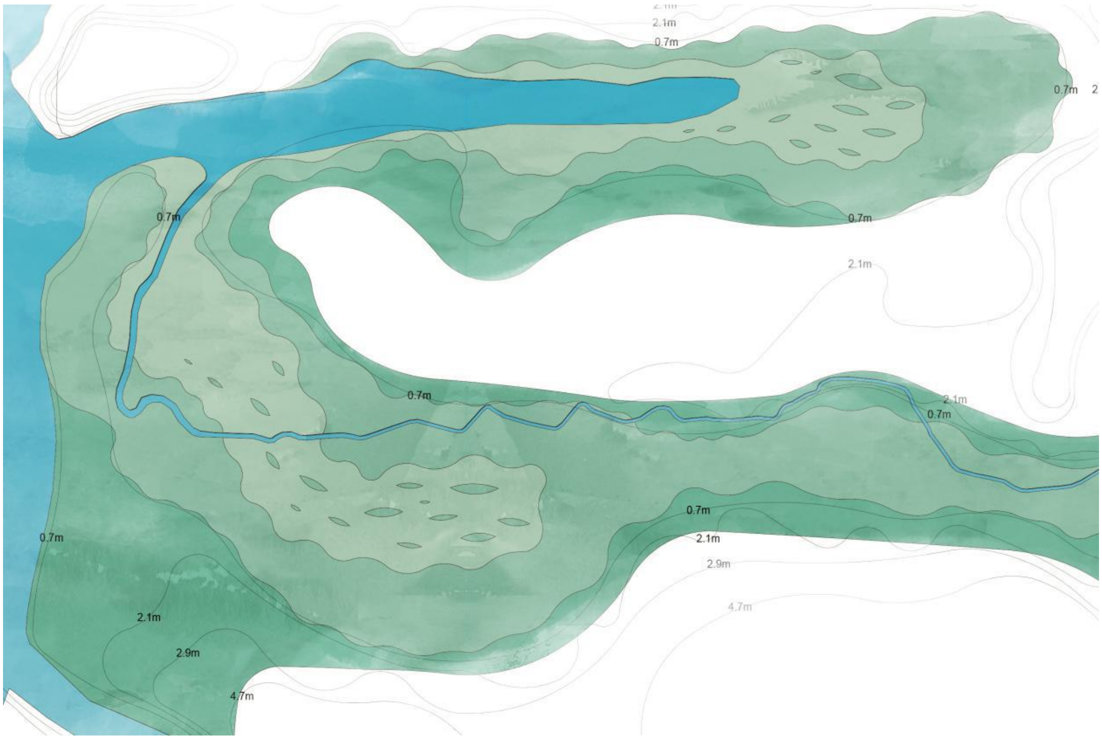


Figure 62. Design details for releasing ecological values on Kaiapoi under SLR

5.52 Productive Components

The entire productive components for releasing ecological values used here are arranged by the differences in elevation towards SLR. From the low elevation to the high elevation (left to right), the components are: native wetlands with standing water; native wetlands with temporary flooding; native forest with infrequent floods; constructed wetlands for water purification; and the community, as shown in figure 63.

Figure 63. Productive components for releasing ecological values in SLR - A

The common native wetland plants found with standing water in New Zealand are kapungawha (lake clubrush) and Purei (Carex secta). The common native wetland plants with temporary flooding in New Zealand are toetoe, harakeke and tikouka. The common native wetland trees with infrequent floods in New Zealand are karamu, manuka and kahikatea.

The productive wetland system for releasing ecological values is created based on the elevation changes and, thus, can adapt to the dynamics of SLR, as shown in figure 64. Linear patches are formed between different elevations of the existing topography, but there are no boundaries between them. Therefore, there will not be a clear separation between different linear patches, such as, productive wetlands for releasing economic values. This is for facilitating the migration of plants, insects and animals within the wetlands in response to SLR.

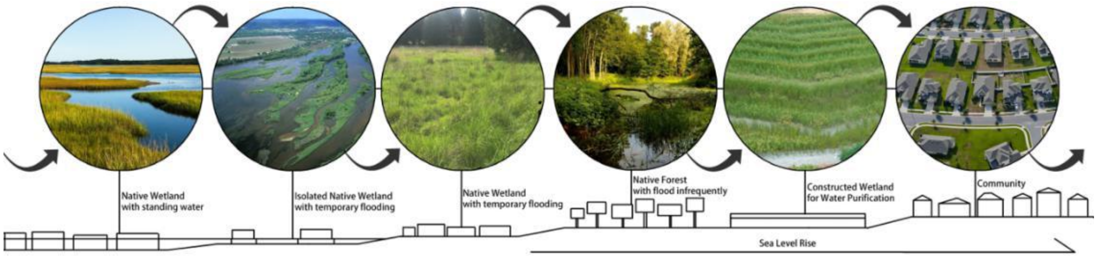


Figure 64. Productive components for releasing ecological values in SLR - B

In addition, the productive wetland components for releasing ecological values could be shifting landward naturally (Enwright et al., 2016). The complete productive wetlands design of Kaiapoi for releasing ecological values on the regional scale is shown in figure 65. How the productive components could be spatially arranged on the linear patches of productive wetlands are indicated on this diagram.

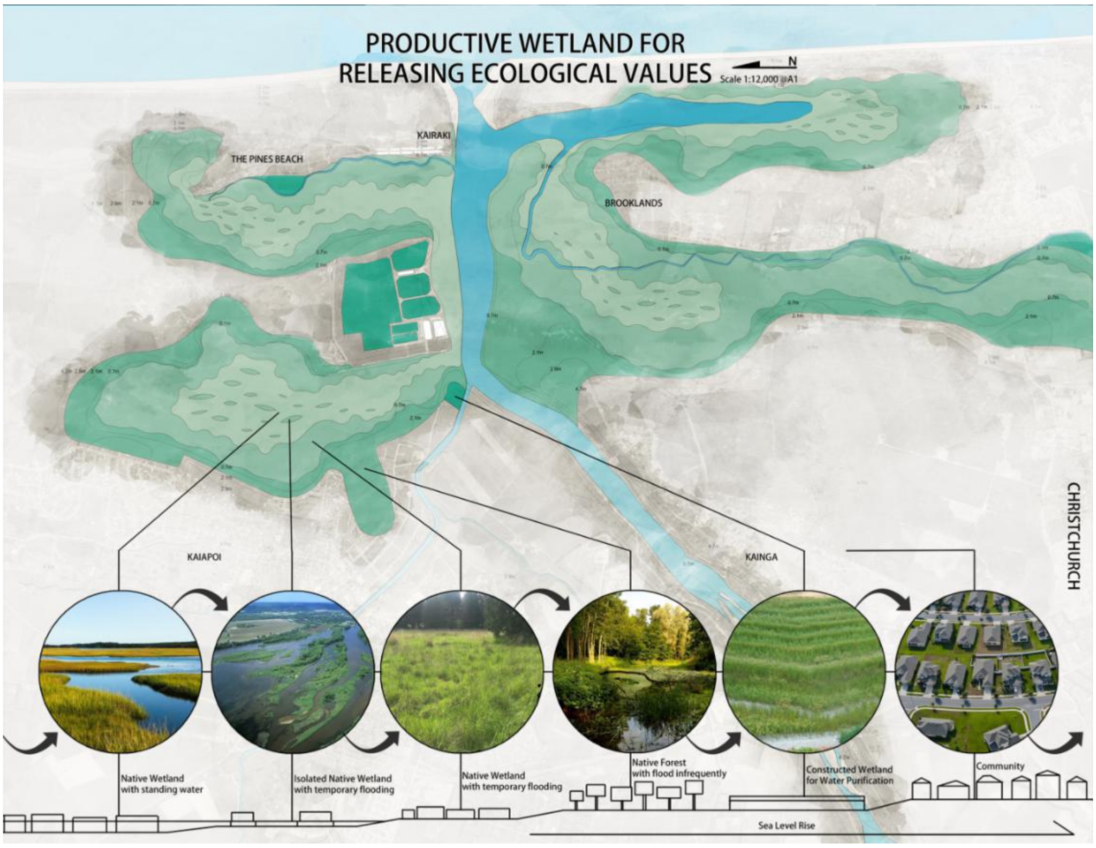


Figure 65. Productive wetlands for releasing ecological values with productive components

In chapter 1.5, the four aspects of the challenges will be induced by SLR, include: increasing hidden risks and costs of infrastructure failure; increasing demand for accommodation and living spaces; the impact food security and the impact on coastal tourism. In the productive wetlands for releasing ecological values, first, the restored natural wetland creates a large buffer zone between the coast and the traditional communities. No buildings with foundations or engineering defensive structures are proposed. Therefore, the risks and costs of infrastructure failures are reduced to a minimum. Second, there are no residential zones proposed in this design so; therefore, reductions in accommodation and living spaces will not be alleviated in this design. Third, there is no food production proposed in this design and, thus, the reduction in crop yields will not be alleviated in this design. Fourth, the opportunities for natural tourism and cultural tourism could be generated with the restoration of native plants. Therefore, the opportunities lost through SLR could be mitigated or, even, enhanced by restoring the wetlands with native plants.

5.6 Discussion

Since the productive wetland design for releasing economic and ecological values are both following the retreating shorelines in responding towards the SLR, they could be easily integrated into one design, as shown in figure 66. This reveals opportunities for integrating different components from both the wetland design for releasing economic values and ecological values. For example, even the plants growing on wetlands with standing water for releasing ecological values and the wetlands with standing water for releasing economic values, are mostly different, they share linear patches with a similar elevation above the sea; thus, they could be allocated in the different zones within the same design. In this chapter, not only the possibilities to join different components in two different focuses but also the opportunities to releasing more value from wetlands through the integration of these two focuses will be discussed. In addition, from figure 41, it also be seen that the opportunities to release more social values could also be generated from this integration.

Figure 66. The integration of wetlands for releasing economic and ecological values

From the research placement (Tan, 2018), as shown in appendix B. six types of social values were identified through the literature review that could be released, including aesthetic values, well-being of the community, research/educational values, recreational values, cultural values and international/national significance. In design practice, these social values are expressed in two ways. First, social values could be directly expressed from a single component of a wetland design, like recreational water activities, which could be available in a polluted lake after water purification is conducted through the constructed wetlands. Second, social values could also be generated from this integration, like cultural harvesting by Maori as one type of cultural activity could be generated through developing both native wetlands and traditional Maori stilt houses.

Compared to best-practice design principles and design patterns, the design components are focused on responding to the dynamic changes from SLR. From the literature review, it could also be found the possibilities in integrating different components within the same focus or different focus. To enhance this finding, I divide the components into six types in response to SLR. From a low elevation to a high elevation, the components are: coast, wetland with standing water, wetland with temporary flooding and wetland with flood infrequently, riparian and land. Under these components, different approaches for releasing different values from wetlands under SLR could be conducted. For design practice, the designers could select approaches under components based both on their intentions and the existing conditions. The productive system that was developed upon the productive components used for releasing economic values is identified in figure 67. Under these productive components, the approaches that could release economic values are coloured as purple.

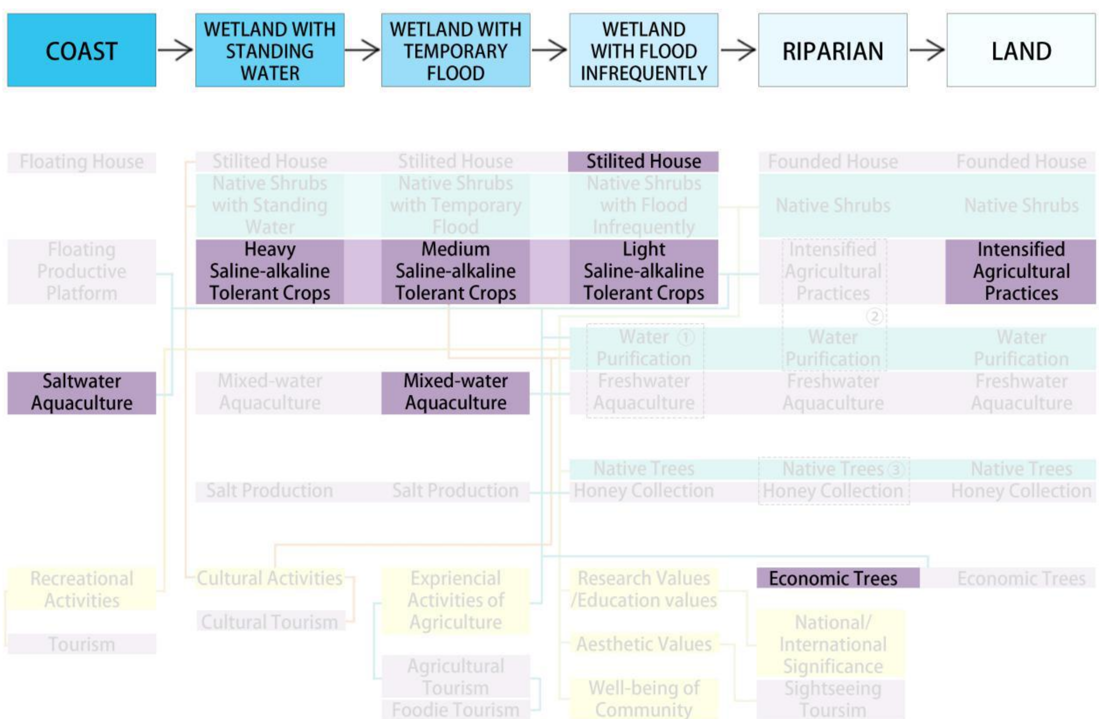


Figure 67. Design-based selective system of productive wetlands for economic values

The productive system that was developed upon the productive components used for releasing ecological values is identified in figure 68. Under these productive components, the approaches that could release ecological value are coloured green.

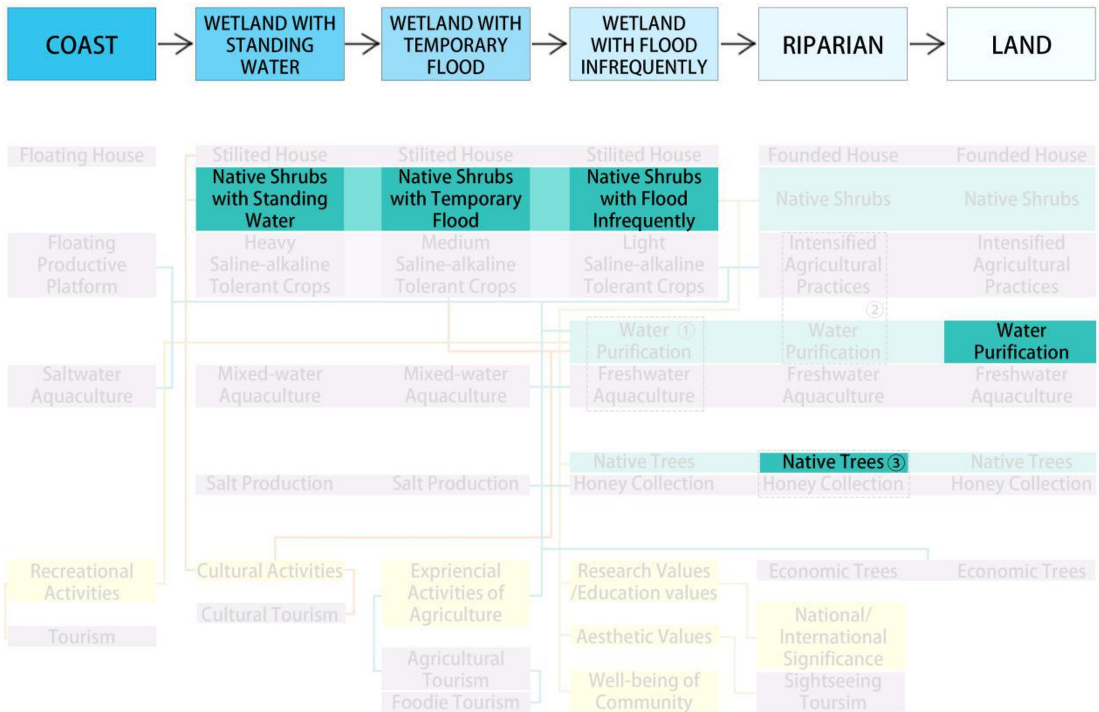


Figure 68. Design-based selective system of productive wetlands for ecological values

The approaches that could release social values are coloured as yellow, as shown in figure 69. The approaches for releasing social values could either be directly generated from economic or ecological approaches, or be generated from their integration. For example, water purification as an ecological approach could be used solely to release recreational social values from a polluted water body; agriculture and aquaculture practices as economic approaches could be corporately used to generate experiential/educational activities; Restoring native shrubs as an ecological approach and development of stilt houses as an economic approach could generate cultural values of Maori.

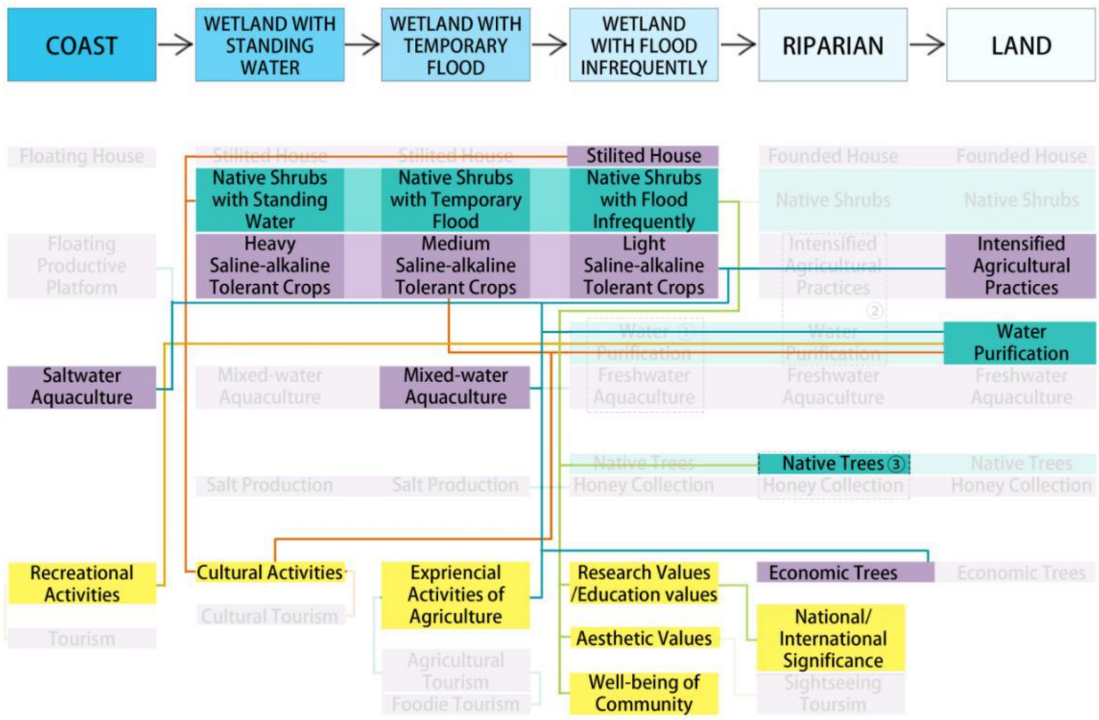


Figure 69. Social values expressed from integration of economic and ecological values

The social values generated from these economic and ecological values could be turned back to contribute to the generation of economic value, such as different kinds of tourism generated from different types of social values, like cultural tourism, food tourism and sightseeing tourism, as shown in figure 70.

Besides the generated social values, the integration of practices each with a different focus could also contribute to the productivity of a wetland design under SLR. For example, the integration of water purification and freshwater aquaculture generate opportunities for using freshwater fish to clean the organic waste and the algae grown from the leached nutrients to purify water, while the efficiency of nutrients used in food production can also be enhanced in this way, as shown in box one of figure 70.

The integration of intensified agriculture and water purification allows more food to be generated with no extra burden on the ecosystem; thus, the ecological cap of food production could be increased, as shown in box two of figure 74. The integration of native trees and honey collection allows farmers or workers to collect honey for free. The most famous honey collected from native tree species in NZ is Manuka honey, which carries a high economic value, as shown in box 3 of figure 70.

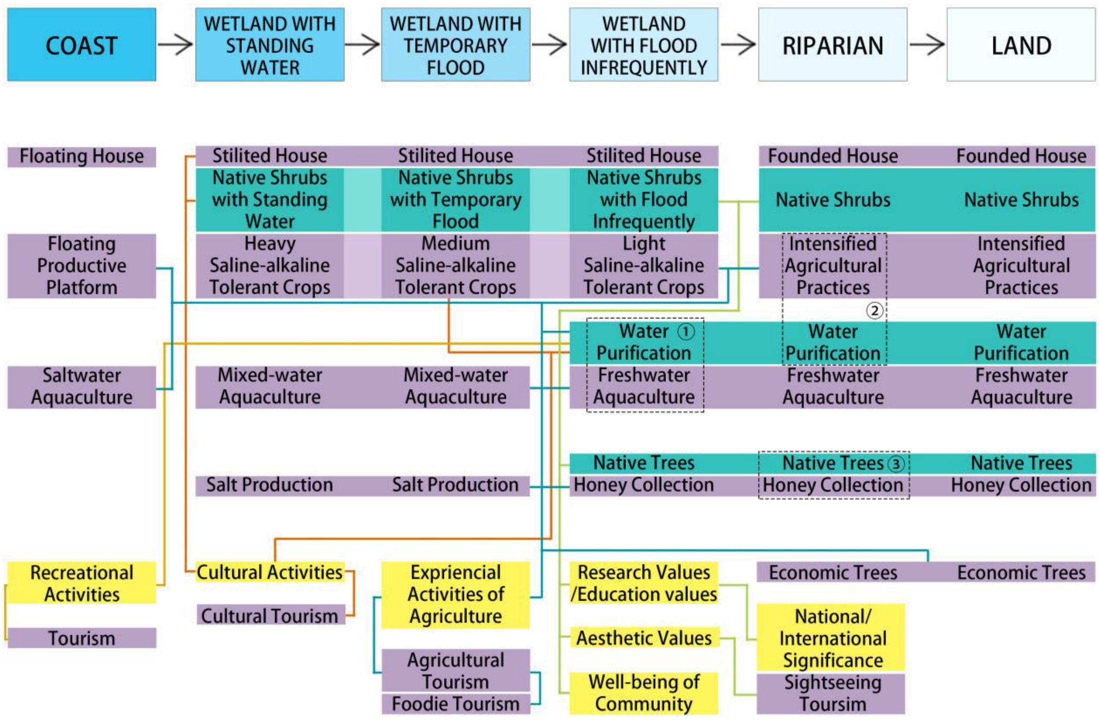


Figure 70. Design-based selective system of productive wetlands in SLR

Compared to the design patterns or the generated productive systems that focus on assisting design, this design-based selective system is more useful for investigating potential productive approaches by constructing alternative systems for meeting the needs of an uncertain future.

The approaches for releasing value from wetlands in SLR, as shown in figure 70, are expandable. New approaches could be added with additional research and new findings. Original approaches could also be cancelled if they were proven to be irrelevant or wrong. From the names of approaches in figure 70, it can also be seen that they are broad in definition, like native trees, economic trees and intensified agricultural practices. The purpose of this is to keep the flexibility and possibilities of the approaches to make them become universal so they can be used in different contexts under the global scenario of SLR.

Chapter Six: Conclusion

6.1 Review Existing Knowledge

6.11 Classification of Wetlands

Coast, wetland with standing water, wetland with temporary flood and wetland with flood infrequently are all related to the wetland classification used in this research that introduced in chapter 1 (Johnson & Gerbeaux, 2004). For example, “marine wetland” in the wetland classification and “coast” in productive components both refer to the offshore water zone. “Estuarine wetland” in the wetland classification and “wetland with standing water” in productive components both refer to the coastal zone. They refer to the same zone in a landscape, because the wetland classification is based on hydrological conditions and the hydrological conditions of “marine wetland” and “estuarine wetland” are mostly affected by the sea.

However, the definitions developed by Johnson and Gerbeaux are based on the hydrological conditions of the wetlands themselves, but the six productive components developed in chapter 5.6 are based on a relative relationship towards the sea. This research reveals some differences between the terms used in wetland classification and productive components. For example, “riverine wetland” and “lacustrine wetland” are identified by their relationship to river and lake, not to the sea. Thus, in the productive components system, both of them could either belong to “wetland with standing water” and/or “wetland with temporary flood”. Another example is the “palustrine wetland”, means the inland wetland that is not connected to any open water in the wetland classification. It is related to the “wetland with flood infrequently” that is also an inland wetland in the productive components, but the difference is a big constructed water pond could turn a “palustrine wetland” into a “lacustrine wetland”, but it will not change the “wetland with flood infrequently”. Therefore, there is more design potential in emphasising wetland’s productive components rather than the categorisations Johnson and Gerbeaux identify.

With SLR, the existing hydrological conditions of wetlands in coastal zones will be significantly affected. Not only estuarine wetland but also riverine wetland, lacustrine wetland and even palustrine wetland could be inundated by sea water. In such condition, the dominating hydrological conditions of these wetland types will be the sea and thus their original classification by Johnson and Gerbeaux will be less useful. Compared to this, the productive components of wetlands are structured on relative relationships to the sea and considered the scenario of SLR, thus this research indicates that the productive components could be more suitable to be used to divide wetland types in a design practice under SLR scenario.

6.12 Ecosystem services VS Value-based framework

The ecosystem services of wetlands from a global perspective have been shown by Clarkson (Clarkson et al., 2013), who divided them into four categories: provisioning services, regulating services, habitat services and cultural services, as shown on table 2, page 5. In this research, the ecosystem services are identified as less strong for application in a design practice. This is because the four categorizes Clarkson used are based on the mechanism of how they functioning, rather than focusing on how could they be applied in a design.

Compared to this, the three categorizes of ecological values, economic values and social values used in the value-based framework (shown on table 3, page 5) are stronger in indicating the specific design aspects that have been enhanced. For example, if food production is improved in a design, the ecosystem services will show that food production is a type of provisioning services, while the value-based framework will show you improved economic value from this practice. This then open up new opportunities for the design, for instance: could the economic values from wetlands be further enhanced; and could food production, as a type of approach to generate economic values be used alongside native wetland restoration, as a type of approach to generate ecological values? With such questions, the designer can explore the productivity of wetlands to a deeper level. In other words, ecosystem services documents what wetlands have provided, the value-based framework identified in this research allows an investigation of what wetlands could provide and potentially benefits landscape architects in generating new values and in enhancing identified values of wetlands through design approaches.

6.13 Scenario Development

Nassauer's approach to scenario development develops a number of scenarios to show predicted futures (Nassauer & Corry, 2004). In this research a sequential approach to scenario development of SLR is developed through overlapping the predicted retreating shorelines for different years. Compared to the Nassauer's approach, the appraoch this research takes allows the designer to more directly review the impacts of SLR from both dynamic and generative positions. In the sequential scenario approach used in this research, productive components of wetlands, as an dynamic response to SLR are created and applied as a means to effectively design wetlands. For example, after the retreating shorelines are identified, productive components can be put into the linear patches between the two adjacent retreating shorelines. From the sea to the hinterland, the productive components will be put in the arrangement of coast, wetland with standing water, wetland with temporary flood, wetland with flood infrequently, riparian and land. When the shoreline invades further and begins to routinely inundate a new linear patch, the productive components can be moved inside for one linear patch. For example, when wetlands with temporary flood become wetlands with standing water, then the wetlands with temporary flood can be replaced in the wetlands with infrequently floods, and wetlands that infrequently flood will be replaced by riparian areas. This method of developing sequential scenarios both allows the ever-changing dynamic nature of SLR to considered, that also enables the generation of novel design approaches.

6.2 Wetland Design Sequence

This research is founded on an earlier research placement (Tan, 2018) and my personal design experience, as shown in Appendix B. In this research, what SLR is and how affects the wetlands of New Zealand was initially discussed. Then, when identifying the role of the landscape architect in SLR, the challenges and opportunities that could be generated through design practice have been identified. They include: increasing hidden risk and cost of infrastructural failure; increasing demand for accommodation and living spaces; impacts on food security and impacts on coastal tourism.

To deal with these four challenges induced by SLR, a review of my previous study in research placement was undertaken, as shown in Appendix B. Among the tools developed or applied in research placement, the best-practice design guidelines, as shown in table 5 on page 18, can be considered the most appropriate for evaluating wetland designs through the use of Yes/No check boxes to evaluate if the design follows the principles. Then the quadrant diagram, as shown in figure 9, is identified as effective in identifying the design approaches have been taken and could be taken.

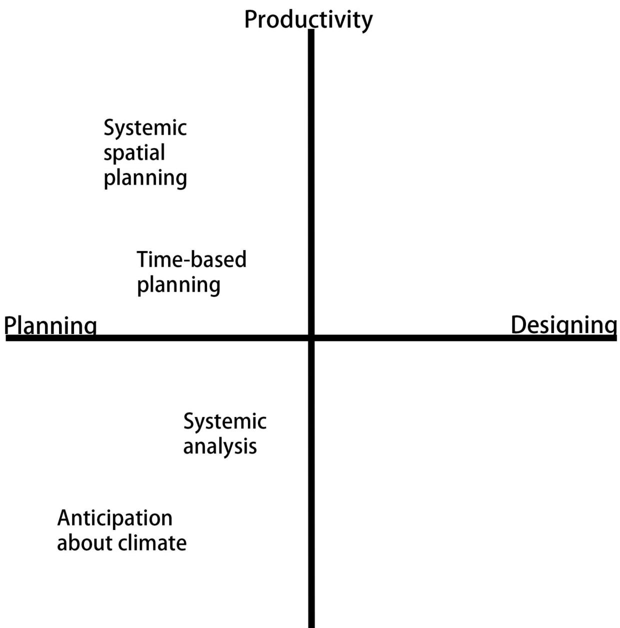


Figure 9. Evaluate the design approaches has taken in major design

From figure 9, it can be seen that there are four major approaches I have taken in major design, includes systemic spatial planning, time-based planning, systemic analysis and anticipation about climate. Through developing the design patterns, new values are identified from the junction zones between two design patterns. Therefore, the diagram of productivity in wetlands design, as shown in figure 41 on page 53, is developed to identify the opportunities in generating new values from wetland through integrating different wetland design patterns or approaches. These design patterns, productive systems and the design approaches I have taken in major design have been used to generate adaptive strategies with focuses on releasing economic values and ecological values on the Kaiapoi, eastern Christchurch under SLR scenario. Since the productive wetland design for releasing economic values and ecological values are both following the retreating shorelines in responding towards the SLR, they could be easily integrated into one design, as shown in figure 66 on page 78. This reveals opportunities in integrating different components from both the wetland design for releasing economic values and ecological values.

Compared to best-practice design principles and design patterns, the design components that are developed in this dissertation are focused in responding to the dynamic changes of SLR. From literature review, it can also be found the possibilities in integrating different components within both the same focus and also those with a different focus. To enhance this finding, this dissertation identifies the components into six types in responding to SLR. From low elevation to high elevation, the components are coast, wetland with standing water, wetland with temporary flooding and wetland with flood infrequently, riparian and land. As a result design components are developed to categorize the design approaches identified from design principles and design patterns. Afterwards, an enhanced design-based selection system of productive wetlands in SLR, as shown in figure 70 on page 82, is generated to show the opportunities of integrating different approaches under the six components. Compared to the design pattern approach or the generated productive system that focus on assisting design, this design-based selective system is stronger for investigating the potentials of productive approaches in constructing alternative productive systems for meeting the needs of uncertain futures.

In this dissertation a number of design tools and frameworks have been considered. In this section I arranged them into a useful design sequence, as a means of identifying an effective process in designing productive wetland under SLR scenario.

1. **Use analytical layers to unpack the required information of a site.** To investigate the future opportunities in a landscape under a SLR scenario, a comprehensive understanding

of the existing context, existing challenges and future challenges is necessary. The six types of analytical maps showed strong relevance in releasing the productivity of wetlands under SLR scenario. These maps are regional planning, existing wetlands, liquification zone, tsunami zone, retreating shorelines and soil moisture. This step is detailed illustrated in section 5.3, as shown in figure 43-48.

2. **Investigate the potential of a site through using a design-based selective system.** This design-based selective system is useful for investigating potentials of productive approaches in constructing alternative productive systems for meeting the needs under SLR scenario. This step is detailed illustrated in section 5.6, as shown in figure 70.

3. **Investigate the opportunity for releasing social values through integrating the approaches of economic values and/or ecological values.** Except for the social values that could be directly expressed from economic or ecological practices, social values of the productive wetlands can also be generated from integration of the practices with the same focus or different focus. This step is illustrated in section 5.4 and 5.5, as shown in figure 69.

4. **Use the design patterns and the productive systems generated from them to provide a more detailed spatial design.** The key principles of wetland design under SLR scenario are indicated through the literature review and then categorized into the two key aspects of wetlands design: resilience and productivity. Each of these key aspects is embodied with many design principles that are translated to design patterns to facilitate the future designer of wetlands. Design patterns of "productivity" are further integrated into three productive systems that are easier to be applied in a design practice. This step is detailed illustrated in chapter 4.

Also, there are opportunities to research ways these frameworks can be extended so as to build their usefulness and relevance. For best-practice design principles and productive design patterns of wetlands, both of them could be added with new findings from different disciplines and professions. For productive system of wetlands, new identified productive components could be integrated into the original productive systems. For design-based selective system, the design approaches under the design components could be added from relevant new findings.

6.3 The challenge of Sea Level Rise

Before the end of 21st century, sea level will rise about 0.3-2.5 meter (Sweet et al., 2017), with the speed of further SLR beyond 2100 further accelerating (Rintoul et al., 2018). Therefore, we are facing an uncertain future and people live in coastal zones will be greatly affected (Nicholls et al., 2011). New Zealand, as an island nation where its major cities Auckland, Wellington, Christchurch and Dunedin are on the coast, and will suffer from the adverse impacts from SLR. Therefore, coastal zones need to actively prepare to reduce the potential losses. However, current measures in dealing with SLR are still dominated by engineering approaches such as the dyke building, and which tend to neglect the intangible needs of the local communities (Jabareen, 2012). This kind of approach is dangerous with unmeasurable hidden costs (Reise, 2017). It also neglects the opportunities that could be generated from SLR. This research has sought to explore and develop opportunities that could effectively mitigate the adverse impacts from SLR, rather than seek to create defence against them.

To explore the opportunities that could be generated through coastscapes uncertain futures, a multi-disciplinary approaches are necessary. It is for this reason that landscape architecture, as a profession that can transform learnt knowledge into practical design is important. Landscape architecture seeks to be sensitive to the intangible needs of people and to design ways the needs of the future can be pro-actively met. As Copley (Copley et al., 2015) suggests, in facing SLR, the landscape architect must "*develop opportunity and innovation, exploring how landscape architects can be crucial to the imagination of more adaptive and resilient futures*." In this research, the approaches and frameworks that have been developed aim to assist the landscape architect in exploring the opportunities from wetland design that can work with sea level rise.

References

Abbott, M. R., & Bowring, J. (2017). A laboratory for design-directed research. Building design scholarship and academic possibility through designing.

Adapting to sea-level rise. (2019). Retrieved from https://www.mfe.govt.nz/climate-change/climate-change-and-government/adapting-climate-change/adapting-sea-level-rise

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and urban planning, 100*(4), 341-343.

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision.

Allam, Z., & Jones, D. (2018). *Promoting resilience, liveability and sustainability through landscape architectural design: A conceptual framework for port louis, mauritius; a small island developing state.* Paper presented at the IFLA World Congress Singapore.

Ashraf, M., & Wu, L. (1994). Breeding for salinity tolerance in plants. *Critical Reviews in Plant Sciences, 13*(1), 17-42.

Ausseil, A.-G. E., Lindsay Chadderton, W., Gerbeaux, P., Theo Stephens, R. T., & Leathwick, J. R. (2011). Applying systematic conservation planning principles to palustrine and inland saline wetlands of New Zealand. *Freshwater biology, 56*(1), 142-161. doi:10.1111/j.1365-2427.2010.02412.x

Aye, T. M., Nguyen, M. L., Bolan, N. S., & Hedley, M. J. (2010). Phosphorus in soils of riparian and non‐riparian wetland and buffer strips in the Waikato area, New Zealand. *New Zealand Journal of Agricultural Research, 49*(3), 349-358. doi:10.1080/00288233.2006.9513725

Bell, R., Lawrence, J., Allan, S., Blackett, P., Stephens, S., Hannah, J., . . . Britton, R. (2017). *Coastal hazards and climate change: Guidance for local government*.

Berg, H. (2002). Rice monoculture and integrated rice-fish farming in the Mekong Delta, Vietnam—economic and ecological considerations. *Ecological Economics, 41*(1), 95-107.

Berg, H., Söderholm, A. E., Söderström, A.-S., & Tam, N. T. (2017). Recognizing wetland ecosystem services for sustainable rice farming in the Mekong Delta, Vietnam. *Sustainability Science, 12*(1), 137-154.

Bhuiyan, M. J. A. N., & Dutta, D. (2012). Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. *Estuarine, Coastal and Shelf Science, 96*, 219-227.

Bilskie, M. V., Hagen, S. C., Medeiros, S. C., & Passeri, D. L. (2014). Dynamics of sea level rise and coastal flooding on a changing landscape. *Geophysical Research Letters, 41*(3), 927-934. doi:10.1002/2013gl058759

Borne, K. E., Fassman-Beck, E. A., & Tanner, C. C. (2014). Floating treatment wetland influences on the fate of metals in road runoff retention ponds. *Water research, 48*, 430-442.

Bornette, G., Amoros, C., & Lamouroux, N. (1998). Aquatic plant diversity in riverine wetlands: the role of connectivity. *Freshwater biology, 39*(2), 267-283.

Botzen, W. W., Michel-Kerjan, E., Kunreuther, H., de Moel, H., & Aerts, J. C. (2016). Political affiliation affects adaptation to climate risks: Evidence from New York City. *Climatic Change, 138*(1-2), 353-360.

Burger, J., O'Neill, K. M., Handel, S. N., Hensold, B., & Ford, G. (2017). The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA. *Landscape and urban planning, 157*, 512-522.

Bush, D. M., Neal, W. J., Longo, N. J., Lindeman, K. C., Esteves, L. S., & Pilkey, D. F. (2004). *Living with Florida's Atlantic beaches: coastal hazards from Amelia Island to Key West*: Duke University Press.

Calheiros, C. S. C., Bessa, V. S., Mesquita, R. B. R., Brix, H., Rangel, A. O. S. S., & Castro, P. M. L. (2015). Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility. *Ecological Engineering, 79*, 1-7. doi:https://doi.org/10.1016/j.ecoleng.2015.03.001

Camacho-Valdez, V., Ruiz-Luna, A., Ghermandi, A., Berlanga-Robles, C. A., & Nunes, P. A. (2014). Effects of land use changes on the ecosystem service values of coastal wetlands. *Environmental management, 54*(4), 852-864.

Cazenave, A., & Cozannet, G. L. (2014). Sea level rise and its coastal impacts. *Earth's Future, 2*(2), 15-34.

CCC Web Waterways, wetlands and drainage guide. (2018). Retrieved from https://www.ccc.govt.nz/environment/water/water-policy-and-strategy/waterways-wetlands-and-drainage-guide.

Change, I. C. (2014). Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *IPCC*.

Clarkson, B. R., Ausseil, A.-G. E., & Gerbeaux, P. (2013). Wetland ecosystem services. *Ecosystem services in New Zealand: conditions and trends. Manaaki Whenua Press, Lincoln*, 192-202.

Copley, N., Bowring, J., & Abbott, M. (2015). Thinking ahead: design-directed research in a city which experienced fifty years of sea level change overnight. *Journal of Landscape Architecture, 10*(2), 70-81.

Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research, 65*(10), 934-941.

Dawson, D., Shaw, J., & Roland Gehrels, W. (2016). Sea-level rise impacts on transport infrastructure: The notorious case of the coastal railway line at Dawlish, England. *Journal of Transport Geography, 51*, 97-109. doi:10.1016/j.jtrangeo.2015.11.009

Do, Y., Kim, S.-B., Kim, J. Y., & Joo, G.-J. (2015). Wetland-based tourism in South Korea: who, when, and why. *Wetlands Ecology and Management, 23*(4), 779-787. doi:10.1007/s11273-015-9418-2

Donald A, H. (1997). Creating freshwater wetlands.

Dramstad, W., Olson, J. D., & Forman, R. T. (1996). *Landscape ecology principles in landscape architecture and land-use planning*: Island press.

Ehrlich, P. R. (1974). Human population and environmental problems. *Environmental Conservation, 1*(1), 15-20.

Ellison, A. M., & Farnsworth, E. J. (1996). Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. *Biotropica*, 549-565.

Enwright, N. M., Griffith, K. T., & Osland, M. J. (2016). Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise. *Frontiers in Ecology and the Environment, 14*(6), 307-316. doi:10.1002/fee.1282

Ertl, A. W. (2008). *Toward an understanding of Europe: a political economic précis of continental integration*: Universal-Publishers.

Ewel, K., Twilley, R., & Ong, J. (1998). Different kinds of mangrove forests provide different goods and services. *Global Ecology & Biogeography Letters, 7*(1), 83-94.

Field, C. R., Gjerdrum, C., & Elphick, C. S. (2016). Forest resistance to sea-level rise prevents landward migration of tidal marsh. *Biological Conservation, 201*, 363-369. doi:10.1016/j.biocon.2016.07.035

Fink, D. F., & Mitsch, W. J. (2007). Hydrology and nutrient biogeochemistry in a created river diversion oxbow wetland. *Ecological Engineering, 30*(2), 93-102.

Frei, M., & Becker, K. (2005). *Integrated rice‐fish culture: Coupled production saves resources.* Paper presented at the Natural Resources Forum.

Geppert, M., & Dufhues, T. B. (2005). Visualizing rural financial market research in Northern Vietnam through pictures.

Gov, N. (1991). Resource Management Act. *Wellington: Government of New Zealand*.

Hall, C. M. (2001). Trends in ocean and coastal tourism: the end of the last frontier? *Ocean & Coastal Management, 44*(9-10), 601-618.

Hammer, D. A. (1989). *Constructed wetlands for wastewater treatment: municipal, industrial and agricultural*: CRC Press.

Hill, K. (2016). Climate change: Implications for the assumptions, goals and methods of urban environmental planning. *Urban Planning, 1*(4), 103-113.

Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S., . . . Levermann, A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences, 111*(9), 3292-3297.

Holling, C. S., & Gunderson, L. H. (2002). Resilience and adaptive cycles. *In: Panarchy: Understanding Transformations in Human and Natural Systems, 25-62*.

Hughes, A. O., Tanner, C. C., McKergow, L. A., & Sukias, J. P. S. (2016). Unrestricted dairy cattle grazing of a pastoral headwater wetland and its effect on water quality. *Agricultural Water Management, 165*, 72-81. doi:10.1016/j.agwat.2015.11.015

J., R. S., Richard, C., D., R. B., Hazel, B., S., M. M., & M., W. J. (2015). Small wetlands are critical for safeguarding rare and threatened plant species. *Applied Vegetation Science, 18*(2), 230-241. doi:doi:10.1111/avsc.12144

Jabareen, Y. (2012). Towards a sustainability education framework: Challenges, concepts and strategies—The contribution from urban planning perspectives. *Sustainability, 4*(9), 2247-2269.

Jevrejeva, S., Jackson, L. P., Riva, R. E. M., Grinsted, A., & Moore, J. C. (2016). Coastal sea level rise with warming above 2 °C. *Proceedings of the National Academy of Sciences, 113*(47), 13342-13347. doi:10.1073/pnas.1605312113

Johnson, P., & Gerbeaux, P. (2004). *Wetland types in New Zealand*. United States: Dept. of Conservation.

Jones, D., Cocklin, C., & Cutting, M. (1995). Institutional and landowner perspectives on wetland management in New Zealand. *Journal of Environmental Management, 45*(2), 143-161.

Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., . . . Dellow, G. (2012). The Mw 6.2 Christchurch earthquake of February 2011: preliminary report. *New Zealand journal of geology and geophysics, 55*(1), 67-90.

Karim, F., Kinsey‐Henderson, A., Wallace, J., Arthington, A. H., & Pearson, R. G. (2012). Modelling wetland connectivity during overbank flooding in a tropical floodplain in north Queensland, Australia. *Hydrological Processes, 26*(18), 2710-2723.

Keddy, P. A. (2010). *Wetland ecology: principles and conservation*: Cambridge University Press.

Khoshkam, M., Marzuki, A., & Al-Mulali, U. (2016). Socio-demographic effects on Anzali wetland tourism development. *Tourism Management, 54*, 96-106.

Knösche, R., Schreckenbach, K., Pfeifer, M., & Weissenbach, H. (2000). Balances of phosphorus and nitrogen in carp ponds. *Fisheries Management and Ecology, 7*(1‐2), 15-22.

Li, C., Qiu, J., Frolking, S., Xiao, X., Salas, W., Moore III, B., . . . Sass, R. (2002). Reduced methane emissions from large‐scale changes in water management of China's rice paddies during 1980–2000. *Geophysical Research Letters, 29*(20), 33-31-33-34.

Lin, M., Li, Z., Liu, J., Gozlan, R. E., Lek, S., Zhang, T., . . . Yuan, J. (2015). Maintaining economic value of ecosystem services whilst reducing environmental cost: a way to achieve freshwater restoration in China. *PloS one, 10*(3), e0120298.

Maori and wetlands. (n.d.). Retrieved from https://www.waikatoregion.govt.nz/community/your-community/iwi/a-maori-perspective-te-ao-maori/maori-and-wetlands/

McDowell, R., Moreau, P., Salmon-Monviola, J., Durand, P., Leterme, P., & Merot, P. (2014). Contrasting the spatial management of nitrogen and phosphorus for improved water quality: Modelling studies in New Zealand and France. *European Journal of Agronomy, 57*, 52-61.

McDowell, R. W., Monaghan, R. M., Dougherty, W., Gourley, C. J. P., Vibart, R., & Shepherd, M. (2017). Balancing water-quality threats from nutrients and production in Australian and New Zealand dairy farms under low profit margins. *Animal Production Science, 57*(7), 1419. doi:10.1071/an16646

McGann, R. (1983). *The climate of Christchurch* (Vol. 167): Ministry of Transport, New Zealand Meteorological Service.

McGlone, M. S. (2009). Postglacial history of New Zealand wetlands and implications for their conservation. *New Zealand Journal of Ecology*, 1-23.

McKerchar, C., Bowers, S., Heta, C., Signal, L., & Matoe, L. (2015). Enhancing Māori food security using traditional kai. *Global health promotion, 22*(3), 15-24.

McKergow, L. A., Matheson, F. E., & Quinn, J. M. (2016). Riparian management: A restoration tool for New Zealand streams. *Ecological Management & Restoration, 17*(3), 218-227. doi:10.1111/emr.12232

Meyer, E. K. (2008). Sustaining beauty. The performance of appearance: A manifesto in three parts. *Journal of Landscape Architecture, 3*(1), 6-23.

Meynecke, J.-O., Lee, S., & Duke, N. (2008). Linking spatial metrics and fish catch reveals the importance of coastal wetland connectivity to inshore fisheries in Queensland, Australia. *Biological Conservation, 141*(4), 981-996.

Mohamed, Y., Bastiaanssen, W. G., Savenije, H., Van den Hurk, B., & Finlayson, C. M. (2012). Wetland versus open water evaporation: An analysis and literature review. *Physics and Chemistry of the Earth, Parts A/B/C, 47*, 114-121.

Mueller, P., Jensen, K., & Megonigal, J. P. (2016). Plants mediate soil organic matter decomposition in response to sea level rise. *Glob Chang Biol, 22*(1), 404-414. doi:10.1111/gcb.13082

Nassauer, J. I., & Corry, R. C. (2004). Using normative scenarios in landscape ecology. *Landscape Ecology, 19*(4), 343-356.

Naylor, R., & Burke, M. (2005). Aquaculture and ocean resources: raising tigers of the sea. *Annu. Rev. Environ. Resour., 30*, 185-218.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding--a global assessment. *PloS one, 10*(3), e0118571. doi:10.1371/journal.pone.0118571

Ni, J., Xu, J., & Zhang, M. (2016). Constructed wetland planning-based bi-level optimization to balance the watershed ecosystem and economic development: A case study at the Chaohu Lake watershed, China. *Ecological Engineering, 97*, 106-121.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*(5985), 1517-1520.

Nicholls, R. J., Marinova, N., Lowe, J. A., Brown, S., Vellinga, P., De Gusmao, D., . . . Tol, R. S. (2011). Sea-level rise and its possible impacts given a 'beyond 4 C world'in the twenty-first century. *Philosophical Transactions of the Royal*

Society of London A: Mathematical, Physical and Engineering Sciences, 369(1934), 161-181.
Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., . . . Arblaster, J. (2007). Coastal systems and low-lying areas.
Nichols, M. M. (1989). Sediment accumulation rates and relative sea-level rise in lagoons. *Marine geology, 88*(3-4), 201-219.
Osland, M. J., Enwright, N. M., Day, R. H., Gabler, C. A., Stagg, C. L., & Grace, J. B. (2016). Beyond just sea‐level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. *Global Change Biology, 22*(1), 1-11.
Parker, M., & Steenkamp, D. (2012). The economic impact of the Canterbury earthquakes. *Reserve Bank of New Zealand Bulletin, 75*(3), 13-25.
Parkyn, S., Shaw, W., & Eades, P. (2000). Review of information on riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions.
Passeri, D. L., Hagen, S. C., Medeiros, S. C., Bilskie, M. V., Alizad, K., & Wang, D. (2015). The dynamic effects of sea level rise on low-gradient coastal landscapes: A review. *Earth's Future, 3*(6), 159-181. doi:10.1002/2015ef000298
Phillips, M. R., & Jones, A. L. (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. *Tourism Management, 27*(3), 517-524.
Ponnamperuma, F. (1984). Straw as a source of nutrients for wetland rice. *Organic matter and rice, 117*, 136.
Racchetti, E., Bartoli, M., Soana, E., Longhi, D., Christian, R., Pinardi, M., & Viaroli, P. (2011). Influence of hydrological connectivity of riverine wetlands on nitrogen removal via denitrification. *Biogeochemistry, 103*(1-3), 335-354.
Reise, K. (2017). Facing the Third Dimension in Coastal Flatlands: Global Sea Level Rise and the Need for Coastal Transformations. *GAIA - Ecological Perspectives for Science and Society, 26*(2), 89-93. doi:10.14512/gaia.26.2.6
Rintoul, S., Chown, S., DeConto, R., England, M., Fricker, H., Masson-Delmotte, V., . . . Xavier, J. (2018). Choosing the future of Antarctica. *Nature, 558*(7709), 233.
Risken, J., Fraser, J., Rutter, H., & Gadsby, M. (2015). *Implications of sea level rise on liquefaction vulnerability in Christchurch.* Paper presented at the 6th International Conference on Earthquake Geotechnical Engineering, Christchurch.
Robb, M. J. G. (2014). *When two worlds collide: Mātauranga Māori, science and health of the Toreparu wetland.* University of Waikato.
Robertson, H. A., & Suggate, R. (2012). *Arawai Kākāriki Wetland Restoration Programme 2007-2010: Implementation Report*: Research and Development Group, Department of Conservation.
Roggema, R. (2018). Design with voids: how inverted urbanism can increase urban resilience. *Architectural Science Review, 61*(5), 349-357.
Runting, R. K., Lovelock, C. E., Beyer, H. L., & Rhodes, J. R. (2017). Costs and Opportunities for Preserving Coastal Wetlands under Sea Level Rise. *Conservation Letters, 10*(1), 49-57. doi:10.1111/conl.12239
Salata, K. D., & Yiannakou, A. (2016). Green Infrastructure and climate change adaptation. *Tema. Journal of Land Use, Mobility and Environment, 9*(1), 7-24.
Sarwar, M. G. M. (2005). Impacts of sea level rise on the coastal zone of Bangladesh. *See* http://static. *weadapt. org/placemarks/files/225/golam_sarwar. pdf*.
Sasmito, S. D., Murdiyarso, D., Friess, D. A., & Kurnianto, S. (2015). Can mangroves keep pace with contemporary sea level rise? A global data

review. *Wetlands Ecology and Management, 24*(2), 263-278. doi:10.1007/s11273-015-9466-7
Schleupner, C. (2008). Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management, 51*(5), 383-390.
Scott, D. (2011). Why sustainable tourism must address climate change. *Journal of Sustainable Tourism, 19*(1), 17-34.
Scott, D., Gössling, S., & Hall, C. M. (2012). International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change, 3*(3), 213-232.
Semlitsch, R. D., & Bodie, J. R. (2003). Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology, 17*(5), 1219-1228.
Sharma, B., Rasul, G., & Chettri, N. (2015). The economic value of wetland ecosystem services: evidence from the Koshi Tappu Wildlife Reserve, Nepal. *Ecosystem Services, 12*, 84-93.
Sheppard, S. R. (2015). Making climate change visible: A critical role for landscape professionals. *Landscape and urban planning, 142*, 95-105.
Shi, L., Chu, E., & Debats, J. (2015). Explaining progress in climate adaptation planning across 156 US municipalities. *Journal of the American Planning Association, 81*(3), 191-202.
Slangen, A. B., Church, J. A., Agosta, C., Fettweis, X., Marzeion, B., & Richter, K. (2016). Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change, 6*(7), 701.
Stottmeister, U., Wießner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., . . . Moormann, H. (2003). Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotechnology advances, 22*(1-2), 93-117.
Sukias, J., Yates, C., & Tanner, C. (2010). *Floating treatment wetlands for remediation of eutrophic lake waters–macro stream trials (Lake Rotoehu).* Paper presented at the Proceedings of NZ Water Conference.
Sweet, W. V., Kopp, R. E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E. R., & Zervas, C. (2017). Global and regional sea level rise scenarios for the United States.
Tait, P. R., & Cullen, R. (2006). *Some external costs of dairy farming in Canterbury.* Paper presented at the Australian Agricultural and Resource Economics Society Annual Conference.
Tan, Z. (2018). *Rsearch placement of exploration on values from wetland*. School of Landscape Architecture, Lincoln University.
Tanner, C., Nguyen, M., & Sukias, J. (2005). Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. *Agriculture, ecosystems & environment, 105*(1-2), 145-162.
Tanner, C. C., & Kloosterman, V. C. (1997). *Guidelines for constructed wetland treatment of farm dairy wastewaters in New Zealand*: NIWA.
Tanner, C. C., Kloosterman, V. C., & Champion, P. D. (2006). *New Zealand constructed wetland planting guidelines*: NZWWA.
Tanner, C. C., Sukias, J., Park, J., Yates, C., & Headley, T. (2011). Floating Treatment Wetlands: A new tool for nutrient management in lakes and waterways. *Methods, 2008*(2011).
Tanner, C. C., Sukias, J. P., Headley, T. R., Yates, C. R., & Stott, R. (2012). Constructed wetlands and denitrifying bioreactors for on-site and decentralised wastewater treatment: comparison of five alternative configurations. *Ecological Engineering, 42*, 112-123.
Turcios, A. E., & Papenbrock, J. (2014). Sustainable treatment of aquaculture effluents—what can we learn from the past for the future? *Sustainability, 6*(2), 836-856.

Uuemaa, E., Palliser, C. C., Hughes, A. O., & Tanner, C. C. (2018). Effectiveness of a Natural Headwater Wetland for Reducing Agricultural Nitrogen Loads. *Water, 10*(3), 287.

Van Ballegooy, S., Malan, P., Lacrosse, V., Jacka, M., Cubrinovski, M., Bray, J., . . . Cowan, H. (2014). Assessment of liquefaction-induced land damage for residential Christchurch. *Earthquake Spectra, 30*(1), 31-55.

Vitousek, S., Barnard, P. L., Fletcher, C. H., Frazer, N., Erikson, L., & Storlazzi, C. D. (2017). Doubling of coastal flooding frequency within decades due to sea-level rise. *Sci Rep, 7*(1), 1399. doi:10.1038/s41598-017-01362-7

Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. *Water, 2*(3), 530-549. doi:10.3390/w2030530

Vymazal, J. (2017). The use of constructed wetlands for nitrogen removal from agricultural drainage: a review. *Scientia Agriculturae Bohemica, 48*(2), 82-91.

Walton, M., Vilas, C., Cañavate, J., González-Ortegón, E., Prieto, A., Van Bergeijk, S., . . . Le Vay, L. (2015). A model for the future: Ecosystem services provided by the aquaculture activities of Veta la Palma, Southern Spain. *Aquaculture, 448*, 382-390.

Walton, M., Vilas, C., Coccia, C., Green, A. J., Cañavate, J. P., Prieto, A., . . . King, J. (2015). The effect of water management on extensive aquaculture food webs in the reconstructed wetlands of the Doñana Natural Park, Southern Spain. *Aquaculture, 448*, 451-463.

Watanabe, T. (2018). Paddy Fields as Artificial and Temporal Wetland *Irrigation in Agroecosystems*: IntechOpen.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, xiii-xxiii.

Wehi, P. M., & Lord, J. M. (2017). Importance of including cultural practices in ecological restoration. *Conservation Biology, 31*(5), 1109-1118.

Whitby, C. L. (2018). *The barriers to, and opportunities for, restoring wetland ecological function on privately-owned New Zealand farms.* University of Otago.

Worku, H. (2017). Integrating climate change adaptation strategies in urban planning and landscape design of Addis Ababa City, Ethiopia: Using urban planning and landscape design to mitigate flooding, drought, and urban heat island effects. *Environmental Quality Management, 27*(1), 5-21.

Worldometers. (2019). New Zealand Population (LIVE). *worldometers.*

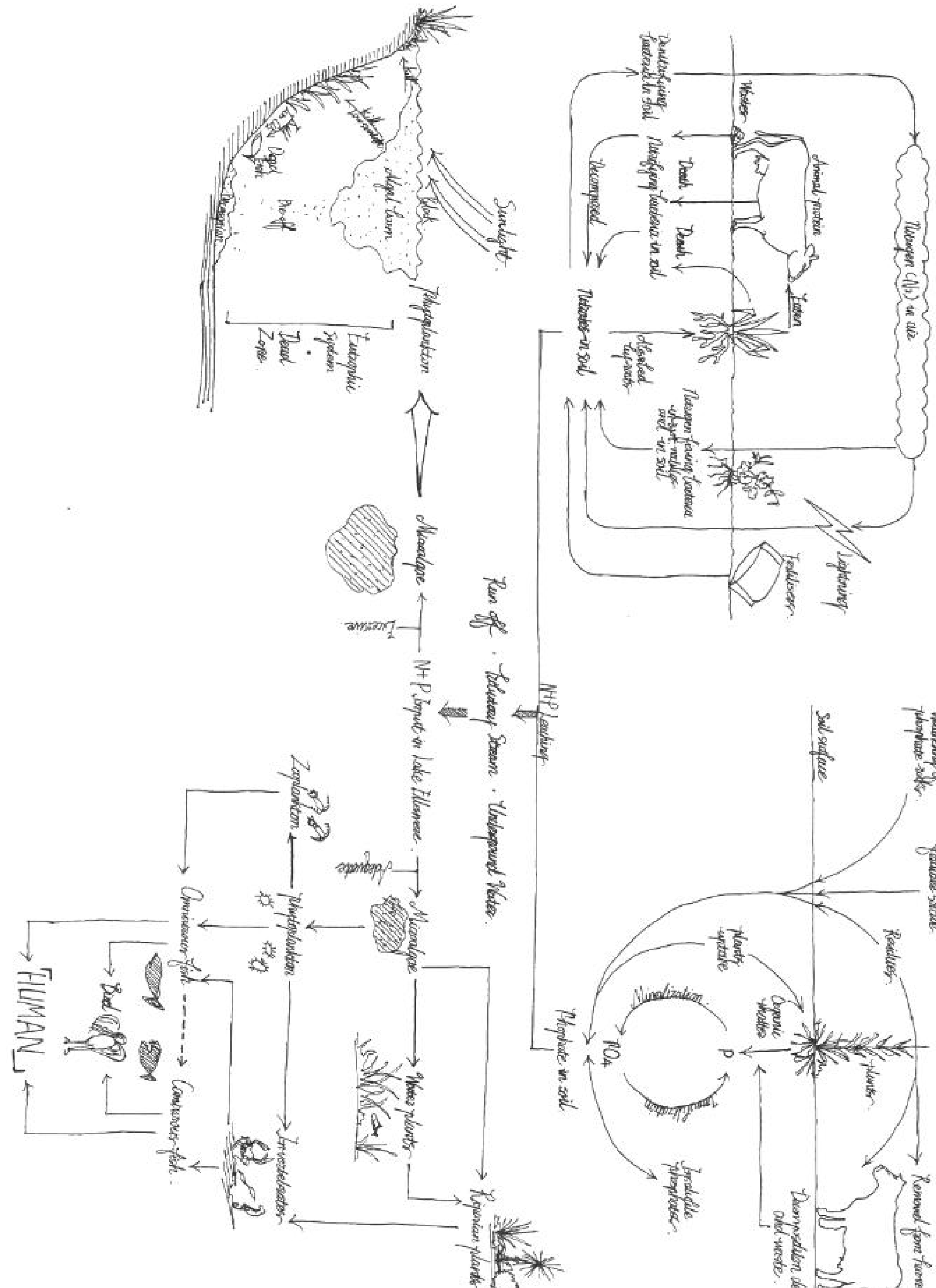
Xiong, Y., Peng, S., Luo, Y., Xu, J., & Yang, S. (2015). A paddy eco-ditch and wetland system to reduce non-point source pollution from rice-based production system while maintaining water use efficiency. *Environmental Science and Pollution Research, 22*(6), 4406-4417. doi:10.1007/s11356-014-3697-7

Yang, P., & Zhu, W. (2013). *The exploitation of rice paddy field and its ecological protection.* Paper presented at the 2013 Third International Conference on Intelligent System Design and Engineering Applications.

Zedler, J. B. (2000). Progress in wetland restoration ecology. *Trends in ecology & evolution, 15*(10), 402-407.

Zhou, S., & Hosomi, M. (2008). Nitrogen transformations and balance in a constructed wetland for nutrient-polluted river water treatment using forage rice in Japan. *Ecological Engineering, 32*(2), 147-155.

Appendix A - Existing nutrients system of Lake Ellesmere



Appendix B - Research placement of exploration on values of wetlands

2. RESEARCH FRAMEWORK

2.1 COLLECT AND STRUCTURE RELEVANT MATERIALS

2.11 Collect Materials

First, resources are collected through online search engine and library. This primary focus on resources within a New Zealand context. For selection Endnote will be used along the way to effectively manage the reference of the collecting resources, as shown in figure 2.

Relevant keywords are identified and used for searching through gathered resources to find out what people from different professions think what values wetlands can create in the New Zealand context. The relevant resources include academic literature, case studies and several official guidelines in New Zealand. The literature represents the views from the academy, case studies represent the opinions from the industry, and official guidelines show general instructions that from the government. In total, 72 materials from various sources that could contribute to our understanding of wetland in New Zealand's perspective has been collected.

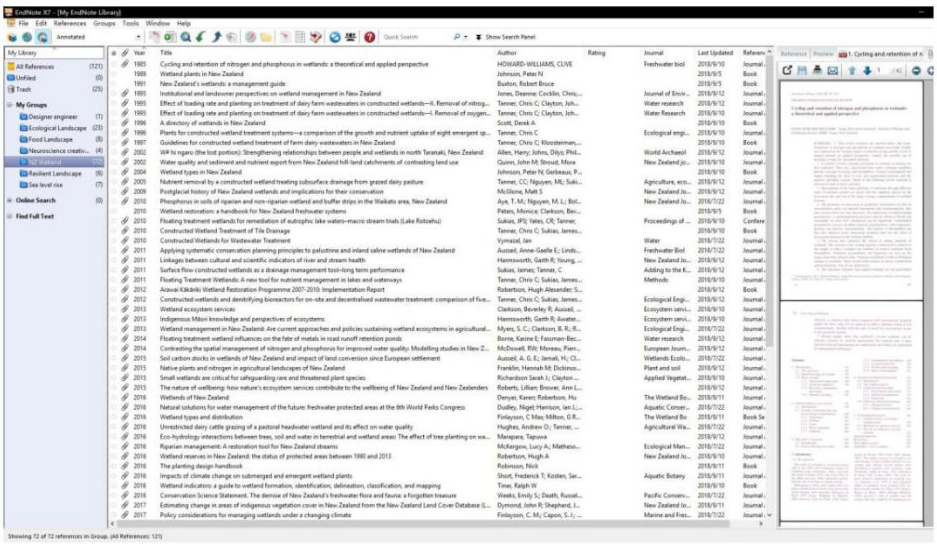


figure 2. Using Endnote to manage reference

2.12 Structure Materials

All materials collected are structured into a table, shown on figure 3, see Appendix One. This table concluded the values of economical, ecological and social-cultural aspects that people recognized in New Zealand's perspective. Values concluded there will be structured into the evaluation framework in section 2.2. In the table, a brief description is made to introduce what the materials talk about, a conclusion is made to conclude the findings of each material. In the end, design related concepts were concluded respectively to express the author's opinion on the wetland in a designer's perspective and these opinions will be used to form the best-practice design guideline of wetland in section 2.3.

RESEARCH PLACEMENT OF EXPLORATION ON VALUES FROM WETLAND - APPENDIX ONE

Materials	Values	No.	Description	Conclusion	Deisgn relate Concepts
HOWARD-WILLIAMS, C. (1985). "Cycling and retention of nitrogen and phosphorus in wetlands: a theoretical and applied perspective." Freshwater biology 15(4): 391-431.	Remove unwanted nutrients	1	• This review considers the internal fluxes and transformations ot nitrogen and phosphorus in wetland ecosystems. • Emphasis is placed on the dynamic nature of nutrient cycling and the review is slanted towards an applied perspective, namely the possible use of wetlands as sinks for unwanted nutrients.	• Wetlands could be used as sinks for unwanted nutrients. • Artifical wetland have greater ability to remove unwanted nutrients.	Artificial wetland are more capable in remove unwanted nutrients.
Johnson, P. N. (1989). Wetland plants in New Zealand, DSIR.	Increase indigenous plants Provide habitat	2	• A field guide to illustrate the native and naturalised plants of New Zealand's bogs, swamps, estuaries and lakes. • Line drawings are complemented by text describing key features, distributions and habitats.	n/a	Wetland plants in NZ has high ecological value
Buxton, R. B. (1991). New Zealand's wetlands: a management guide, Department of Conservation and the former Environmental Council.	Increase Biodiversity	3	• This guide is a joint publication of the former Environmental Council and the Department of Conservation, New Zealand. Include bibliographic references.	• Wetland of NewZealand carry high ecological value, but also is threatened.	Wetland plants in NZ has high ecological value
Jones, D., et al. (1995). "Institutional and landowner perspectives on wetland management in New Zealand." Journal of Environmental Management 45(2): 143-161.	Increase indigenous plants Provide habitat Improve Water quality	4	• The new institutional arrangements for resource management in New Zealand are outlined and their implications for wetland protection and management are highlighted. • We report on a questionnaire survey administered to resource management agencies (local and regional councils) throughout the country on the subject of wetland protection and management. • This is followed by a discussion of a second questionnaire survey, administered to a sample of landowners in one planning jurisdiction.	• Wetland of NZ carry high ecological value and emerging economic value, which are undervalued. • Only 8% Natural wetland of NZ remain. • Wetland of NZ suffer from people's view, to them, wetlands are indeed wastelands. • Utilitarian attitudes of landowners may cause issues by transform the use of wetland. • The Resource Management Ac may provide an improved framework for the protection and management of wetlands.	landowners attitude matters a lot.

figure 3. An example of values-exploring framework

2.13 Discussion

From Appendix One, it could be seen that 50 out of 72 related materials are focusing or shows recognize on the ecological values of the wetland. Meanwhile, 15 out of 72 are focusing or shows recognize on the social-cultural values of wetland and only 8 out of 72 are on economical aspect, especially only 1 of them are mainly focusing on expressing economy value. Thus, this indicates that existing New Zealand's studies are more focused on releasing ecological values and least on economical values. Therefore, it could be the research gap which requires further study on expressing economical values in a New Zealand's perspective.

In order to fill the gap found in collected New Zealand based materials, 20 selected materials out of 33 from overseas are used to create another table which has similar structure like figure 3 to conclude foreign academic's recognition on values expressing from the wetland, see Appendix 3. The selection of research papers is firstly searched by the combination of keywords, like wetland + economy and wetland + income. In order to find more relevant materials, more specific words based on common knowledge are used in the combination, like wetland + rice production and wetland + tourism. Then 20 of them are selected based on their citation number shown on google scholar as generally more cited academic papers could show a more general or popular understanding about the topic. Therefore, this table could contribute to our understanding of the economic values of the wetland in global perspectives.

2.2 ANALYSIS MATERIALS

2.21 Analysis Materials

The second stage of this research aims to review collected resources and identify different key ideas and concepts on wetlands, which might include how they should be structured for maximising economic values, or what they might mean to the indigenous culture.

By indicating how these ideas and concepts are changing gradually through time. It might be possible to capture the dynamic of these trends and reveal the actual values of wetland that people expected in now or even the near future. In this, the wetland that is designed based on this guideline could be more adaptable in the future, especially in performing ecosystem services.

An analytical table is used to list out these values with their supporting materials. Major authors from these materials are listed as well to facilitate the readers to find the specialists of wetland in New Zealand. This table shows what are the values of wetland and how much the people values, shown in figure 4, see Appendix 3.

RESEARCH PLACEMENT OF EXPLORATION ON VALUES FROM WETLAND

- APPENDIX THREE -

No.	Values Explored	Supporting Resources	Major Authors in NZ
1	Remove unwanted nutrients	NZ: 1,5,6,8,9,13,15,17,18,19,22,23,25,26,28,30,34,48,50,54,55,56,71	
2	Provide habitat for wildlife	NZ: 2,4,5,24,26,40,43,44,46,58,60,67,71	
3	Improve Water quality & Security	NZ: 4,11,34,36,38,39,43,44,58,67,71	
4	Increase Biodiversity	NZ: 3,7,12,20,24,26,28,35,45,60,71	Ausseil, A.G.E x 2
5	Defences against flood	NZ: 26,28,34,39,58	Clarkson, Beverley x 2
6	Regulate water	NZ: 26,34,44,71	Finlayson, C. M x 3
7	Trap sediment	NZ: 5,11,71	Johnson, Peter N x 2
8	Climate regulator	NZ: 5,26,34	McDowell, RW x 2
9	Provide condition for indigenous plants	NZ:2,4,40	Robertson, Hugh A x 2
10	Sinks of carbon	NZ: 31,71	Tanner, Chris C x 8
11	Increase resilience of ecological system	NZ: 26,34	Vymazal, Jan x 2
12	lifecycle maintenance	NZ: 26,34	
13	Keep endangered plants	NZ: 33	
14	Increase sedimentation of heavy metals	NZ: 29	
15	Increase decompostion of organic matter	NZ: 5	
16	Generate Income/Reduce Lost	NZ: 26,28,34,39,58 ------ GLOBAL: 7,8,12,16,17,20	Clarkson, Beverley x 1
17	Food Production	NZ: 26,44 ----------------- GLOBAL: 1,2,4,6,9,10,11,18,19	Myers, S. C. x 1
18	Tourist attraction/services	NZ: 26,49 ----------------- GLOBAL: 3,5,13,14,15	Ndebele, T. x 1
19	Provide Cultural value of Maori	NZ: 7,10,14,21,26,27,35	
20	Increase Well-being	NZ: 12,26,34,67	
21	Educational	NZ: 26,34,58,60	
22	Recreational	NZ: 26,34,35,58	Allen, Harry x1
23	Aestheic value	NZ: 5,26	Clarkson, Beverley x 1
24	International and national significance	NZ: 28, 58	Denyer, K x 1
25	Provide Cultural value of European	NZ: 7	Harmsworth, Garth R x2
26	Science research	NZ: 45	
27	cultural harvest	NZ: 60	
28	Spiritual	NZ: 26	

figure 4. Table of values exploring from wetland

2.22 Discussion

In total, 28 types of values from the wetland are found in a New Zealand's perspective. Among them, 15 of them are ecological values, such as Remove unwanted nutrients, Provide habitat for wildlife and Improve Water Quality & Security. 10 of them are social-cultural values, such as Provide Cultural value of Maori, Increase Well-being and Educational. 3 of them are economical, such as Generate Income/Reduce Lost, Food Production and Tourist attraction/services.

From above, it could be seen that most values explored by New Zealand based research are ecological, which its top three values, remove unwanted nutrients, provide habitat and improve water quality are the most popular values embraced by New Zealand researchers. In this way, from the values expressed above, the wetlands in New Zealand are most recognized for its ecological values. Among these researchers, Tanner, Chris C as the most contributory author about exploring ecological values of wetland, is the profession you want to talk about in designing a wetland in New Zealand.

The number of social-cultural values is explored a lot. Even the supporting materials are still outnumbered by ecological values. The most important value in this aspect is the cultural value of Maori, who have been having a long history of living with wetland and carry abundant traditions about living with wetland as well. The well-being, educational and recreational values have been brought up a lot as well. In this way, from the values expressed above, the wetlands in New Zealand are also recognized for its social-cultural values.

There are only three economical values generally expressed from New Zealand based wetland researches, generate income/reduce lost, food production and tourist attraction/services. This could indicate that there is still a research gap on exploring economical values of the wetland. With 20 materials which are focusing on releasing economical values of the wetland in the global aspect, the existing values become stronger, but there is still none new values have been identified.

The most recognized economical values of the wetland are generated income/reduce lost. The reason I put them together, is because (Nelson, Loomis et al. 2015) implies that a new perspective that reduce lost could also be seen a part of generate income, especially when we plan to reduce lost for the future. Compare to the other two values, food production and tourism, generate income/reduce lost seems to be more generally. Other than it is an umbrella idea that brought up by some authors who did not dig further, this value here also represents to those values which still had to be quantified or hard to estimate.

From here, it could be seen that the economical values of the wetland are not much diversified and this means in order to explore economical values from the wetland, we need to go deeper to build the economical values of the wetland stronger. To this goal, a set of best-practice guidelines are provided, discussed and be applied to the example in the following sections.

3. BEST-PRACTICE DESIGN PRINCIPALS

With a summary report of useful findings, the third stage focus on developing a set of best practice guidelines, which includes relevant conceptual schematics to facilitate future designers in exploring desired values from New Zealand wetland. The best-practice design principles of wetland have five types:

1. Principals for planning
2. Principals for design
3. Principals for releasing ecological values
4. Principals for releasing social-cultural values
5. Principals for releasing economical values

3.1 GENERAL PRINCIPALS IN PLANNING STAGE

3.11 Site selection for wetland should first consider its soil condition, and thus where used to be wetland is more suitable for establishment of wetland

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*the correct substrate conditions are critical for proper plant and animal colonisation and growth in wetlands*" and "*An analysis of existing soil conditions should be conducted before wetland restoration or creation*". Then it further states that "*soils of former wetlands will be more suitable for native plant and animal species than soils at newly created sites*".

I conclude this principle in a landscape design aspect as site selection for wetland should first consider its soil condition, and thus were used to be wetland is more suitable for the establishment of wetland. This means in designing a wetland, we should consider the soil condition first for wetland site selection as it is one of the few things that hard or expensive to change the implementation.

3.12 The size and types of wetland should be considered based on the water resources available

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*The most important considerations involve estimates of water inputs and outputs to the proposed design*" and "*the water regime balance will help determine parameters such as stream width, basin depth, and whether it needs additional water*".

I conclude this principle in a landscape design aspect as the size and types of the wetland should be considered based on the water resources available. This means in designing a wetland in a dry zone like Christchurch, we could reduce water output by reducing evaporation, like reduce water exposed zone in wetland or even totally cover the wetland with a vegetated surface.

3.13 Planning of wetland should be considered within the bigger context

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*Wetland protection, restoration, and management must consider the larger area of which the system is a part, to achieve sustainable outcomes*" and it further explained "*this includes catchment properties, especially upstream effects but including downstream effects in tidal systems. A transitional buffer between residential development or farmland and a wetland will greatly assist the management of a wetland, by ameliorating these adverse effects*"

I conclude this principal in a landscape design aspect as planning of wetland should be considered within the bigger context.

3.2 GENERAL PRINCIPALS IN DESIGN STAGE

3.21 Flexible and mufti-functional design can improve environmental adaptability

The first principal Tanner (Tanner and Kloosterman 1997) has provided is "*Flexibility and versatility, to enable operation in a number of different modes, at a range of water levels and flows.*" After this, the author tried to explore more on flexibility out of wetland in joining a floating wetland research with Sukias (Sukias, Yates et al. 2010). Then the author (Tanner, Sukias et al. 2011) finished his own research on FTW(Floating Wetland) and found FTW *"tolerance of deep and fluctuating water levels, enables FTWs to be retrofitted into ponds, lakes and slow-flowing waterways."* Besides, the function of FTW system is further illustrated by (Borne, Fassman-Beck et al. 2014) who states "*FTW in a conventional retention pond would increase the overall sequestration of Cu and Zn in the pond sediment.*"

From here, I conclude the first principal in a landscape design aspect as flexible and multi-functional design can improve environmental adaptability. This means in designing a wetland, we should break a big zone into several small zones first and then try to explore the opportunities from each of them by analysing its environments like topography, water-level and sun-shade. For example, If we design a big zone of wetland where consisted of a small deep pond, there could be a high chance for designers to ignore the possibility of developing wetland on the deep pond. But by breaking it down into parts, it could be easier for the designer to see the opportunity to implement FTW on the deep pond. In this way, the wetland could express stronger multiple ecosystem services as a whole and adopt the environment better.

3.22 Constructed wetland should cover about 1% of the site to maximize its nutrient removal ability

Tanner (Tanner, Nguyen et al. 2005) stated that "*constructed wetlands comprising □ 1% of catchment area can markedly reduce N export via pastoral drainage*" and this was further discussed by Vymazal (Vymazal 2017) who indicates that "*the W/C greater than 1% does not result in any substantial increase of nitrogen removal*".

I conclude this principle in a landscape design aspect as constructed wetland should cover about 1% of the site to maximize its nutrient removal ability. This means in designing a wetland, we should not use more than 1% catchment area to build a constructed wetland for removing current unwanted nutrients. Other available zones could be used to build restored natural wetland to express more ecological values and/or develop more economical values from food production.

3.23 Constructed wetland can deal with storm water directly, natural wetland is supposed to only handle the pre-treated storm water

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*stormwater should be directed to constructed wetlands and other treatment systems, whereas natural wetlands should only receive treated stormwater*" and this idea is supported by "*Obviously, pristine, low nutrient, high diversity natural bogs and wetlands with special conservation value should not be subject to wastewater disposal*" (Tanner and Kloosterman 1997). However, Tanner also debates that "*most wetlands and wetland remnants in agricultural landscapes are highly modified and relatively high in nutrient status...will generally be less sensitive to change and readily able to assimilate additions of appropriately treated wastewater*".

I conclude this principle in a landscape design aspect as constructed wetland can deal with stormwater directly, natural wetland is supposed to only handle the pre-treated stormwater. This means in designing a wetland, we could see a constructed wetland as a green infrastructure that purifies water, but we should not regard the same for natural wetland as it bears much more values which make it more vulnerable. For example, even in a natural wetland, there still could be needed to set a constructed wetland to treat surrounding wastewater as pre-treatment. Already Highly nutrient wetland is an exception.

3.24 Whether water level of wetland is allowed to change and how much should we expected should be include in the design

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*wetlands with fluctuating water levels are inherently different from those with essentially stable water levels. Design thus needs to determine the total hydrological regime*" and "*Wetlands comprise a transition sequence from water to dry land. This diversity of habitat and plant types provides for a diversity of animal species and communities. Induced changes to the water level regime are clearly the greatest threat to these habitats*".

I conclude this principle in a landscape design aspect as of whether the water level of the wetland is allowed to change and how much should we expect should be included in the design. This means in designing a wetland, for where we plan to keep endangered species or providing habitat effect, less water level change would be better. For where are supposed to deal with the water change, the input and output need to be carefully designed to mitigate the effect of water level changing.

3.25 life span of wetland should be considered in design, and designer need to decide if you need to replace it or rejuvenate it

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*natural successional processes result in accumulation of organic matter and silt, moving towards a drier, less wet state. This succession process will likely be sped up in urban and rural areas through increased sedimentation and nutrient levels.*" and "*One major consideration in the construction of wetlands is their intended life. It needs to be decided whether succession will be allowed to proceed and new wetlands created elsewhere to compensate, or if wetlands will need to be rejuvenated by eventual dredging and replanting*".

I conclude this principle in a landscape design aspect as the lifespan of the wetland should be considered in the design, and designer needs to decide if you need to replace it or rejuvenate it. This means in designing a wetland, the shallow wetland has better nutrient removal ability, but deep wetland has a longer lifespan, thus the depth of the wetland should be considered based on what outcome do you want and how long do you want it to last.

3.26 Plan route carefully to avoid external damage on sensitive plants

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states "*Wetlands provide opportunities for environmental education, passive recreation, and cultural harvest*" and "*However, wetland wildlife and some wetland plants are very sensitive to disturbance. Thus wetland access by people and pets should always be considered carefully*".

I conclude this principle in a landscape design aspect as plan route carefully to avoid external damage on sensitive plants. This means in designing a wetland, we should guide the public to go in where wetland express social-cultural values while reducing the negative effects on a high ecological valued zone. There are some suggestions from The Waterways, wetlands and drainage guide from Christchurch City Council (2018):
1) signage and interpretation: clearly outline the desirable and expected behaviour.

2) formed tracks and boardwalks: locate these away from sensitive areas.
3) fences: simple post and wire fences can effectively isolate sensitive areas.
4) shrub planting: densely planted shrub associations provide shelter and screening for wildlife islands and moats: these provide both refuges and nesting sites for wildlife. Note that some predators are not deterred by water.

3.3 PRINCIPALS FOR RELEASING ECOLOGICAL VALUES

3.31 Hybrid use of different types of constructed wetland can improve nutrient removal ability

Jan (Vymazal 2010) states that "*All types of constructed wetlands are very effective in removing organics and suspended solids, whereas removal of nitrogen is lower but could be enhanced by using a combination of various types of CWs(constructed wetlands)*". This idea if further supported by Tanner (Tanner, Sukias et al. 2012), who said "*Simple hybrid systems combining wetland and denitrifying bioreactor components are capable of achieving advanced effluent quality with low energy inputs*".

I conclude this principle in a landscape design aspect as the hybrid use of different types of constructed wetland can improve nutrient removal ability. This means in designing a wetland, we should use different types of constructed wetlands like the horizontal constructed wetland, vertical constructed wetland and floating constructed wetland with various advantages in removing unwanted nutrients to enhance the total efficiency of nutrient removal.

3.32 Wetland on critical zones can enhance efficiency of nutrient removal while control the cost

McDowell (McDowell, Moreau et al. 2014) stated that "*It is recommend to manage critical source areas to improve water quality and minimise the impact on farm profitability*" and this vision is supported by the author's (McDowell, Monaghan et al. 2017) further study which stated that "*Prioritising on the basis of mitigation cost-effectiveness for a specific nutrient will lead to more rapid reductions in losses of the target nutrient.*" and he also mentioned "*but with fewer co-benefits for the non-target nutrient or other water pollutants, such as faecal microorganisms and sediment*". Uuemaa

(Uuemaa, Palliser et al. 2018) further explain the critical zones mentioned abo "*small seepage wetlands in the headwaters of New Zealand streams can be very effective at removing nitrogen loads*".

I conclude this principle in a landscape design aspect, the wetland of critical zones can enhance the efficiency of nutrient removal while controlling the cost. This means in designing a wetland, we should put a constructed wetland on critical zones like the headwaters to remove unwanted nutrients in a more economical way.

3.33 Big wetland can express more ecological values, but small wetland could contribute to protect the endangered species

McGlone (McGlone 2009) states that "*the major conservation emphasis should be on larger wetlands that provide a range of ecosystem services*" and Ausseil (Ausseil, Lindsay Chadderton et al. 2011) added "*Highest ranked (ecological value) sites in each biogeographic unit were usually the largest remaining wetlands that contained multiple wetland classes*". From here, it could be seen that bigger wetland could express much more ecological values than small wetlands. However, Richard (J., Richard et al. 2015) explore more values from small wetlands by indicating "*Small wetlands are critical for safeguarding rare and threatened plant species*".

I conclude this principle in a landscape design aspect as big wetland can express more ecological values, but small wetland could contribute to protecting the endangered species. As there is no research on describing how to categorize a wetland as big or small, this means in designing a wetland, we should plan bigger wetland or connected wetlands to express more ecosystem services rather than put several disconnected small wetlands. However, even if there is a small wetland that hard to combine with others, its value of protecting endangered species should be valued as well.

3.34 Complex topography could generate more vegetation and animal community

The Waterways, wetlands and drainage guide from Christchurch City Council (2018) states that "*Hydrology is directly affected by local topography. The variation in both elevation and flow that are associated with a complex topography are required for heterogeneous hydrological processes, which in turn create variable vegetation and animal communities*".

I conclude this principle in a landscape design aspect as complex topography could generate more vegetation and animal community. This means in designing a wetland, we should make good use of the differences in existing topography like from horizontal and vertical to create a variable environment for different types of wetland where various wild animals live.

3.35 Shallow wetland has greater ability of nutrient removal, but fence protection is required

Aye (Aye, Nguyen et al. 2010) states that "*Soils at lower depths (2.5 – 7.5 and 7.5 – 15 cm) were found to have higher P sorption and higher P buffering capacity*" and "*subsoils may therefore play an important role in controlling P release*". From here, it implies that shallow wetland could remove more nutrients like P from the water body. However, Robertson (Robertson and Suggate 2012) indicates that shallow wetlands are vulnerable to herding animals and he recommends to put fence for protection and this idea is supported by McKergow (McKergow, Matheson et al. 2016) who further states that "*riparian fencing and planting are now standard best practice tools for water quality and habitat restoration*" and by (McKergow, Matheson et al. 2016) "*In 2015, 96% of dairy cows had been excluded from water-ways >1 m wide and >30 cm deep on land that cows graze during the milking season*". In contrast with shallow wetland, deep wetland seems to be prone from herding animal's damage which states by Hughes (Hughes, Tanner et al. 2016) "*We attribute the low level of wetland grazing to the cattle recognizing the risk of entrapment in the deep (up to 2 m), boggy wetland soil*" and "*Exclusion of cattle from our study wetland by fencing is therefore unlikely to substantially improve downstream water quality*".

I conclude this principle in a landscape design aspect as shallow wetland has a greater ability of nutrient removal, but fence protection is required. This means in designing a wetland in the pastoral field, we should protect the shallow wetland by fence, riparian plants or surround by deep water or deep wetland (up to 2 m).

3.4 PRINCIPALS FOR RELEASING SOCIAL-CULTURAL VALUES

3.41 Increase the use of native plants can enhance indigenous values

Franklin (Franklin, Dickinson et al. 2015) states that "*native plants have a role in riparian zones and paddock margins designed to protect waterways from N leachates*".

I conclude this principle in a landscape design aspect as increase the use of native plants can enhance indigenous values. This means in designing a wetland, we should use more native plants which also perform relatively good ecosystem services to improve indigenous value.

3.42 Respect and explore indigenous cultural value in designing wetland

Scott (Scott 1996) states "*there is considerable history of modification and use of wetlands by both Maori and Europeans. The history of wetland conversion and modification often relates to expansive phases of New Zealand history*" and this idea is supported by Allen (Allen, Johns et al. 2002) who states "*one of their (M ā ori) concerns is with cultural wetlands. Wetlands contain M ā ori, archaeological and ecological values*". Besides, Harmsworth (Harmsworth, Young et al. 2011) further explored the cultural value in monitoring the wetland and states "*using scientific approaches alongside culturally based monitoring provides a wealth of knowledge to understand better what we mean by river health*".

I conclude this principle in a landscape design aspect as respect and explore indigenous cultural value in designing wetland.

3.43 Introduce ornamental plants into wetland could express more aesthetic and ecological values

Calheiros (Calheiros, Bessa et al. 2015) states that "*It was demonstrated that CW systems planted with a polyculture of ornamental plant species, besides the water treatment function, possess several additional benefits including aesthetics and biodiversity enhancement*".

I conclude this principle in a landscape design aspect as introduce ornamental plants into wetland could express more aesthetic and ecological values. This means in designing a wetland, we should plant more ornamental plant species alongside or inside of the wetland to add more structure to the plant composition to increase amenity and provides some ecological values like providing shade, become habitat or stabilize the riparian soil.

3.44 Develop wetland tourism could contribute to public awareness of wetland protection, especially with the assist of visitor center and guiding services

Do (Do, Kim et al. 2015) states "*visiting wetlands is becoming an increasingly popular form of ecotourism in South Korea, supporting the importance of preserving this fragile ecosystem service*" and this idea is supported by Sharma (Sharma, Rasul et al. 2015) "*proper planning and management of community-based tourism to ensure wider benefit to the local community*". Do (Do, Kim et al. 2015) further indicate two two related findings "*wetland visitor centers have an important role in wetland ecotourism and education*" and "*Guided educational and sightseeing programs for visitors, including independent, group, and family tourists, are helpful for effectively raising awareness of wetlands and distributing ecotourism concepts*". Khoshkam (Khoshkam, Marzuki et al. 2016) did study on similar aspect and indicate "*A positive relationship was found between the economic impact of tourism development and family size, distance from tourism zone, and length of residency*".

I conclude this principle in a landscape design aspect to developing wetland tourism could contribute to public awareness of wetland protection, especially with the assistance of the visitor centre and guiding services.

3.5 PRINCIPALS FOR RELEASING ECONOMICAL VALUES

3.51 Simple-constructed and easy-operated design can reduce cost on implementation

The second principal Tanner (Tanner and Kloosterman 1997) has provided is "*Simplicity of construction and operation. Control structures should be easy to operate, and require minimal day to day maintenance.*"

I conclude this principle in a landscape design aspect as simple-constructed and easy-operated design can reduce cost on implementation. This means in designing a wetland, we should keep the design simple to avoid creating difficulties by abusing complicated patterns, more focus should be put on releasing more ecosystem services from the wetland by applying the simple and practical design. In other words, the function is prior than form in wetland design. Thus, the design is easier to work well and also reduce the cost of implementation.

3.52 Easy-maintained design of wetland can reduce cost on maintenance

The third principal Tanner (Tanner and Kloosterman 1997) has provided is "*Provision for maintenance works to be carried out easily and quickly*".

I conclude this principle in a landscape design aspect as easy-maintained design of wetland can reduce cost on maintenance. This means in designing a wetland, we should bear some thought about maintenance in mind. For example, follow the topography in design will reduce much effort on maintenance compare to against it, even though sometimes against it could express more aesthetic values. An easier maintained wetland which requires less effort from the landowner should increase their will to establish their wetland in the first place.

3.53 Design should go along with the owner's personal and business goals to make it happen

Jones (Jones, Cocklin et al. 1995) states that "*an important prerequisite to the improved protection and management of wetlands may be the wider dissemination of knowledge about the full range of values that are based in these ecosystems.*" Then he further added "*environmental protection will follow from improved information and understanding, and this is undeniably true in the case of wetlands*". From here, it highlights that people's awareness about the values from wetland is the first thing for effective wetland protection. Then he further indicates that "*in order to be effective, conservation management programmes will need to engage a range of planning mechanisms, including specifically those based on economic incentives and perhaps financial compensation*" and "*the effort must involve restoration of degraded ecosystems and even the creation of new areas*". From here, the author implies economic incentives and creation of new wetland are important for wetland protection. Whitby (Whitby 2018) further added that "*it was important for wetland projects to align with farmers' wider goals, which increased their motivation to develop their wetlands*" and "*the success of wetland developments would be greatly increased if farmers were motivated to create wetlands and recognise the benefits of restoring EF without the enforcement of regulations*".

I conclude this principle in a landscape design aspect as design should go along with the owner's personal and business goals to make it happen. This means in designing a wetland, we should explore more values from the wetland that desired by the owner. For example, if the owner wants more money, then the wetland should be designed on releasing more economical values. If the owner wants to have more amenity, then the aesthetic values should be the first to release.

3.54 Plan and design wetland to prepare for anticipated climate change and its following impacts

Short (Short, Kosten et al. 2016) states "*effects of GCC on all these communities have already been seen with many others predicted, including: shifts in species composition, shifts in range and distribution, and declines in plant species richness*" and "*Overall, losses are likely in all these wetland plant communities yet their species can adapt to GCC to some degree if well managed and protected*".

I conclude this principle in a landscape design aspect as plan and design wetland to prepare for anticipated climate change and its following impacts. This means in designing a wetland, we should use design measures to prepare for the anticipated climate change and its following impacts. For example, a less exposed and deep wetland has greater ability to deal with extreme weather and carry more water.

3.55 Integrate food production into wetland system could contribute to the balance the watershed ecosystem and economic development

Camacho (Camacho-Valdez, Ruiz-Luna et al. 2014) states "*14 % decrease in the saltmarsh/forested mangrove area and a 12 % increase in the area of shrimp pond aquaculture*" and "*the total value flow increased by 9 % from $215 to $233 million (2007 USD) during the 10-year period*". And this idea is supported by Turcios (Turcios and Papenbrock 2014) who further added "*Constructed wetlands technology is becoming more and more important in recirculating aquaculture systems (RAS) because wetlands have proven to be well-established and a cost-effective method for treating wastewater*".

Walton (Walton, Vilas et al. 2015) further conclude the relationship between aquaculture and wetland "*The study demonstrates the possibility of using aquaculture to mitigate the historical loss of wetlands, provide significant ecosystem services and contribute to achievement of the European environmental legislative goals, and furthers the opportunity for the expansion of aquaculture into sensitive but impacted habitats*" and this idea is supported by Ni (Ni, Xu et al. 2016) who states "*CW was an effective method to balance the watershed ecosystem and economic development. Provide a mechanism map in the evaluating the economical development and ecological values in CW*". From here, it reveals that aquaculture could be a profitable practice developed along with wetland and this have the potential to achieve bigger goals and build a sustainable development mechanism.

Then Turcios (Turcios and Papenbrock 2014) introduce two profitable system "*Fish–phytoplankton–shellfish systems convert the fish waste into bivalves, which have a large global market value*" and "*Fish–seaweed–macroalgivore systems have a choice of marketing either the seaweed or the macroalgivore, while they use less land than the fish–phytoplankton–shellfish systems and maintain a more stable water quality*".

For the economical agricultural output, Lin (Lin, Li et al. 2015) illustrates "*annual fish yield decreased slightly after the change in management, whereas fisheries income increased 2.6 times*" and "*during this six year period, water clarity increased significantly from 61 cm to 111 cm*". From here, it shows that high economical valued species could generate more income with less population and thus less organic waste effluent output. Thus in selection for aquaculture species along with constructed wetland, high valued species will be beneficial for both economical and ecological aspects.

The author further discussed about wetland with aquaculture system "*wetland methods may need a large land area when a great amount of aquaculture wastewater needs to be treated*" and "*the combination of effective pre-treatment (80% TSS removal) with small constructed wetlands processing high hydraulic loads, are economically most feasible*". From here, it means big constructed wetland could treat wastewater with minimum energy input, but in joining with a pre-treated system, more waste water could be treated with less land occupation.

Berg (Berg, Söderholm et al. 2017) further illustrate the rice - fish farming system "*This study shows that integrated rice – fish farming and integrated pest management strategies provide sustainable* *options to intensive rice farming, because of a more balanced use of multiple ecosystem services that benefit the farmers ' health, economy and the environment*". Walton (Walton, Vilas et al. 2015) states that "*extensive aquaculture productivity appears to be positively correlated with water exchange rates*". From here, it means we could design wetland to increase water exchange to increase agricultural production.

I conclude this principle in a landscape design aspect as integrate food production into wetland system could contribute to the balance the watershed ecosystem and economic development.

3.56 Integrate wetland into green infrastructure could mitigate effect of flood

Nelson (Nelson, Loomis et al. 2015) states "*Utah households who recreate on Utah's waters ("Users") are willing to pay up to $13.63 monthly to prevent deterioration of water quality whereas nonusers are willing to pay up to $8.31 per month*" and "*Users are willing to pay up to $32 per month to improve water quality in areas that have already been—or are expected to be—degraded by excess nutrients*". This research provides a new perspective that instead of generating new income of wetland, we also could estimate and make people aware of how much economical value wetland land has been provided. Thus, on top of this, it is also possible to ask for support from the council budget and the community's support and use the money to have wetland restoration and further development. This idea is supported by Waston (Watson, Ricketts et al. 2016) who states "*Functioning ecosystems can buffer communities from many negative impacts of a changing climate*" and the author further indicates "*Economic impacts of this magnitude stress the importance of floodplain and wetland conservation, warrant the consideration of ecosystem services in land use decisions, and make a compelling case for the role of green infrastructure in building resilience to climate change*". Narayan (Narayan, Beck et al. 2017) further added "*The local study combines these models with a database of synthetic storms in Ocean County and estimates a 16% average reduction in annual flood losses by salt marshes with higher reductions at lower elevations*".

I conclude this principle in a landscape design aspect as integrate wetland into green infrastructure could mitigate the effect of flooding. This means in designing a wetland, CW could provide economic values by mitigating the negative effects from flood and its economic contribution could be further improved by planning and designing CW as part of the green infrastructure in the urban area.

3.6 LIST OF BEST-PRACTICE PRINCIPALS

1. Site selection for wetland should first consider its soil condition, and thus where used to be wetland is more suitable for establishment of wetland
2. The size and types of wetland should be considered based on the water resources available
3. Planning of wetland should be considered within the bigger context
4. Flexible and mufti-functional design can improve environmental adaptability
5. Constructed wetland should cover about 1% of the site to maximize its nutrient removal ability
6. Constructed wetland can deal with storm water directly, natural wetland is supposed to only handle the pre-treated storm water
7. Whether water level of wetland is allowed to change and how much should we expected should be include in the design
8. life span of wetland should be considered in design, and designer need to decide if you need to replace it or rejuvenate it
9. Plan route carefully to avoid external damage on sensitive plants
10. Hybrid use of different types of constructed wetland can improve nutrient removal ability
11. Wetland on critical zones can enhance efficiency of nutrient removal while control the cost
12. Big wetland can express more ecological values, but small wetland could contribute to protect the endangered species
13. Complex topography could generate more vegetation and animal community
14. Shallow wetland has greater ability of nutrient removal, but fence protection is required
15. Increase the use of native plants can enhance indigenous values
16. Respect and explore indigenous cultural value in designing wetland
17. Introduce ornamental plants into wetland could express more aesthetic and ecological values
18. Develop wetland tourism could contribute to public awareness of wetland protection, especially with the assist of visitor center and guiding services
19. Simple-constructed and easy-operated design can reduce cost on implementation
20. Easy-maintained design of wetland can reduce cost on maintenance
21. Design should go along with the owner’s personal and business goals to make it happen
22. Plan and design wetland to prepare for anticipated climate change and its following impacts
23. Integrate food production into wetland system could contribute to the balance the watershed ecosystem and economic development
24. Integrate wetland into green infrastructure could mitigate effect of flood

REFERENCE

Abbott, M. R., & Bowring, J. (2017). A laboratory for design-directed research. Building design scholarship and academic possibility through designing.

Adapting to sea-level rise. (2019). Retrieved from https://www.mfe.govt.nz/climate-change/climate-change-and-government/adapting-climate-change/adapting-sea-level-rise

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and urban planning, 100*(4), 341-343.

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision.

Allam, Z., & Jones, D. (2018). *Promoting resilience, liveability and sustainability through landscape architectural design: A conceptual framework for port louis, mauritius; a small island developing state.* Paper presented at the IFLA World Congress Singapore.

Ashraf, M., & Wu, L. (1994). Breeding for salinity tolerance in plants. *Critical Reviews in Plant Sciences, 13*(1), 17-42.

Ausseil, A.-G. E., Lindsay Chadderton, W., Gerbeaux, P., Theo Stephens, R. T., & Leathwick, J. R. (2011). Applying systematic conservation planning principles to palustrine and inland saline wetlands of New Zealand. *Freshwater biology, 56*(1), 142-161. doi:10.1111/j.1365-2427.2010.02412.x

Aye, T. M., Nguyen, M. L., Bolan, N. S., & Hedley, M. J. (2010). Phosphorus in soils of riparian and non‐riparian wetland and buffer strips in the Waikato area, New Zealand. *New Zealand Journal of Agricultural Research, 49*(3), 349-358. doi:10.1080/00288233.2006.9513725

Bell, R., Lawrence, J., Allan, S., Blackett, P., Stephens, S., Hannah, J., . . . Britton, R. (2017). *Coastal hazards and climate change: Guidance for local government*.

Berg, H. (2002). Rice monoculture and integrated rice-fish farming in the Mekong Delta, Vietnam—economic and ecological considerations. *Ecological Economics, 41*(1), 95-107.

Berg, H., Söderholm, A. E., Söderström, A.-S., & Tam, N. T. (2017). Recognizing wetland ecosystem services for sustainable rice farming in the Mekong Delta, Vietnam. *Sustainability Science, 12*(1), 137-154.

Bhuiyan, M. J. A. N., & Dutta, D. (2012). Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. *Estuarine, Coastal and Shelf Science, 96*, 219-227.

Bilskie, M. V., Hagen, S. C., Medeiros, S. C., & Passeri, D. L. (2014). Dynamics of sea level rise and coastal flooding on a changing landscape. *Geophysical Research Letters, 41*(3), 927-934. doi:10.1002/2013gl058759

Borne, K. E., Fassman-Beck, E. A., & Tanner, C. C. (2014). Floating treatment wetland influences on the fate of metals in road runoff retention ponds. *Water research, 48*, 430-442.

Bornette, G., Amoros, C., & Lamouroux, N. (1998). Aquatic plant diversity in riverine wetlands: the role of connectivity. *Freshwater biology, 39*(2), 267-283.

Botzen, W. W., Michel-Kerjan, E., Kunreuther, H., de Moel, H., & Aerts, J. C. (2016). Political affiliation affects adaptation to climate risks: Evidence from New York City. *Climatic Change, 138*(1-2), 353-360.

Burger, J., O'Neill, K. M., Handel, S. N., Hensold, B., & Ford, G. (2017). The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA. *Landscape and urban planning, 157*, 512-522.

Bush, D. M., Neal, W. J., Longo, N. J., Lindeman, K. C., Esteves, L. S., & Pilkey, D. F. (2004). *Living with Florida's Atlantic beaches: coastal hazards from Amelia Island to Key West*: Duke University Press.

Calheiros, C. S. C., Bessa, V. S., Mesquita, R. B. R., Brix, H., Rangel, A. O. S. S., & Castro, P. M. L. (2015). Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility. *Ecological Engineering, 79*, 1-7. doi:https://doi.org/10.1016/j.ecoleng.2015.03.001

Camacho-Valdez, V., Ruiz-Luna, A., Ghermandi, A., Berlanga-Robles, C. A., & Nunes, P. A. (2014). Effects of land use changes on the ecosystem service values of coastal wetlands. *Environmental management, 54*(4), 852-864.

Cazenave, A., & Cozannet, G. L. (2014). Sea level rise and its coastal impacts. *Earth's Future, 2*(2), 15-34.

CCC Web Waterways, wetlands and drainage guide. (2018). Retrieved from https://www.ccc.govt.nz/environment/water/water-policy-and-strategy/waterways-wetlands-and-drainage-guide.

Change, I. C. (2014). Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *IPCC*.

Clarkson, B. R., Ausseil, A.-G. E., & Gerbeaux, P. (2013). Wetland ecosystem services. *Ecosystem services in New Zealand: conditions and trends. Manaaki Whenua Press, Lincoln*, 192-202.

Copley, N., Bowring, J., & Abbott, M. (2015). Thinking ahead: design-directed research in a city which experienced fifty years of sea level change overnight. *Journal of Landscape Architecture, 10*(2), 70-81.

Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research, 65*(10), 934-941.

Dawson, D., Shaw, J., & Roland Gehrels, W. (2016). Sea-level rise impacts on transport infrastructure: The notorious case of the coastal railway line at Dawlish, England. *Journal of Transport Geography, 51*, 97-109. doi:10.1016/j.jtrangeo.2015.11.009

Do, Y., Kim, S.-B., Kim, J. Y., & Joo, G.-J. (2015). Wetland-based tourism in South Korea: who, when, and why. *Wetlands Ecology and Management, 23*(4), 779-787. doi:10.1007/s11273-015-9418-2

Donald A, H. (1997). Creating freshwater wetlands.

Dramstad, W., Olson, J. D., & Forman, R. T. (1996). *Landscape ecology principles in landscape architecture and land-use planning*: Island press.

Ehrlich, P. R. (1974). Human population and environmental problems. *Environmental Conservation, 1*(1), 15-20.

Ellison, A. M., & Farnsworth, E. J. (1996). Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. *Biotropica*, 549-565.

Enwright, N. M., Griffith, K. T., & Osland, M. J. (2016). Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise. *Frontiers in Ecology and the Environment, 14*(6), 307-316. doi:10.1002/fee.1282

Ertl, A. W. (2008). *Toward an understanding of Europe: a political economic précis of continental integration*: Universal-Publishers.

Ewel, K., Twilley, R., & Ong, J. (1998). Different kinds of mangrove forests provide different goods and services. *Global Ecology & Biogeography Letters, 7*(1), 83-94.

Field, C. R., Gjerdrum, C., & Elphick, C. S. (2016). Forest resistance to sea-level rise prevents landward migration of tidal marsh. *Biological Conservation, 201*, 363-369. doi:10.1016/j.biocon.2016.07.035

Fink, D. F., & Mitsch, W. J. (2007). Hydrology and nutrient biogeochemistry in a created river diversion oxbow wetland. *Ecological Engineering, 30*(2), 93-102.
Frei, M., & Becker, K. (2005). *Integrated rice‐fish culture: Coupled production saves resources.* Paper presented at the Natural Resources Forum.
Geppert, M., & Dufhues, T. B. (2005). Visualizing rural financial market research in Northern Vietnam through pictures.
Gov, N. (1991). Resource Management Act. *Wellington: Government of New Zealand*.
Hall, C. M. (2001). Trends in ocean and coastal tourism: the end of the last frontier? *Ocean & Coastal Management, 44*(9-10), 601-618.
Hammer, D. A. (1989). *Constructed wetlands for wastewater treatment: municipal, industrial and agricultural*: CRC Press.
Hill, K. (2016). Climate change: Implications for the assumptions, goals and methods of urban environmental planning. *Urban Planning, 1*(4), 103-113.
Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S., . . . Levermann, A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences, 111*(9), 3292-3297.
Holling, C. S., & Gunderson, L. H. (2002). Resilience and adaptive cycles. *In: Panarchy: Understanding Transformations in Human and Natural Systems, 25-62*.
Hughes, A. O., Tanner, C. C., McKergow, L. A., & Sukias, J. P. S. (2016). Unrestricted dairy cattle grazing of a pastoral headwater wetland and its effect on water quality. *Agricultural Water Management, 165*, 72-81. doi:10.1016/j.agwat.2015.11.015
J., R. S., Richard, C., D., R. B., Hazel, B., S., M. M., & M., W. J. (2015). Small wetlands are critical for safeguarding rare and threatened plant species. *Applied Vegetation Science, 18*(2), 230-241. doi:doi:10.1111/avsc.12144
Jabareen, Y. (2012). Towards a sustainability education framework: Challenges, concepts and strategies—The contribution from urban planning perspectives. *Sustainability, 4*(9), 2247-2269.
Jevrejeva, S., Jackson, L. P., Riva, R. E. M., Grinsted, A., & Moore, J. C. (2016). Coastal sea level rise with warming above 2 °C. *Proceedings of the National Academy of Sciences, 113*(47), 13342-13347. doi:10.1073/pnas.1605312113
Johnson, P., & Gerbeaux, P. (2004). *Wetland types in New Zealand*. United States: Dept. of Conservation.
Jones, D., Cocklin, C., & Cutting, M. (1995). Institutional and landowner perspectives on wetland management in New Zealand. *Journal of Environmental Management, 45*(2), 143-161.
Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., . . . Dellow, G. (2012). The Mw 6.2 Christchurch earthquake of February 2011: preliminary report. *New Zealand journal of geology and geophysics, 55*(1), 67-90.
Karim, F., Kinsey‐Henderson, A., Wallace, J., Arthington, A. H., & Pearson, R. G. (2012). Modelling wetland connectivity during overbank flooding in a tropical floodplain in north Queensland, Australia. *Hydrological Processes, 26*(18), 2710-2723.
Keddy, P. A. (2010). *Wetland ecology: principles and conservation*: Cambridge University Press.
Khoshkam, M., Marzuki, A., & Al-Mulali, U. (2016). Socio-demographic effects on Anzali wetland tourism development. *Tourism Management, 54*, 96-106.
Knösche, R., Schreckenbach, K., Pfeifer, M., & Weissenbach, H. (2000). Balances of phosphorus and nitrogen in carp ponds. *Fisheries Management and Ecology, 7*(1‐2), 15-22.

Li, C., Qiu, J., Frolking, S., Xiao, X., Salas, W., Moore III, B., . . . Sass, R. (2002). Reduced methane emissions from large‐scale changes in water management of China's rice paddies during 1980–2000. *Geophysical Research Letters, 29*(20), 33-31-33-34.

Lin, M., Li, Z., Liu, J., Gozlan, R. E., Lek, S., Zhang, T., . . . Yuan, J. (2015). Maintaining economic value of ecosystem services whilst reducing environmental cost: a way to achieve freshwater restoration in China. *PloS one, 10*(3), e0120298.

Maori and wetlands. (n.d.). Retrieved from https://www.waikatoregion.govt.nz/community/your-community/iwi/a-maori-perspective-te-ao-maori/maori-and-wetlands/

McDowell, R., Moreau, P., Salmon-Monviola, J., Durand, P., Leterme, P., & Merot, P. (2014). Contrasting the spatial management of nitrogen and phosphorus for improved water quality: Modelling studies in New Zealand and France. *European Journal of Agronomy, 57*, 52-61.

McDowell, R. W., Monaghan, R. M., Dougherty, W., Gourley, C. J. P., Vibart, R., & Shepherd, M. (2017). Balancing water-quality threats from nutrients and production in Australian and New Zealand dairy farms under low profit margins. *Animal Production Science, 57*(7), 1419. doi:10.1071/an16646

McGann, R. (1983). *The climate of Christchurch* (Vol. 167): Ministry of Transport, New Zealand Meteorological Service.

McGlone, M. S. (2009). Postglacial history of New Zealand wetlands and implications for their conservation. *New Zealand Journal of Ecology*, 1-23.

McKerchar, C., Bowers, S., Heta, C., Signal, L., & Matoe, L. (2015). Enhancing Māori food security using traditional kai. *Global health promotion, 22*(3), 15-24.

McKergow, L. A., Matheson, F. E., & Quinn, J. M. (2016). Riparian management: A restoration tool for New Zealand streams. *Ecological Management & Restoration, 17*(3), 218-227. doi:10.1111/emr.12232

Meyer, E. K. (2008). Sustaining beauty. The performance of appearance: A manifesto in three parts. *Journal of Landscape Architecture, 3*(1), 6-23.

Meynecke, J.-O., Lee, S., & Duke, N. (2008). Linking spatial metrics and fish catch reveals the importance of coastal wetland connectivity to inshore fisheries in Queensland, Australia. *Biological Conservation, 141*(4), 981-996.

Mohamed, Y., Bastiaanssen, W. G., Savenije, H., Van den Hurk, B., & Finlayson, C. M. (2012). Wetland versus open water evaporation: An analysis and literature review. *Physics and Chemistry of the Earth, Parts A/B/C, 47*, 114-121.

Mueller, P., Jensen, K., & Megonigal, J. P. (2016). Plants mediate soil organic matter decomposition in response to sea level rise. *Glob Chang Biol, 22*(1), 404-414. doi:10.1111/gcb.13082

Nassauer, J. I., & Corry, R. C. (2004). Using normative scenarios in landscape ecology. *Landscape Ecology, 19*(4), 343-356.

Naylor, R., & Burke, M. (2005). Aquaculture and ocean resources: raising tigers of the sea. *Annu. Rev. Environ. Resour., 30*, 185-218.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding--a global assessment. *PloS one, 10*(3), e0118571. doi:10.1371/journal.pone.0118571

Ni, J., Xu, J., & Zhang, M. (2016). Constructed wetland planning-based bi-level optimization to balance the watershed ecosystem and economic development: A case study at the Chaohu Lake watershed, China. *Ecological Engineering, 97*, 106-121.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*(5985), 1517-1520.

Nicholls, R. J., Marinova, N., Lowe, J. A., Brown, S., Vellinga, P., De Gusmao, D., . . . Tol, R. S. (2011). Sea-level rise and its possible impacts given a 'beyond 4 C world'in the twenty-first century. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 369*(1934), 161-181.

Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., . . . Arblaster, J. (2007). Coastal systems and low-lying areas.

Nichols, M. M. (1989). Sediment accumulation rates and relative sea-level rise in lagoons. *Marine geology, 88*(3-4), 201-219.

Osland, M. J., Enwright, N. M., Day, R. H., Gabler, C. A., Stagg, C. L., & Grace, J. B. (2016). Beyond just sea‐level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. *Global Change Biology, 22*(1), 1-11.

Parker, M., & Steenkamp, D. (2012). The economic impact of the Canterbury earthquakes. *Reserve Bank of New Zealand Bulletin, 75*(3), 13-25.

Parkyn, S., Shaw, W., & Eades, P. (2000). Review of information on riparian buffer widths necessary to support sustainable vegetation and meet aquatic functions.

Passeri, D. L., Hagen, S. C., Medeiros, S. C., Bilskie, M. V., Alizad, K., & Wang, D. (2015). The dynamic effects of sea level rise on low-gradient coastal landscapes: A review. *Earth's Future, 3*(6), 159-181. doi:10.1002/2015ef000298

Phillips, M. R., & Jones, A. L. (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. *Tourism Management, 27*(3), 517-524.

Ponnamperuma, F. (1984). Straw as a source of nutrients for wetland rice. *Organic matter and rice, 117*, 136.

Racchetti, E., Bartoli, M., Soana, E., Longhi, D., Christian, R., Pinardi, M., & Viaroli, P. (2011). Influence of hydrological connectivity of riverine wetlands on nitrogen removal via denitrification. *Biogeochemistry, 103*(1-3), 335-354.

Reise, K. (2017). Facing the Third Dimension in Coastal Flatlands: Global Sea Level Rise and the Need for Coastal Transformations. *GAIA - Ecological Perspectives for Science and Society, 26*(2), 89-93. doi:10.14512/gaia.26.2.6

Rintoul, S., Chown, S., DeConto, R., England, M., Fricker, H., Masson-Delmotte, V., . . . Xavier, J. (2018). Choosing the future of Antarctica. *Nature, 558*(7709), 233.

Risken, J., Fraser, J., Rutter, H., & Gadsby, M. (2015). *Implications of sea level rise on liquefaction vulnerability in Christchurch.* Paper presented at the 6th International Conference on Earthquake Geotechnical Engineering, Christchurch.

Robb, M. J. G. (2014). *When two worlds collide: Mātauranga Māori, science and health of the Toreparu wetland.* University of Waikato.

Robertson, H. A., & Suggate, R. (2012). *Arawai Kākāriki Wetland Restoration Programme 2007-2010: Implementation Report*: Research and Development Group, Department of Conservation.

Roggema, R. (2018). Design with voids: how inverted urbanism can increase urban resilience. *Architectural Science Review, 61*(5), 349-357.

Runting, R. K., Lovelock, C. E., Beyer, H. L., & Rhodes, J. R. (2017). Costs and Opportunities for Preserving Coastal Wetlands under Sea Level Rise. *Conservation Letters, 10*(1), 49-57. doi:10.1111/conl.12239

Salata, K. D., & Yiannakou, A. (2016). Green Infrastructure and climate change adaptation. *Tema. Journal of Land Use, Mobility and Environment, 9*(1), 7-24.

Sarwar, M. G. M. (2005). Impacts of sea level rise on the coastal zone of Bangladesh. *See* http://static. *weadapt. org/placemarks/files/225/golam_sarwar. pdf*.
Sasmito, S. D., Murdiyarso, D., Friess, D. A., & Kurnianto, S. (2015). Can mangroves keep pace with contemporary sea level rise? A global data review. *Wetlands Ecology and Management, 24*(2), 263-278. doi:10.1007/s11273-015-9466-7
Schleupner, C. (2008). Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management, 51*(5), 383-390.
Scott, D. (2011). Why sustainable tourism must address climate change. *Journal of Sustainable Tourism, 19*(1), 17-34.
Scott, D., Gössling, S., & Hall, C. M. (2012). International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change, 3*(3), 213-232.
Semlitsch, R. D., & Bodie, J. R. (2003). Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology, 17*(5), 1219-1228.
Sharma, B., Rasul, G., & Chettri, N. (2015). The economic value of wetland ecosystem services: evidence from the Koshi Tappu Wildlife Reserve, Nepal. *Ecosystem Services, 12*, 84-93.
Sheppard, S. R. (2015). Making climate change visible: A critical role for landscape professionals. *Landscape and urban planning, 142*, 95-105.
Shi, L., Chu, E., & Debats, J. (2015). Explaining progress in climate adaptation planning across 156 US municipalities. *Journal of the American Planning Association, 81*(3), 191-202.
Slangen, A. B., Church, J. A., Agosta, C., Fettweis, X., Marzeion, B., & Richter, K. (2016). Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change, 6*(7), 701.
Stottmeister, U., Wießner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., . . . Moormann, H. (2003). Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotechnology advances, 22*(1-2), 93-117.
Sukias, J., Yates, C., & Tanner, C. (2010). *Floating treatment wetlands for remediation of eutrophic lake waters–macro stream trials (Lake Rotoehu).* Paper presented at the Proceedings of NZ Water Conference.
Sweet, W. V., Kopp, R. E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E. R., & Zervas, C. (2017). Global and regional sea level rise scenarios for the United States.
Tait, P. R., & Cullen, R. (2006). *Some external costs of dairy farming in Canterbury.* Paper presented at the Australian Agricultural and Resource Economics Society Annual Conference.
Tan, Z. (2018). *Rsearch placement of exploration on values from wetland*. School of Landscape Architecture, Lincoln University.
Tanner, C., Nguyen, M., & Sukias, J. (2005). Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. *Agriculture, ecosystems & environment, 105*(1-2), 145-162.
Tanner, C. C., & Kloosterman, V. C. (1997). *Guidelines for constructed wetland treatment of farm dairy wastewaters in New Zealand*: NIWA.
Tanner, C. C., Kloosterman, V. C., & Champion, P. D. (2006). *New Zealand constructed wetland planting guidelines*: NZWWA.
Tanner, C. C., Sukias, J., Park, J., Yates, C., & Headley, T. (2011). Floating Treatment Wetlands: A new tool for nutrient management in lakes and waterways. *Methods, 2008*(2011).
Tanner, C. C., Sukias, J. P., Headley, T. R., Yates, C. R., & Stott, R. (2012). Constructed wetlands and denitrifying bioreactors for on-site and

decentralised wastewater treatment: comparison of five alternative configurations. *Ecological Engineering, 42*, 112-123.

Turcios, A. E., & Papenbrock, J. (2014). Sustainable treatment of aquaculture effluents—what can we learn from the past for the future? *Sustainability, 6*(2), 836-856.

Uuemaa, E., Palliser, C. C., Hughes, A. O., & Tanner, C. C. (2018). Effectiveness of a Natural Headwater Wetland for Reducing Agricultural Nitrogen Loads. *Water, 10*(3), 287.

Van Ballegooy, S., Malan, P., Lacrosse, V., Jacka, M., Cubrinovski, M., Bray, J., . . . Cowan, H. (2014). Assessment of liquefaction-induced land damage for residential Christchurch. *Earthquake Spectra, 30*(1), 31-55.

Vitousek, S., Barnard, P. L., Fletcher, C. H., Frazer, N., Erikson, L., & Storlazzi, C. D. (2017). Doubling of coastal flooding frequency within decades due to sea-level rise. *Sci Rep, 7*(1), 1399. doi:10.1038/s41598-017-01362-7

Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. *Water, 2*(3), 530-549. doi:10.3390/w2030530

Vymazal, J. (2017). The use of constructed wetlands for nitrogen removal from agricultural drainage: a review. *Scientia Agriculturae Bohemica, 48*(2), 82-91.

Walton, M., Vilas, C., Cañavate, J., González-Ortegón, E., Prieto, A., Van Bergeijk, S., . . . Le Vay, L. (2015). A model for the future: Ecosystem services provided by the aquaculture activities of Veta la Palma, Southern Spain. *Aquaculture, 448*, 382-390.

Walton, M., Vilas, C., Coccia, C., Green, A. J., Cañavate, J. P., Prieto, A., . . . King, J. (2015). The effect of water management on extensive aquaculture food webs in the reconstructed wetlands of the Doñana Natural Park, Southern Spain. *Aquaculture, 448*, 451-463.

Watanabe, T. (2018). Paddy Fields as Artificial and Temporal Wetland *Irrigation in Agroecosystems*: IntechOpen.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, xiii-xxiii.

Wehi, P. M., & Lord, J. M. (2017). Importance of including cultural practices in ecological restoration. *Conservation Biology, 31*(5), 1109-1118.

Whitby, C. L. (2018). *The barriers to, and opportunities for, restoring wetland ecological function on privately-owned New Zealand farms.* University of Otago.

Worku, H. (2017). Integrating climate change adaptation strategies in urban planning and landscape design of Addis Ababa City, Ethiopia: Using urban planning and landscape design to mitigate flooding, drought, and urban heat island effects. *Environmental Quality Management, 27*(1), 5-21.

Worldometers. (2019). New Zealand Population (LIVE). *worldometers.*

Xiong, Y., Peng, S., Luo, Y., Xu, J., & Yang, S. (2015). A paddy eco-ditch and wetland system to reduce non-point source pollution from rice-based production system while maintaining water use efficiency. *Environmental Science and Pollution Research, 22*(6), 4406-4417. doi:10.1007/s11356-014-3697-7

Yang, P., & Zhu, W. (2013). *The exploitation of rice paddy field and its ecological protection.* Paper presented at the 2013 Third International Conference on Intelligent System Design and Engineering Applications.

Zedler, J. B. (2000). Progress in wetland restoration ecology. *Trends in ecology & evolution, 15*(10), 402-407.

Zhou, S., & Hosomi, M. (2008). Nitrogen transformations and balance in a constructed wetland for nutrient-polluted river water treatment using forage rice in Japan. *Ecological Engineering, 32*(2), 147-155.