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建立具都市化特徵的氣候變遷調適能力指標

Incorporating the Effect of Urbanization in Measuring Climate Adaptive Capacity

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本論文係朱驊君(學號 R03541219)在國立臺灣大學環境工程學研究所完成之碩士學位論文，於民國 105 年 6 月 3 日承下列考試委員審查通過及口試及格，特此證明

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中文摘要

氣候變遷調適能力的評估可用以推估當地政府與人民在未來面對氣候變遷影響時，是否能採行足夠且適當的調適措施。但目前相關指標的發展並未考量都市化對調適措施的影響，因此可能會高估調適能力。本研究目的為建立氣候變遷調適能力指標系統，該系統中納入與都市化相關指標 如：建設面積和教育程度，並設定三種社會經濟發展情境，包括：基線（情境 BAU，Business As Usual）、重視經濟發展(情境 A）及重視環境與社會（情境 B)；以期能提高氣候變遷調適能力評估的準確性，並可供地方發展與規劃之參考。以美國佛羅里達洲的 West Palm Beach 和臺灣新北市的淡水區為研究案例，使用土地利用模擬軟體 What if，分別模擬三種社會經濟發展情境，於 2030 年及 2050 年之土地利用狀況；並將結果輸入本研究所建立之指標系統計，以推估兩地的氣候變遷調適能力。在 West Palm Beach，情境 A 在 2030 年的調適能力為三者最高，然而在 2050 年的則降低為各情境中最低；情境 BAU 與情境 A 類似，但起伏的程度較小；情境 B 在 2030 年和 2050 年的分數都呈逐步上升，並於 2050 年具有最佳的氣候變遷調適能力。淡水區的趨勢測不同於 West Palm Beach，從基準年起三個情境的調適能力都會下降，但以情境 B 降低的幅度較小。綜合而言，情境 A 是短期最佳的發展方向，不過以長期來看會有調適能力的限制，而情境 B 雖然發展較慢，但到 2050 年會有較高的氣候變遷調適能力。本研究可做為當地政府規劃未來發展的參考。

關鍵字:都市化、土地利用變遷、氣候變遷、調適能力、調適

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English Abstract:

Measuring the ability of a community to face climatic changes, or its adaptive capacity, is necessary in order to plan and guide development as the global climate continues to warm. One factor that has not been thoroughly addressed by previous attempts at measuring adaptive capacity is urbanization. This study looks to measure adaptive capacity in relation to urbanization, as many areas of the world are undergoing this rapid transition. An indicator system was created with land-use sensitive measures and applied to three different land use projection scenarios (high, medium, and low growth) to 2030 and 2050 for two case study areas, Tamsui, Taiwan and West Palm Beach, USA. In Tamsui, the adaptive capacity decreased in all scenarios, but most dramatically for the high growth scenario. The low growth scenario decreased more slowly through each time slice. For West Palm Beach, the high growth scenario had the highest score in 2030, but declined in 2050. The medium growth Scenario BAU, also had a higher adaptive capacity score in 2030 than in 2050. The low growth Scenario B had a score that improved less dramatically but continued to rise through 2050. Scenario A would be ideal for short term gains, but its benefits would plateau in the long term. Scenario B, with conservation measures and more restricted growth would be the most ideal alternative. This study shows that urbanization has short term socioeconomic

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gains, but long term environmental consequences, and it successfully incorporates the effect of land use change into an adaptive capacity indicator system and can be used in other localities expecting significant increases in urbanization.

Keywords: urbanization, land use change, climate change, adaptive capacity, adaptation

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Table of Contents

doi:10.6342/NTU201600887

doi:10.6342/NTU201600887

doi:10.6342/NTU201600887

List of Tables

doi:10.6342/NTU201600887

List of Figures

Figures:

doi:10.6342/NTU201600887

doi:10.6342/NTU201600887

Chapter I: Introduction

In the coming centuries, humanity must adapt or perish. Changes in precipitation patterns, average temperatures, and frequency of extreme climate events are being observed and attributed to global climate change; with no end in sight for carbon emissions these changes are likely to lead to negative impacts such as water stress, food shortages, and higher health risks, and even a rise in conflict as a result of these effects (IPCC 2014). Along with this increase in climatic pressures on societies, urbanization is continuing at a breakneck pace. The development of cities is spatially uneven, as are its effects on social systems and ecosystems, with its effect on climate change being a prime example. Urban development and climate change both have resounding effects on society that are further complicated by their complex relationship with each other. As international attempts at climate change mitigation continue to stall, climate adaptation is increasingly important on a local scale in order to lessen potential impacts on communities.

Considering that environmental, economic, political, and social factors all play critical roles in the capacity of communities to adapt to climate change, it has become increasingly relevant to consider how land development affects adaptive capacity at a local level. In areas that are undergoing massive land use change, how will adaptive capacity be influenced? To answer these questions, this research will focus on Tamsui

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in northern Taiwan, and West Palm Beach in Southern Florida in the US. Both are areas that have experienced significant growth, and are slated for still more urban development and land use change in the next decade, making them interesting cases for an international comparison of how these changes affect adaptive capacity. This research aims to contribute to existing adaptation science by creating a new indicator system, the Urbanizing Adaptive Capacity Index (UACI), targeted specifically at areas in transition, which can measure current and future adaptive capacities under various scenarios based on both biophysical and socioeconomic factors to assist decision makers and policy builders in climate adaptation planning. This will be the first small-scale adaptive capacity index which accounts for the pressures of urbanization on communities.

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Chapter II: Literature Review

2.1 Introduction

The purpose of this literature review is to cover concepts and previous literature utilized in this research, as well as provide literature-based explanations for methods to be covered in the next chapter. The complexities of concepts and practicalities will be discussed as both a theoretical and practical understanding of the literature is necessary as a foundation to this study.

The structure of this literature has two main parts, the conceptual overview and the study-specific review. This conceptual overview has four main subsections that review the overarching tenets of this research. The first subsection of the first half, "Failure of Mitigation and the Ascent of Adaptation," is a general overview of climate change and the modern history of human response, which introduces the wider context of my research. Subsection two, "Relating Adaptation, Adaptive Capacity, Vulnerability, Resilience, and Risk," covers a basic review of several concepts that are important in climate adaptation research and explains adaptive capacity as a main component of this study. "Indicators" is the third subsection, which discusses the use of indicators and indices as ways of measuring concepts reviewed in subsection two. The last subsection of the first half, "Land Use and Urbanization Dynamics," covers

doi:10.6342/NTU201600887

the effect of urbanization, land use, and land cover on aspects of climate adaptation, and reviews the latest studies on these topics.

Following the conceptual overview of the literature review, the second section is separated into three subsections and functions an in-depth look at the more specific studies that influence the methodology choices in this research. First, the two case study sites are described and relation to the concepts reviewed in the first half of the literature review. The second subsection reviews previous studies which constructed similar kinds of indicator systems and provide justifications for the methods of this study, and the last subsection reviews literature on scenario building.

With these two halves, a conceptual overview to theory behind this field of research as well as a practical, study-specific review, we can understand the underlying contextual basis for this study.

2. 2 Conceptual Overview

2.2.1 Failure of Mitigation and the Ascent of Adaptation

Climate change adaptation was once considered to be a defeatist strategy, a path for those who had prematurely given up efforts of mitigating of greenhouse gas emissions. Many in the climate change community actively discouraged the thought

doi:10.6342/NTU201600887

that adaptation might important, because mitigation, the decrease of carbon emissions to reduce overall atmospheric greenhouse gas concentration, was a preventative strategy and would render adaptation unnecessary. As Benjamin Franklin once said, "an ounce of prevention is worth a pound of cure." There used to be a time where many hoped, and many believed, that if society hurried, we could succeed in mitigating climate change.

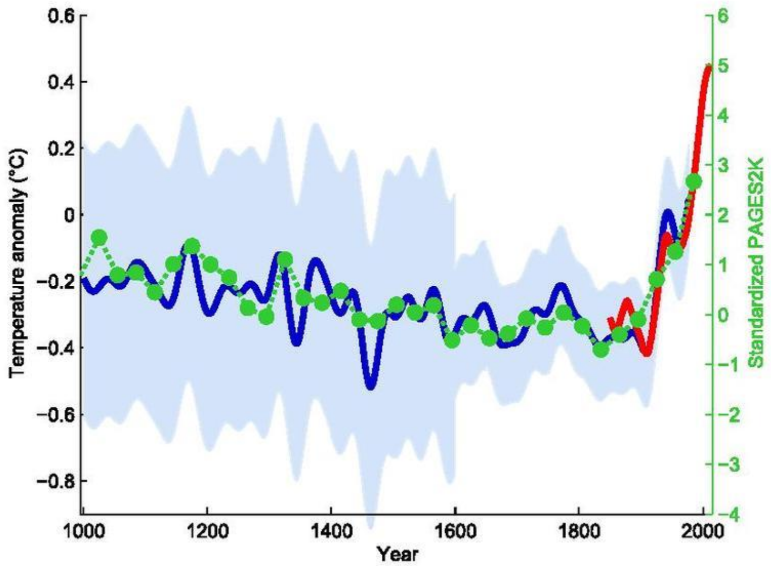
That time, unfortunately, has passed.

Now, in 2016, few in that same community think that adaptation should not be pursued. Adaptive moves, such as building seawalls, relocation, or developing drought-resistant crops, are all seriously considered or enacted. Despite all efforts, scientists and activists and policy makers have not succeeded in decreasing emissions and thus carbon dioxide concentrations have soared past 400 ppm, the concentration historically considered the threshold at which effects are "acceptable." The science is clear that humanity will experience effects of climate change for the foreseeable future. Due to carbon's staying power in the atmosphere, even if emissions decline or stop immediately, communities will still have to deal with shifting temperature ranges and precipitation patterns, rising sea levels, changes in biodiversity, differences in availability and quality of water and other resources for centuries to come (IPCC 2014). There is now no choice but to adapt.

doi:10.6342/NTU201600887

With such drastic implications, one might wonder: How did this happen, and what is being done?

Carbon emissions began to rise with the advent of the Industrial Revolution, a result of burning of fossil fuels to power factories and burgeoning cities, and average global temperature rose soon after. The infamous "hockey stick graph" illustrates the increase in temperature over the last thousand years, which directly corresponds anthropogenic causes and is shown in **Figure 1** (Mann et al 1998).



Mann et al (1998)

Figure 1: Hockey Stick Graph showing increase in temperature anomaly over time

doi:10.6342/NTU201600887

While studying the mechanisms of heating effects of carbon dioxide and other gases in 1896, Arrhenius and Chamberlin were the first to speculate that human activity could have a significant impact on Earth's climate via anthropogenic emissions. Although greenhouse gas effects were well studied by various scientists throughout the 19^{th} century, anthropogenic climate change was not considered at the time and thus the full scope of the phenomenon did not mature until almost a century later. A complete scientific theory on anthropogenic climate change would not materialize until the late 1950s and it took until the late 1980s for the information on climate change to finally reach the general populace. (Maslin 2004)

When it finally became clear in the scientific community that climate change would have significant global impacts, the United Nations Environment Programme and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) in 1988 (IPCC 2016), which is now considered the international authority on climate change science. The IPCC has since published five highly reputable and are widely cited reports of compiled science regarding the different aspects of climate change since its inception. The United Nations Framework Convention on Climate Change was signed in 1992 and is currently the most important international climate policy body, and has held annual international climate

doi:10.6342/NTU201600887

negotiations since 1995, most famously in Copenhagen in 2009 and most recently in Paris.

Despite the overwhelming scientific consensus presented by climate scientists and the IPCC, skepticism remains, particularly in the US, the highest per capita emitter of carbon dioxide in the world. As of 2015, only 67% of Americans believe in anthropogenic climate change (Yale 2015), compared to 81% of Taiwanese in 2008, which represents one of the highest percentages of countries where the study was conducted (Gallup 2009). Taiwan, despite not having UN membership and thus no ability to join the UNFCC, takes climate change matters seriously both programmatically and legally (Su 2011). On the other hand, over the last twenty years, the percentage of Americans that believe that climate change is happening or will happen in their lifetime has hovered a bit above 50 percent, and has never in the history of the poll has it risen above 61% (Gallup 2015). Naomi Oreskes and Eric Conway outline the origins of this phenomenon in their book *Merchants of Doubt* (2010), in which they describe how the public perception of climate science was skewed and how controversy was engineered. The legacy of this denial remains today in the minds of the American people: the public most responsible for climate change refuses to believe in its validity. Furthermore, the US government never ratified any binding agreements to cut carbon emissions. This refusal incited much debate about which countries should

doi:10.6342/NTU201600887

bear the responsibility of the more intense emissions cuts, considering historical emission rates. Factions arose between developed and developing countries. The exact methods through which emissions agreements were to be executed were another issue, and those debates continue every year.

Without broad commitments, particularly by the US, carbon concentration in the atmosphere continues to climb. The purpose of mitigation is to prevent or decrease the impact of climate change. But society has, on an international level, failed in this endeavor to reduce carbon emissions enough to prevent global climate change. Consensus and commitments do not seem to be in the near future.

We are now "locked in" to climate change, as many earth systems are not linear but rather change due to global feedbacks and have "tipping points" which govern cycles. Many scientists believe there is enough evidence to say we are now beyond those tipping points. Carbon emission decreases now cannot completely prevent the effects that are already ongoing; thus, climate change is no longer a question of "if" but rather of "when" and "how much." The opportunity for complete or even substantial mitigation has passed, and adaptation will be increasingly important. Because of the inevitability of climate impacts, trends such as sea level rise and higher global average temperatures will be, and already are, a reality to be dealt with.

doi:10.6342/NTU201600887

2.2.2 Relating Adaptation, Adaptive Capacity, Vulnerability, Resilience, and Risk

If adaptation is a necessity for our rapidly changing environment, how is it defined and operationalized? What are its origins and under what contexts is it used? What other terms are relevant to its utilization? These questions are to be addressed in this section.

The origins of adaptation can be traced back to evolutionary ecology, particularly in terms of species being well adapted to a specific environment. This definition of adaptation describes having traits that are more suited to thriving in a particular environment or the process of adapting to a different environment, but the literature now includes a larger breadth of possibilities. A word that once referred to an evolved state has now itself evolved to refer to an active human process -- a key concept in various social sciences and in the realm of global environmental change, and particularly important in regards to climate change. But also because of this diversity, many different definitions of adaptation exist, with a wide range of geographic and temporal scales, stimuli, and adapters (Smit & Wandel 2006). Even within the focus of climate change adaptation specifically, there exist myriad conceptual differences. The United Nations Development Program (UNDP) defines adaptation as "a process by

doi:10.6342/NTU201600887

which individuals, communities and countries seek to cope with the consequences of climate change, including variability" (Lim et al 2004). Adaptation, defined by Brooks (2003), is "adjustments in a system's behavior and characteristics that enhance its ability to cope with external stress," and for Smit et al (2000) adaptations are "adjustments in ecological-socio-economic systems in response to actual or expected climatic stimuli, their effects or impacts." Despite the variety, the definitions of adaptation generally include a stressor or stimuli, as well as a potential response to the stress, or a capacity of response. Stressors can be hazards such as flooding or drought. Responses to these stimuli can manifest in a suite of forms that respond to both biophysical and socioeconomic changes, such as seawalls and levees, heat stress plans, diversifying revenue, adjustment of planting and harvest times, and relocation (IPCC 2007). But maladaptations can also occur, in which responses to stimuli are not positive or are not constructive. Some maladaptations are beneficial in the short term but damaging in the long term.

Discussions of adaptation to climate impacts are almost always followed by references to vulnerability and resilience. Adaptation is often viewed in terms of reducing vulnerability to climate impacts and increase resilience of systems. But, like adaptation, the way in which these terms are used and operationalized vary greatly, and their relationship with each other is often even more confusing. Vulnerability and

doi:10.6342/NTU201600887

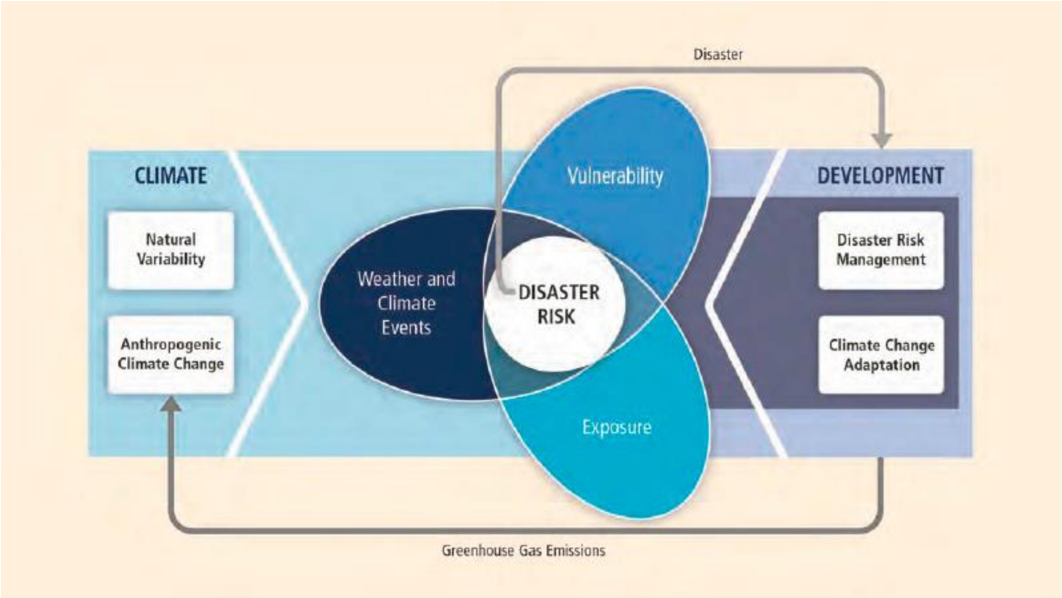
resilience also are rooted in different traditions that approach problems in divergent ways.

The field of vulnerability has been described as being in a state of "Babylonian confusion" and there have been over 35 definitions compiled (Hinkel 2011). The IPCC definition in the Fifth Annual Report describes vulnerability as the propensity or predisposition to be adversely affected (IPCC, 2014). Exposure and sensitivity are often listed as components of vulnerability, sometimes accompanied by adaptive capacity. However, there is more consensus on the meanings of exposure and sensitivity with regards to vulnerability, exposure being understood as contact with hazards as hurricanes or disease, and sensitivity being defined as the degree to which that hazard may negatively affect the system (Monterroso et al 2014, Engle 2011, IPCC 2007, Adger 2006, Cutter 2008). For example, a population with frequent outside contact may be more or less vulnerable to disease outbreak, depending on exposure and sensitivity. Exposure may refer to the amount of contact with infected individuals from outside the area, whereas sensitivity might be the general immunity of the population as a whole. Both exposure and sensitivity are seen as directly impacting vulnerability; as either increases, vulnerability also increases. Vulnerability is often conceptualized as shown in the equation below (Ahsan and Warner 2014, Binita et al 2015, Pandey and Bardsley 2015, Salik et al 2015):

doi:10.6342/NTU201600887

$$\text{vulnerability} = \frac{exposure\ \times sensitivity}{adaptive\ capacity} \quad \textbf{(1)}$$

The IPCC released a special report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) which conceptualizes vulnerability as a component of risk, along with exposure and climate events (i.e. hazard), as seen in **Figure 2** (IPCC 2012). Moving exposure outside the realm of vulnerability and into a component of risk allows the separation of social and physical aspects of risk. This a refined version of the conception seen in **Equation 1**.



IPCC 2012

Figure 2: SREX conception of disaster risk

SREX also addresses the strengths of vulnerability studies as a lens for disaster risk. Vulnerability originated in hazard-risk and poverty studies, and the recent

doi:10.6342/NTU201600887

literature still reflects this disciplinary legacy. The concept was prominent in development, food security studies, and political ecology, particularly in the fields of geography and anthropology (Janssen & Ostrom 2006, Gallopin 2006, Engle 2011, Adger, 2006). This history of approaches, compared to resilience studies, lends itself well to program and policy applications, which is helpful for those working on climate change adaptation (Engle 2011).

From this context, vulnerability is often described in negative terms but its relationship to adaptation is unclear. Is a system vulnerable because it is less able to adapt or is it less vulnerable after adapting? Some scholars disagree that vulnerability is always a negative trait (Gallopin 2006) and that vulnerability to transformation (rather than collapse) may provide unforeseen opportunities that can lead to more equitable or more effective systems. For instance, some studies have also shown that in certain cases increased exposure may actually decrease sensitivity by encouraging preparation by households or communities or governments, or by a sense of practice. (Coulston and Deeny 2010). In other words, if a community is plagued by regular flooding, they may developing coping mechanisms that strengthen society at large. This is sometimes described as increasing resilience. However, it is not clear that vulnerability is necessarily unequivocally negative, nor that the equation above holds in all cases.

doi:10.6342/NTU201600887

Relatedly, resilience is not necessarily always a positive thing. An invasive species, for example, may be resilient yet detrimental to the ecosystem. Additionally, an undesirable state, such as an oppressive political system, may be very resilient and able to revert back from different sources of stress (Engel 2011, Gallopin 2006). Resilience is sometimes seen as the opposite of vulnerability, meaning if vulnerability is generally "bad" then resilience is generally "good." But, it is possible a system can vulnerable yet resilient, or both invulnerable and not resilient. "The relation of resilience to the sensitivity component of vulnerability is also unclear. A sensitive system may or may not be resilient. An insensitive system (i.e., an ''armored system'') may exhibit low vulnerability and low resilience (it is the exposure to perturbation that builds resilience in natural systems)." Furthermore, "sensitivity may open a system to threats, but an insensitive system may be unable to adapt and seize opportunity. The concept of resilience does not include exposure (similar to vulnerability as adopted here) but refers to the reaction of the system when exposed to perturbations. On the other hand, a history of past exposures may be important to build resilience." (Gallopin 2006)

Although it is clear that situations can vary, vulnerability and resilience are seen to have generally inversely related connotations in most practical applications thus far. But a more nuanced understanding and consensus on issues may provide clarity for further collaborative works.

doi:10.6342/NTU201600887

The concept of resilience is rooted in ecology, particularly within population studies, and it has a strong basis in mathematical models. Complexity theory, agent-based modeling, and systems analysis play a role in resilience studies and thus there is great emphasis on interactions, dynamics, and processes (Janssen & Ostrom 2006, Gallopin 2006, Engle 2011). Resilience in a climate change context is sometimes defined as "as the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change," (Adger 2000) or, in a wider context, "achieving desirable states in the face of change" (Folke 2006). These understandings are helpful in both pre- and post-disaster circumstances, unlike vulnerability which tends to focus on pre-disaster or pre-harm situations.

When faced with the challenge of combining the strengths of resilience studies with vulnerability studies, having a clear conception of how they are related becomes essential. Many attempts have been made to consolidate the discrepancies of vulnerability, resilience, and adaptation (Folke 2006, Gallopin 2006, Engle 2011, Cutter 2008) and the concept of adaptive capacity as a common bridge comes up repeatedly in the literature. The question then becomes: how exactly can adaptive capacity clarify the discord between these issues and what about it is most useful to policy applications?

doi:10.6342/NTU201600887

Smit and Wandel (2006) outline the concept of adaptive capacity in relation to adaptation and vulnerability. Both Gallopin (2006) and Engle (2011) stated that the concept of adaptive capacity is key in combining resilience and vulnerability literatures, despite the range of definitions that it also carries. It is “the ability of social actors to make deliberate changes that influence the resilience of their complex social-ecological systems” (Ensor 2011, Walker et al 2004) and also “the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC 2001, Brooks et al 2005) or “a vector of resources and assets that represents the asset base from which adaptation actions and investments can be made,” according to Vincent (2007). The SREC report also encourages the integration of vulnerability and resilience with adaptive capacity, seeing adaptive capacity as similar to resilience concepts, and as a component of vulnerability (IPCC 2012). Cutter (2008) consolidated much of the discussion into the figure below to display the wide range of combinations that had been proposed.

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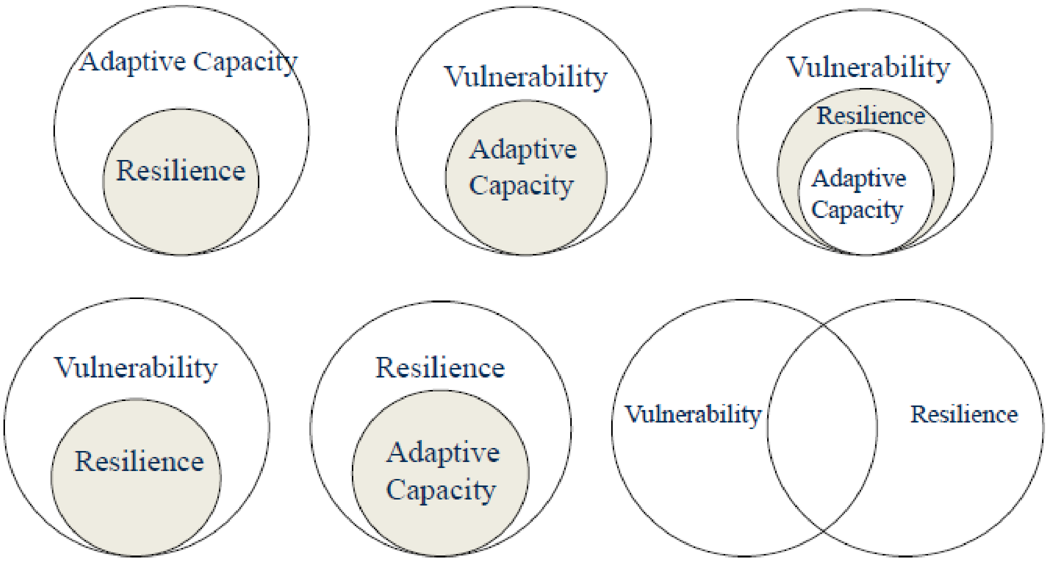

Cutter et al (2008)

Figure 3: Relationships between Adaptive Capacity, Resilience, and Vulnerability

For the purposes of this research, the arrangement in which Gallopin (2006) combines the concepts of resilience, vulnerability, and adaptive capacity will be utilized, and is shown in **Figure 4.** Adaptive capacity is taken to mean capacity of response, and thus a subset of vulnerability, clarifying its relationship with resilience and vulnerability. Resilience and adaptive capacity are internal to a system, whereas vulnerability can refer to outside pressures. Exposure in this model would point to climate change pressures, and sensitivity would be defined as how affected the system is by climate change, whether in reduced crop output, health impacts or any number of other manifestations.

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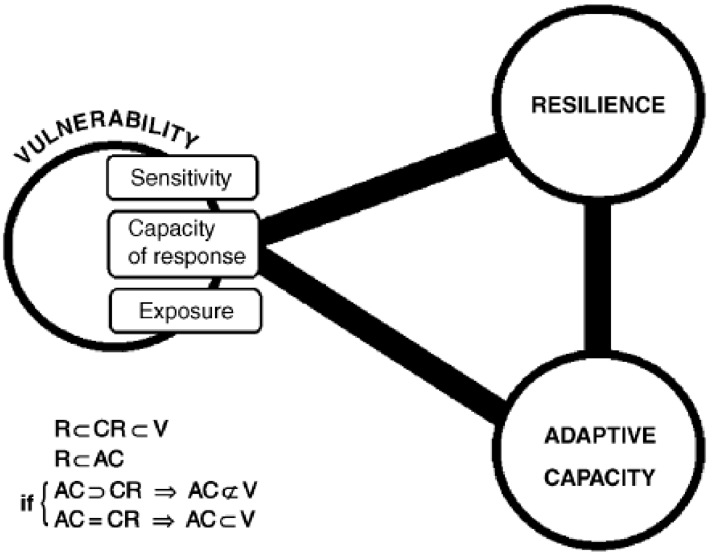

Gallopin (2006)

Figure 4: Relationship between Adaptive Capacity, Resilience, and Vulnerability. "A diagrammatic summary of the conceptual relations among vulnerability, resilience…The signs represent relations between sets: ⊂ = "subset of"; ⊄ ="not a subset of"."

Thus, adaptation, vulnerability, adaptive capacity, and resilience are often discussed together and are related, despite the specific relationships being highly inconsistent in the literature. Yet despite this wide range of definitions, there exist coherent ways to combine the ideas into a cohesive framework. Adaptive capacity remains key, as it is a useful measurement to help with climate adaptation because, unlike resilience and vulnerability, it is always positive, and there is no limit or maximum amount of capacity. It is a mutable property and can effectively incorporate the key concepts of vulnerability and resilience literatures (Engle 2011). Its diversity in definitions does not take away from its conceptual strength. Vulnerability studies are more easily translated into actionable policies. Similarly, due to its strong relationship

doi:10.6342/NTU201600887

to vulnerability, adaptive capacity can also be smoothly utilized in policy applications. But, incorporation of resilience concepts is also more easily encompassed by adaptive capacity than using vulnerability alone because of its flexibility in both pre- and post-harm conditions.

It is most beneficial to see vulnerability and resilience not as opposite sides of a spectrum but rather two somewhat opposing concepts that are not necessarily "good" or "bad" in all contexts. Of the various relations that have been previously discussed, adaptive capacity has the strongest theoretical basis in which to incorporate different strengths of vulnerability and resilience studies. It has been utilized in many studies regarding environmental change (Acosta et al 2006, Posey 2009, Panda et al 2012, Goldman and Riosmena 2013, Quiroga et al 2014, Hogarth 2015, Nhuan et al 2016). The literature does support the idea that systems with high adaptive capacity tend to be less vulnerable to harm and therefor are more capable of moving towards desirable states. These concepts are much more nuanced and context dependent, yet are both closely linked with adaptive capacity, which is more easily defined and represents a more tangible goal for climate adaptation.

This study will take adaptive capacity as a common focal point between vulnerability and resilience literatures, as a way to see community adaptation as continually flexible. Adapting Gallopin's conception of adaptive capacity as a

doi:10.6342/NTU201600887

component of vulnerability, emphasis will be placed on understanding adaptive capacity via a top-down approach. As such, resilience will not ultimately underpin the methodology of this research, but a grasp on the contributions of resilience studies anchors the definition of adaptive capacity and allows it to be more robust in understanding the dynamics of different social and ecological systems. Due to the nature of this project, the use of adaptive capacity will tend more towards the vulnerability studies perspective, but will incorporate resilience studies' nuances in an attempt to bring the fields of study closer together. Climate change remains a continuously complex topic which necessitates interdisciplinary approaches to address.

2.2.3 Indicators

Not only are the concepts of vulnerability, resilience, or adaptive capacity complicated, but measuring them is also fraught with difficulties. All are multidimensional concepts that some would argue, that by their nature, cannot be measured at all (Vincent 2006, Hinkel 2011). But when trying to measure the immeasurable, particularly in the socioeconomic realm, indicators are often the yardstick used.

doi:10.6342/NTU201600887

Indicators are a way of making theoretical concepts, like vulnerability or adaptive capacity, operational. Indicators are data that quantify and rank via different aspects, and are often used to compare areas to one another or from time frame to time frame. Single indicators are often scalar and linear, and can be combined to create composite indices (Hinkel 2011). Indicator systems have been created for a variety of scales and have been applied in a number of ways, as they are a useful way in which to evaluate adaptive capacity and provide insights on the areas where strengthening is most needed.

Indicators are most often associated with socioeconomic indicators, particularly large national indicators of well-being as put out by institutions like the World Bank. Some common socioeconomic indicators are GDP as an indicator of wealth, literacy rate as an indicator of education level, or the Gini Index as a measure of inequality. Indicators can be measures of biophysical qualities too, particularly ones which are difficult to directly measure or calculate. Species richness as a way of representing ecological health, or AQI as a measure of air quality, and CTSI for measuring eutrophication, are biophysical indicators or indices commonly used.

Many studies using indicator systems to measure vulnerability and adaptive capacity have been conducted. Yohe and Tol (2002) constructed a system based on adaptive capacity determinants which they tested on increased flooding situations in the Netherlands, whereas Brooks et al (2005) created a national scale vulnerability index

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between many different countries, with particular emphasis on data-based indicator weighting. Acosta et al (2006) applied a novel, spatially-explicit adaptive capacity index to Europe. Sietchipeng (2006) and Vincent (2007) investigated indicator uncertainty across scales with cross-country and household case studies, Jubeh and Mimi (2012) focused on national level water resource stress and vulnerability in the Middle East, and Monterroso et al (2012) researched agricultural vulnerability to climate change. Ahsan and Warner (2014), Binita et al (2015), Pandey and Bardsley (2015), Salik et al (2015), and Xenarios et al (2016) conducted vulnerability assessment indices in various case study areas. Whatever the system, indicators provided quantitative, easily understood data on which to draw conclusions.

Despite being commonly used, easily understood, and generally accepted, many indices are often considered incomplete, unrepresentative, or have too much uncertainty to be relied on for policy or program planning. The use of indicators is widespread, but the critiques of the method are prevalent also.

Hinkel (2011) outlines many of the issues with indicator use in regards to concepts such as vulnerability. From a science to policy perspective, unclear objectives and confusion about what indicators are able to achieve often undermines the usefulness of indicators and indices. Steps from selective indicators to how to aggregate them and validate them are all difficult to evaluate and substantiate. Socioeconomic systems are

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never completely defined by a few variables, nor are they linear, yet indicators used to describe them often are. Sufficient data is also difficult to find at smaller, more context-specific scales. Hinkel argues that indicators are the wrong method for identifying mitigation targets, raising awareness of climate change, and monitoring adaptation policy. But Hinkel suggests that indicators may be a helpful tool in identifying particularly vulnerability of communities or sectors, providing the system can more narrowly defined. It is also suggested that, "they should only serve as high-level entry points to further more detailed information behind. Since indicators reduce complexity, they can be interpreted in a variety of different ways and background information is necessary to prevent misinterpretation." He further recommends that "the different types of arguments used in developing indicators should be made transparent. In particular, normative arguments should be made explicit and be based on the preferences of stakeholders." Finally, it is recommended that "due to the inherent "wickedness" of the task, any vulnerability indicator would need to be updated regularly, based on new research findings."

Vincent (2006) also described some aspects of uncertainty with regards to indicators, particularly in terms of scale, and both Vincent and Hinkel describe the issues with both inductive and deductive foundations for building indicators. Many researchers, like Yohe and Tol (2002), focus on deductive (theory-driven) selection of

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indicators, based on theoretical determinants of adaptive capacity, whereas studies like Brooks et al (2005) or Monterroso et al (2012) take a more inductive (data-driven) approach. Deductive systems often do not have complete frameworks for all variables necessary or do not have theories available for how to aggregate data. Inductive methods often suffer from lack of data (particularly experienced harm through past disasters) and systems that are not narrow defined.

Thus, creating indices of value are difficult, but there are indeed ways that mitigate problems with methodologies and continue to improve them. As data becomes more widely available at smaller scales, uncertainty can be decreased. The literature suggests that narrowly defined systems with clearly outlined purposes for the indicator system, transparency in methodology, and awareness of the weaknesses of indicators as a whole are the most important in creating and utilizing an indicator system for measuring adaptive capacity.

2.2.4 Land Use and Urbanization Dynamics

With all these issues in mind, from climate change to climate adaptation to adaptive capacity, there are several ways to refine these concepts for application. One

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phenomenon in particular has not been well addressed in discussions of measuring adaptive capacity, and that is urbanization. This section hopes to draw connections between urbanization, land use and land cover (LULC) change, climate and adaptive capacity, as “accelerated urbanization is an important trend in human settlement, which has implications for the consideration of exposure and vulnerability to extreme events” (IPCC 2012).

In 2014, 54% of the world’s population lived in urban areas, and that figure has surely risen since. Urbanization is expected to continue well into the future all over the world. By 2050, the global urban population is predicted to be two thirds of the global population, with most of the change concentrated in Africa and Asia. Asia, in particular, will continue to hold about half of the world’s urban population. Driven by a number of social and economic transformations, urbanization catalyzes a number of its own changes, affecting the state of poverty, of land use and land cover, and more. This has, and will continue to have, a great effect on demographic and environmental developments. (UN WUP 2014)

World urbanization has a profound impact on the extent and spatial character of urban land cover and land use. With geographic movement of demography comes geographic change of resources, capital, and demand, all of which have corresponding physical manifestations. With more people living and working in cities, metropolises

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expand and agricultural and natural vegetated land cover is developed, increasing the concentration and total area urban land. Natural land cover, due to its physical and chemical properties, has cooling and water retention functions, as well as important for soil and ecological health. Transition to urban land cover can lead to the heat island effect and pollution problems. Thus when urbanization causes a decrease in natural land surface it affects carbon, energy, and water budgets, and a number of other biophysical mechanisms with far reaching consequences (Dale 1997, Pyke and Andelman 2007, Pielke et al 2011).

Land use and land cover (LULC) and urbanization are also both major drivers *and* results of global climate change (Dale 1997, Kalnay and Cai 2003, van der Werf and Peterson 2009). LULC have complex interactions with atmospheric conditions, which contributes to climate change while simultaneously compounding or mitigating climate impacts at a range of scales (Dale 1997, Pyke and Andelman 2007, Lee 2009, Pielke et al 2011). Most notably, deforestation can add significantly to carbon dioxide levels by releasing carbon from vegetation, and removal of wetlands can have similar effects. Conversely, climate impacts can also spur urbanization or reallocation of agriculture land or pasture land (Lee 2009). Pyke and Andelman (2007) state that "the impact of global climate change is mediated at regional and local scales by biophysical processes associated with LULC." LULC and climate change are intimately linked;

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both climate mitigation and adaptation are influenced by, and in turn influence back, LULC and urbanization.

These have impacts on both socioeconomic and biophysical systems. More specifically, LULC affect soil moisture, length of growing season, diurnal temperature range, temperature extremes, suspended dust volumes, rainfall patterns, albedo, and storm frequency, which all influence agricultural production and thus food security. Urban land increases heat at lower levels of the atmosphere and can change peak heat times and elevate minimum temperatures, affecting thermal comfort and health. The increase in impervious surfaces and decrease in forest coverage that comes with urbanization tend to have negative effects on ecological functions, such as loss of soil fertility or decline in species diversity. Thus, from both historical data and modeling results, it has been shown that climate is intertwined closely with changes in LULC.

As mentioned before, changes in land use have clear, observable effects on greenhouse gas emissions and vice versa (Liao et al 2013, Jones et al 2013). But it would be remiss not to realize that climate adaptation is also mediated by LULC. Many determinants of adaptive capacity are affected by levels of urbanization as LULC have effects on both social and ecological systems. Socioeconomic determinants, like access to resources or income level, are highly related to urbanization. The rural-urban disparity is key in considering factors that influence adaptive capacity. Many economic

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resources are concentrated in urban areas, as they are linked to international markets and finance. Also, urban areas tend to be well serviced by infrastructure from roads to electricity, compared to rural areas that may not have as easy access to things like running water or cellular service. But cities are complex places, and have both positive and negative impacts on adaptive capacity. Cities may be associated with more resources, but they also bring many consequences like increased inequality or weaker social ties that provide support in times of stress. Biophysical factors are also often dependent on land cover, as previously mentioned; for example, flooding impacts are exacerbated by loss of coastal wetlands and wetlands have historically been filled in for the sake of agriculture or other kinds of development. Forest cover has also been shown to have cooling effects, or other positive impacts on soil retention or precipitation patterns.

Studies have shown clear links between LULC and climate change and the feedback between them, but a literature gap remains in drawing connections between LULC change and measuring adaptive capacity, although SREX addressed urbanization specifically as a potential driver of vulnerability. This study aims to use the existing literature to create a new measure in which to connect the effects of urbanization on the ability of communities like Tamsui and West Palm Beach to adapt to oncoming climate change.

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2.3 Study Specific Review

2.3.1 Case Study Sites

To illustrate the influence of urbanization on adaptive capacity, this research will focus on Tamsui in northern Taiwan, and West Palm Beach in Southern Florida in the US as case study sites. Both are areas that have experienced significant growth in recent years, and are slated for still more development and land use change in the next decade, making them suitable for investigation. Further background on the two case study sites will be continued in the Methods section. Here, the study sites will be reviewed in terms of the literature regarding their ecological, historical, and legal implications. This section will clarify some of the effects of land use change on the two sites.

2.3.1.1 Tamsui, New Taipei City, Taiwan

There have been numerous studies on climate change in Taiwan, land use change processes, as well as several on the relationship between the two. Taiwan will be strongly affected by climate change and has already begun to see significant warming trends and changes in precipitation patterns. Taiwan will likely see greater change between the rainfall difference in the wet and dry season, temperature increases, increases in extreme rainfall events, as well as a number of other varying local changes (Hsu et al 2011, Hsu and Chen 2002). These changes will affect a number of facets in

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Taiwanese life, such as food and agriculture, energy, and health (Hsu et al 2011, Chang 2002), yet Taiwan has limitations in the international realm of climate negotiations as it is not a member of the UN and has different, if not limited, capacity to affect change on a larger scale (Su 2011).

Much of previous land use policy and planning law has inadvertently promoted urban sprawl and the conversion to low density development**.** Chou and Chang (2008) found that politics in local planning governance led to an oversupply of serviced land, resulting in urban sprawl in Taiwan. Regulations for development were relaxed, and local politicians used "land use plans to channel dynamic economic activities and urban development into their own territories." Local capitalists took advantage of a series of rezoning and lack of taxation policies for land speculation in rural and suburban areas.

The effect of LULC on hydrology of northern Taiwanese watersheds was investigated by Lin et al (2009) and Lin et al (2007). Increased land use intensity increased hydrological output, in fact the percentage of forest converted to built-up land was the factor that most strongly influenced peak flow and runoff volume. Total vegetated landscape outweighed landscape configuration in importance regarding hydrological output of the watershed, which indicates that in some cases, quantity still overshadows some qualitative characteristics. But "the hydrological components were impacted by land use change even through time and low land use change pressure.

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Runoff from built up areas increased and groundwater discharge decreased as infiltration reduced owing to replacement of vegetation resulting from development." The study found that increased peak differences in streamflow, surface runoff, groundwater discharge, and stream-flow variability were all linked to land use change (Lin et al 2009).

Chen and Huang (2013) investigated land use on mountainous areas and its effect on landslide ratios. Agricultural products like betel nuts or tea have shallow roots and tend to result in higher landslide ratios than land covered with natural forest, and development also results in higher occurrence of landslides. These studies show the effect of LULC change on ecosystem processes, not just from vegetated to urban transitions but also from forest to agricultural uses. These changes have complex interactions with hydrology and disaster rates in Taiwan.

2.3.1.2 West Palm Beach, Florida, USA

Southern Florida is also an area that is vulnerable to climate impacts. As a low-lying state, it is particularly concerned with sea-level rise, elevated storm surges, and saltwater intrusion, and like Taiwan, there have been recorded changes in precipitation patterns and temperatures due to urbanization, natural variability, and climate change (Obeysekera et al 2011). Water stress is of particular concern.

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Urbanization and agriculture have been the main drivers for the land use change in Florida over the last century, which has resulted in draining of large portions of marshland. Crop freezes have been linked to LULC changes across Florida, which were attributed to converting wetland to agricultural land across the state that resulted in larger temperature ranges (Obeysekera et al 2011, Marshal et al 2003). In a climate report, overviews of previous studies in southern Florida showed that "urbanization has also dramatically altered the local climate. From an analysis of 57 weather stations for a 58-year period (1950–2007) in the state of Florida, Winsberg and Simmons (2009) found that the length of the hot season has increased at most locations. However, of the seven stations that had at least a three-week increase, five were in large cities and, therefore, Winsberg and Simmons (2009) attributed the "urban heat island" effect (urban areas tend to increase temperatures locally due to increased radiation of heat and reduced evaporation from asphalt surfaces, roofs, etc.) as the primary cause of the change in the length of the hot season." The urban heat island effect was also report to have changed precipitation patterns downwind of urban areas. But real estate is a massively influential sector in Florida, and is a main driver of land use change, zoning decision-making, and adaptation decisions (Obeysekera et al 2011). The history of human activity in Florida has led to a number of ecological and climatic changes that

doi:10.6342/NTU201600887

will in turn influence many aspects of society in Florida, from real estate to health.

2.3.3 Indicator Systems – Previous Studies and Indicator Selection

This study bases indicators on the determinants of adaptive capacity, which were adapted from IPCC's report "Adaptation to Climate Change in the Context of Sustainable Development and Equity" (Smit et al 2001). Below are the indicators chosen for the Urbanizing Adaptive Capacity Index (UACI) and some reasoning for their selection, as well as a list of previous studies that used variants of these determinants in their indicator systems. Data availability, previous literature, and relationship to urbanization were the major priorities in choosing indicators.

2.3.3.1 Biophysical Indicators

Storm water and Runoff: percent impervious surface – This is a very important indicator associated with urbanization and its effect on adaptive capacity. LULC change can influence flood intensity and frequency (IPCC 2012). As discussed in Lin et al (2002, 2009), built up land area is closely related to the increase in runoff and stress on storm water systems, as water is not able to be absorbed into the soil and trickle down into aquifers and instead runs along the top of impervious surfaces in larger volumes. It

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increases the number of flood events or intensity of flood events (Remondi et al 2016). With the increase of impervious surfaces like concrete or asphalt, biophysical systems are less able to adapt to changing precipitation patterns, as the land's ability to retain water or ability to remove it from the surface decreases. Cutter (2008), Jubeh and Mimi (2012), and Monterroso (2014) also used similar measures in their indicator systems.

Temperature Variance: degrees difference – Surface temperature is another aspect affected by urbanization through transformation of material with varying capacity for heat-retention (Fu and Weng 2016, Zhou et al 2016, Maimaitiyiming et al 2014). The urban heat island effect is a phenomenon associated with cities, and it can exacerbate many health-related issues (Li et al 2016). With more urban surfaces, areas are less able to adapt to changes as temperature differences are exacerbated, affecting both people and ecosystems. Monterroso (2014) and Binita et al (2015) both included temperature related indicators in their assessments.

Surface Water Stability: percent natural land cover – This indicator is related to the issues discussed with impervious surfaces. Hydrological changes are often linked to amount of natural vegetated land cover (Lin et al 2002, 2007). The more natural land cover, such as wetland or forest, rather than agriculture, the better the land is able to

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provide ecosystem services and remain productive. Development into higher elevations or steeper sloped areas can be decrease the stability of land, potentially resulting in landslides during rains. Brooks et al (2005) also used a similar indicator.

Each of these adaptive capacity indicators has been used in previous studies and are correlated with urbanization in one way or another. Iframed differently, they may also be seen as indicators of exposure to climate impacts or indicators of urbanization as a driving force of climate change. But in this study, they will be used as indicators of ecosystem adaptive capacity

. The UACI as a whole will be used to measure adaptive capacity as a function of urbanization, which will be covered in the Methods section.

2.3.3.2 Socioeconomic Indicators

Networks – occupancy rate and trust: Networks, social capital, and community ties are important support systems for individuals and families during times of crisis, but are among some of the most difficult things to measure. The social ties that people have to others that can help them are very important for adaptive capacity and other benchmarks of wellbeing. However, urban populations are often found to have fewer community

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ties as compared to rural areas (Beggs et al 2010, Ziersch et al 2009). Because of this determinant's difficulty to measure and lack of comparable measures across international borders, two indicators, occupancy rate and trust, were chosen to represent them. Cutter et al 2008, Monterroso 2014, Salik et al 2015, Xenarios et al 2016, and Nhuan et al 2016 all used some form of network measure in their indicator systems.

Economic Resources – GDP and median household income: GDP and income were the most frequent and straightforward measure used in many of the previous studies on adaptive capacity and vulnerability. More economic resources allows entities to prepare better for or recover more quickly from disasters or stressors. GDP is an indicator of the health of the entire economy, whereas median household income measures household or individual level adaptive capacity, and both are included in the UACI. GDP and household income are both positively correlated with urbanization (Hope and Edge 1996). Acosta et al 2013, Cutter et al 2008, Jubeh and Mimi 2012, Posey 2009, Daramola et al 2016, Brooks et al 2005, Cutter et al 2008, Kelly 2000, Metzger et al 2006, Sietchipeng 2006, Vincent 2007, Binita et al 2015, Ahsan and Warner 2014, Xenarios et al 2016, Nhuan et al 2016, Panda et al 2013 all used economic resources in their indicator systems or listed it as a contributing factor for adaptive capacity and vulnerability.

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Information and Skills – education level: Education level or literacy are almost ubiquitously positive characteristics and are the most commonly used general measure of information and skills. Education levels are also shown to be positively related to urbanization (USDA 2015, Pradhan et al 2000, Hope and Edge 1996). Among those that used education level in their studies of adaptive capacity and vulnerability, some are listed here: Acosta et al 2013, Brooks et al 2005, Jubeh and Mimi 2012, Metzger et al 2006, Monterroso 2014m, Sietchipeng 2006, Binita et al 2015, Ahsan and Warner 2014, Salik et al 2015, Xenarios et al 2016, Nhuan et al 2016, Panda et al 2013, Posey 2009.

Equity – Gini Index Score: The Gini index has its shortcomings, but has been measured at various levels for an extended period of time and remains the most widely used and comparable measure of economic equality. Urban areas, particularly in the developing world, have higher levels of inequality than rural areas (UN 2014, 2011). Equity is one of the 6 main determinants of adaptive capacity, and thus this indicator uses the Gini to account for this influence. Acosta et al 2013, Brooks et al 2005, Kelly 2000, Metzger et al 2006, Pandey and Bardsley 2015, McManus et al 2014 are several previous studies

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which used equity in their indicators, on the assumption that greater levels of equality were positively correlated with adaptive capacity.

Management and Institutions – existence of government plans: Governmental management is a huge factor in adaptive capacity and general well-being. Effective government is also measured in a number of ways, and has been used for many different indicator systems, but for the purpose of this study existence of emergency plans were chosen to show government attention to adaptive capacity. Trends show that rural areas do not receive the same level of service from government entities as urban areas (UN 2014). Brooks et al 2005, Cutter et al 2008, Jubeh and Mimi 2012, Kelly 2000, Sietchipeng 2006, and Posey 2009 all utilized a measure of government or institutions in their studies.

Technology and Infrastructure – internet access: Internet access was chosen to represent technology and infrastructure. Internet access is and will continue to be a major conduit of information access, which is crucial for adaptation. Internet access tends to be higher in urban areas, and is an important technology. There are a number of factors that influence internet access and its diffusion, but "countries with a larger urban population and stronger participation within a global network of urban civilization would develop

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the internet faster than others" (Li and Shiu 2012). Acosta et al 2013, Cutter et al 2008, Metzger et al 2006, Sietchipeng 2006, Vincent 2007, Ahsan and Warner 2014, Salik et al 2015, Xenarios et al 2016, Nhuan et al 2016, and Panda et al 2013 all highlighted the importance of technology and infrastructure in their indicator systems.

2.3.4 Scenario Building

IPCC defines a scenario as a coherent, internally consistent description of a future state. The basis for scenario building in this study are several IPCC reports. The Special Report on Emission Scenarios (2000) and Chapter 3 of Working Group II from TAR on Developing and Application of Scenarios (2001) and Scenario Process for AR5 (2014) are the key references used in this research.

Socioeconomic, land use and land cover, environmental, climate, and sea-level rise, are the types of scenarios outlined by IPCC. They can each have a number of functions, such as illustrating impacts of climate change, to communicate potential consequences, to assist in strategic planning, guide emission policies, or for other methodological purposes (IPCC 2001). Because the emphasis of this study, land use and land cover change is the scenario used, based on socioeconomic rather than climatic drivers. Land use can be affected by climate change but tends to be mostly influenced by socioeconomic trends.

doi:10.6342/NTU201600887

The Special Report on Emission Scenarios (SRES) created four different narrative storylines based on socioeconomic development paths (2000). The scenarios fall along two axes, A to B and 1 to 2. A represents an emphasis on rapid economic growth, whereas B is environmentally and equity oriented. Scenarios that fall along 1 are more globally oriented, in contrast to regionally or locally centered scenarios along B.

For Assessment Report 5 (AR5), IPCC changed their approach to scenarios from a sequential approach to a parallel approach, as shown in **Figure 5** from the IPCC website (2014). No new SRES would be published, IPCC would instead take on an assistive role and rely on scenarios created by the research community. Narrative storylines from SRES would continue to be referenced, but no longer as the first step in scenario generation.

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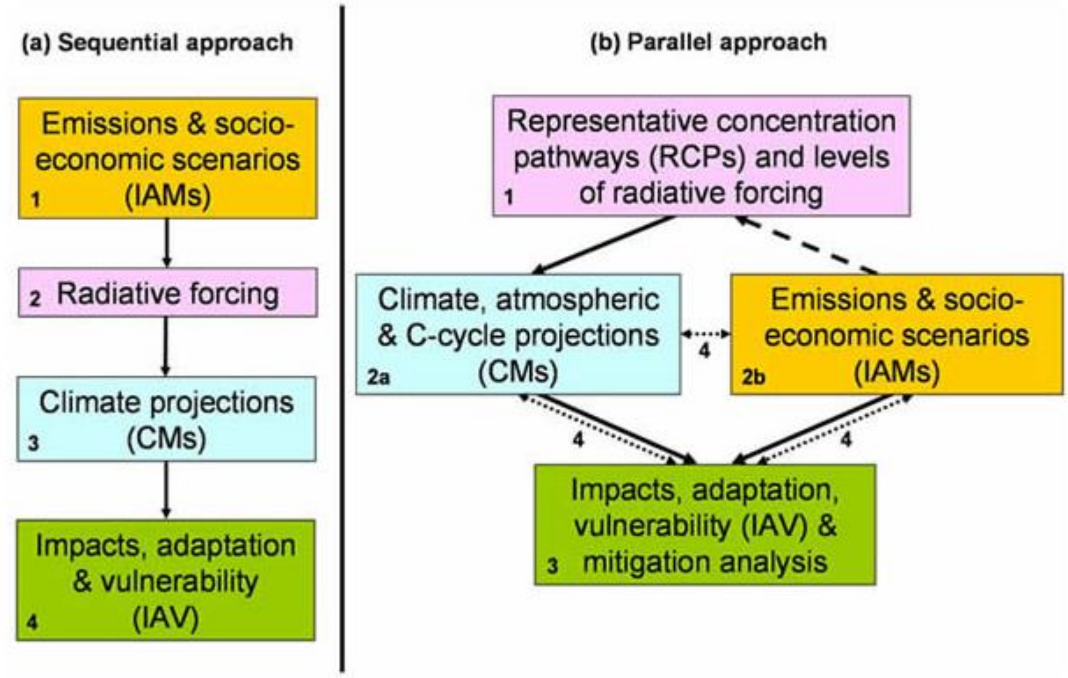

IPCC, (2014)

Figure 5: IPCC scenario approach

One previous study that has utilized the storylines to investigate adaptive capacity or vulnerability is Acosta et al (2006), which models adaptive capacity in Europe under the four storylines, A1, A2, B1, and B2 with twelve socioeconomic indicators. But not many studies combine future scenarios, land use change, and indicator systems, and thus this research aims to address, in part, this gap.

2.4 Conclusion

In order to prepare for the inevitable climatic changes of the future, local adaptation strategies are key to attempting to allay potential harm, such as sea level rise

doi:10.6342/NTU201600887

or changes in precipitation patterns, but to do so assessments of adaptive capacity must be made. Such a task is a complex undertaking, requiring a clear understanding terms such as adaptation, adaptive capacity, vulnerability, and resilience, as well as their relation to each other, to make appropriate decisions and contextualize information. Their different perspectives allows for and necessitates an interdisciplinary approach to climate change adaptation policy. Furthermore, when measuring adaptive capacity, limitations of measurement methods must be kept in mind. This study focuses on adaptive capacity through the lens of urbanization, which is not only a wider global phenomenon but a specific direction of LULC change, namely, from vegetated land cover to agriculture and built-up land.

To investigate this, an adaptive capacity indicator was constructed based on socioeconomic and biophysical indicators affected by land use change, called the Urbanizing Adaptive Capacity Index (UACI). Two sites—Tamsui, Taiwan and West Palm Beach, US – were chosen as case studies to illustrate the difference between three different scenarios. This literature reviewed the conceptual underpinnings of this research, as well as some literature-based justifications for methodological directions, which will be elaborated on in the next section.

doi:10.6342/NTU201600887

Chapter III: Methods

This section describes the methodology behind the Urbanizing Adaptive Capacity Index (UACI). Indicators influenced by land use change and urbanization were chosen, and both biophysical and socioeconomic aspects are considered. Data for indicators from years 2000 and 2010 were used as a baseline for the index. ArcGIS and *What if?* were used to create three alternative future land use scenarios based on land use and socioeconomic inputs. Indicators were pushed to future time slices along each scenario to predict the adaptive capacity for both Tamsui and West Palm Beach. This research design is shown in **Figure 6**.

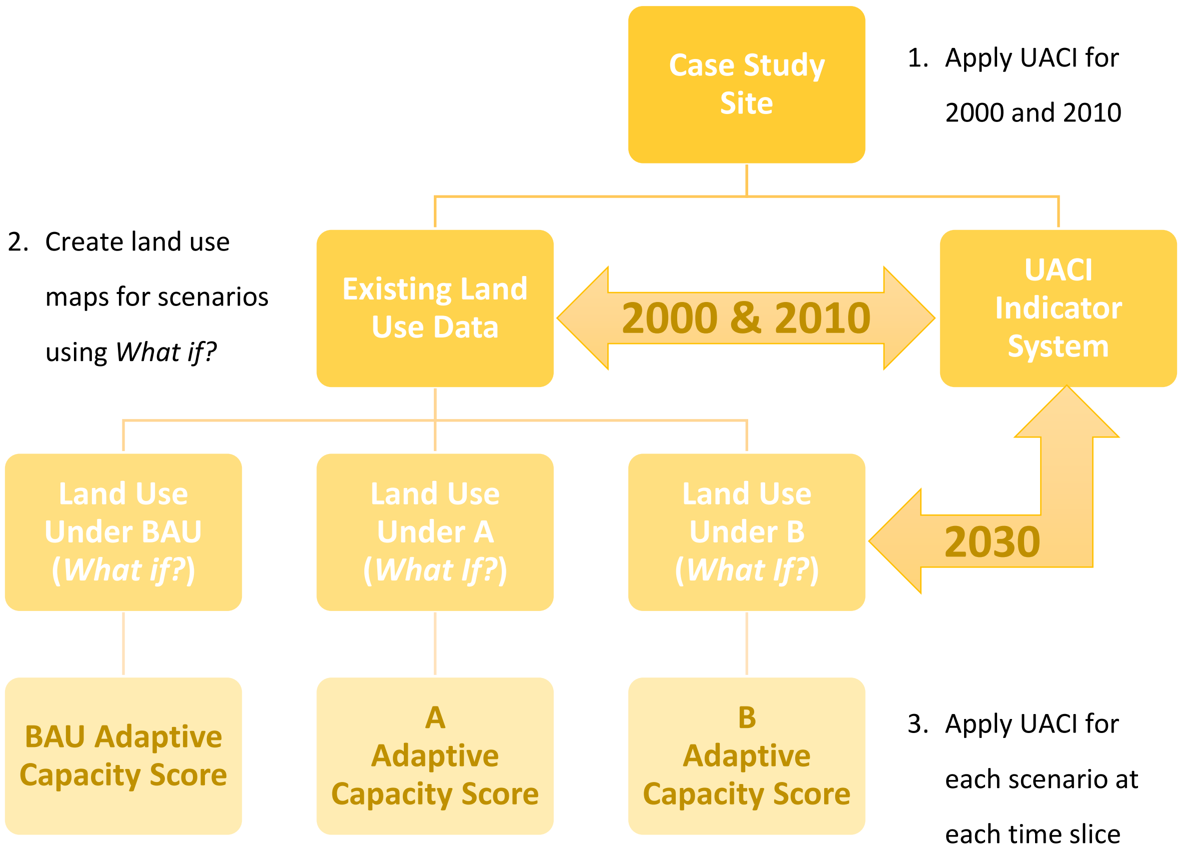

Figure 6: Research Flow

doi:10.6342/NTU201600887

3. 1 Case Study Sites:

The two study sites in this research are Tamsui District, New Taipei City, Taiwan and the City of West Palm Beach, Florida, USA, as shown in the map below. These two sites were chosen due to several key similarities. Both sites are relatively small, coastal areas with tropical/subtropical climates which have experienced over 20% growth in the last decade, are dependent on tourism, have relatively large tracts of natural land cover, and are continuously exposed to a number of natural disasters, such as hurricanes or typhoons. Both sites are expected to continue to see high rates of population growth in coming years, making them revealing cases in which to observe urbanization processes under the context of climate change.

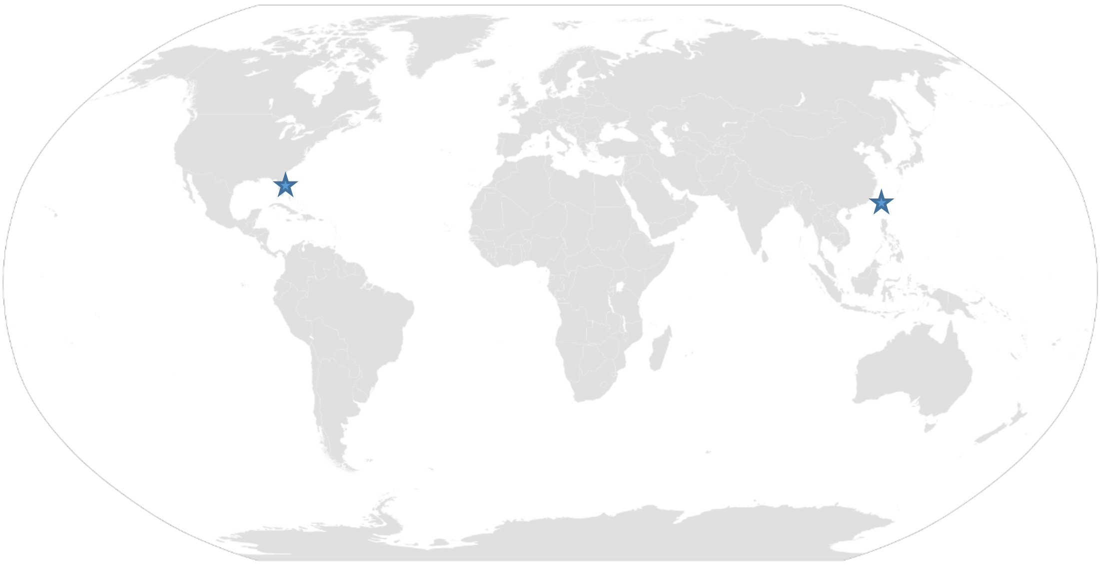

Figure 7: Relative positions of Tamsui and West Palm Beach

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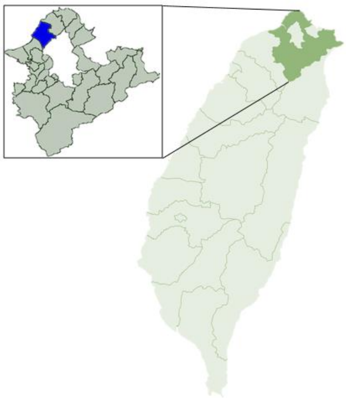

Figure 8: Map of Tamsui

3.1.1 Tamsui

Tamsui is a district in New Taipei City, within the larger Taipei metropolitan area, home to over 150,000 people. Over 70 square kilometers large, the district is known for several historic sites and boardwalk tourist attractions on the Tamsui River. Major developments came with the linking of Tamsui to the central city by the metro system in the 1990s, and another public transportation project, a light rail system, is currently in the works for the area. Being in northern Taiwan, Tamsui has a subtropical climate and is prone to experiencing typhoons.

The inland terrain is forested mountain, with patches of agriculture. Urban development has been most heavy on the southwest side of the district, along the river and fisherman's wharf. Housing development has also started to creep north, especially with the new TamHai township development, but has remained relatively concentrated. The majority of the district remains primarily mountainous forest. Changes are shown **in Figures 9, 10** and **11**.

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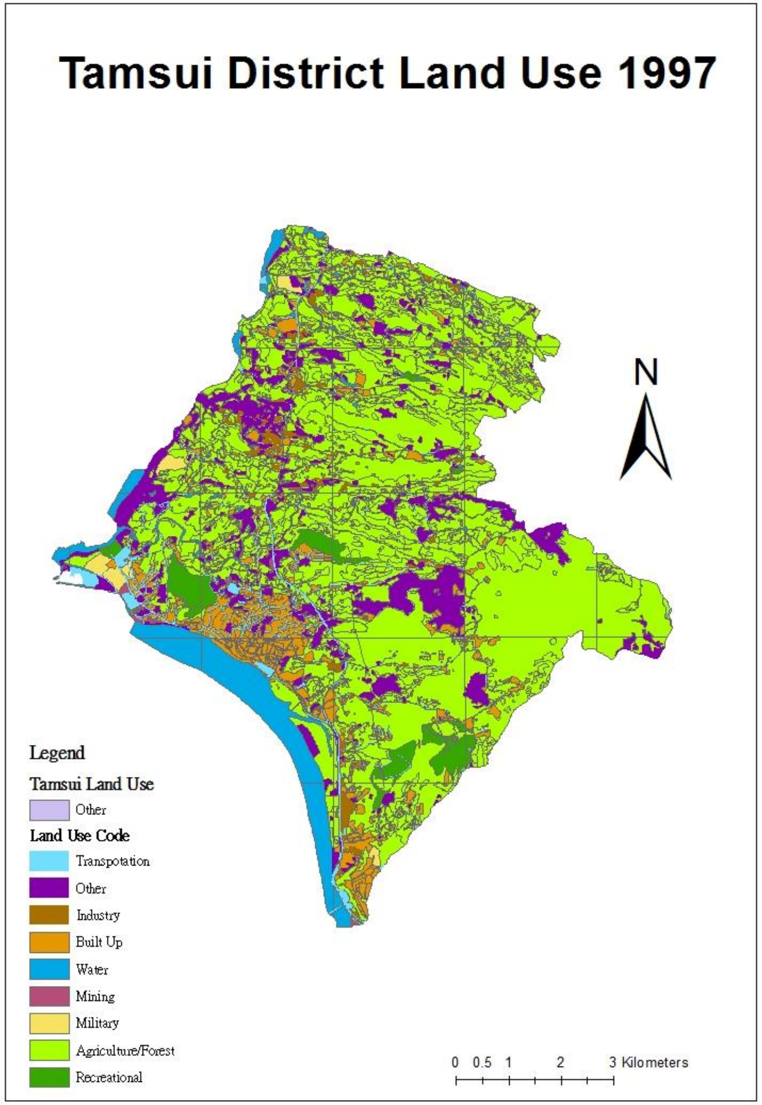

Figure 9: Tamsui Land Use 1997

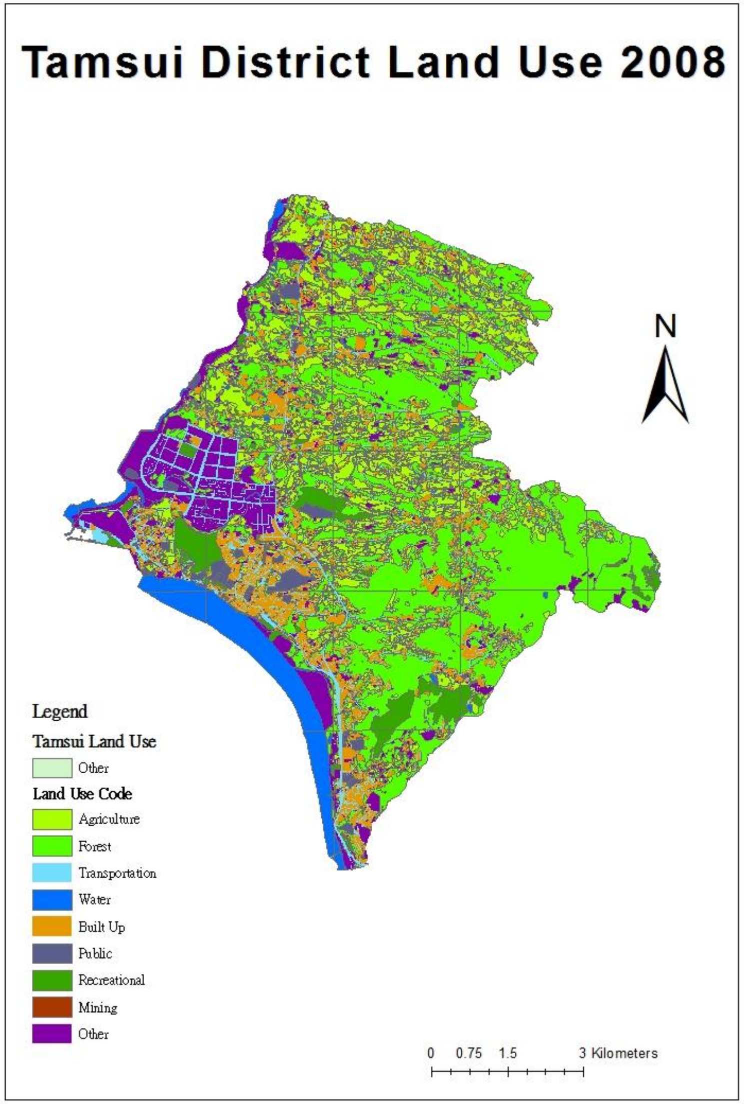

Figure 10: Tamsui Land Use 2008

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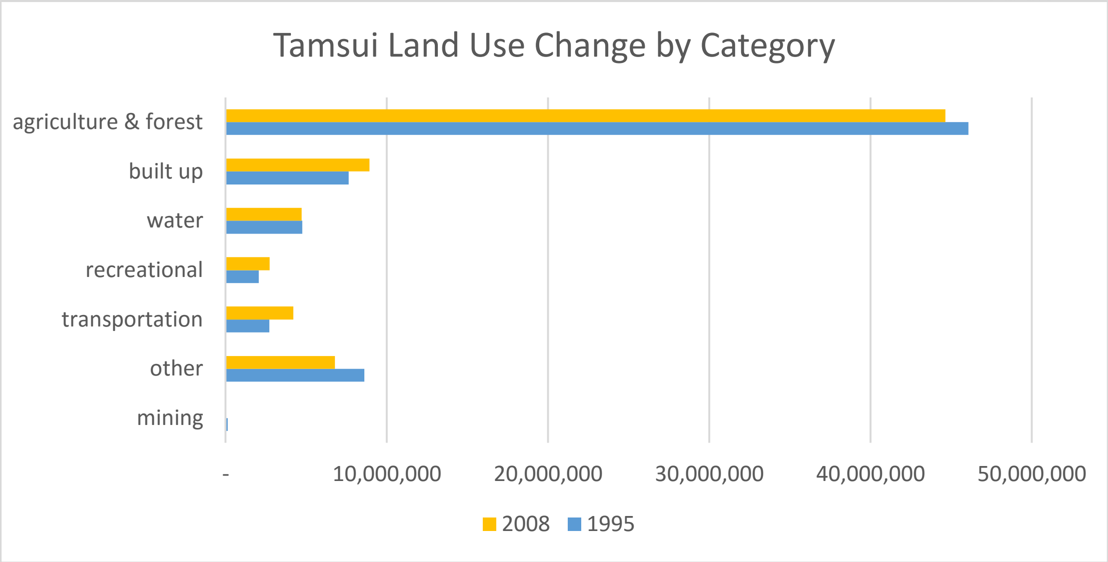

Figure 11: Tamsui land use change by category

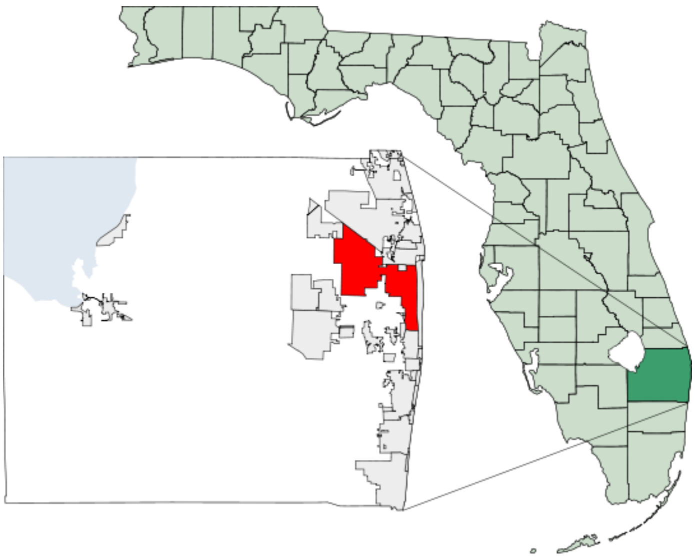

Figure 12: Map of West Palm Beach

3.1.2 West Palm Beach

The City of West Palm Beach, shown in **Figure 12**, is over 150 square kilometers in area with a population of about 100,000 as of 2015. As one of the oldest cities in

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South Florida, West Palm Beach is also has an active tourism sector for beach going and shopping. Development has mainly been concentrated along the beachline on east side of the city.

This area of Florida has a tropical climate, with high rainfall and temperatures, making it fairly similar to Taiwan in most respects. Where it differs most starkly from Tamsui is that the topography is low-lying and has extensive tracts of wetlands to the west. Between 2000 and 2009, urban build-up and transportation-communication-utilities gained land coverage, whereas agriculture, barren land, rangeland, water, wetland, and forest all lost land coverage. Almost four million square meters of upland forest and two million square meters of inland water were lost to urban development. Agriculture covered a much smaller percentage of the land in the city, but in this time period has been nearly eliminated. The wetlands in Grassy Waters Preserve, in comparison, have remained largely intact. (See **Figures 13**, **14** and **15**)

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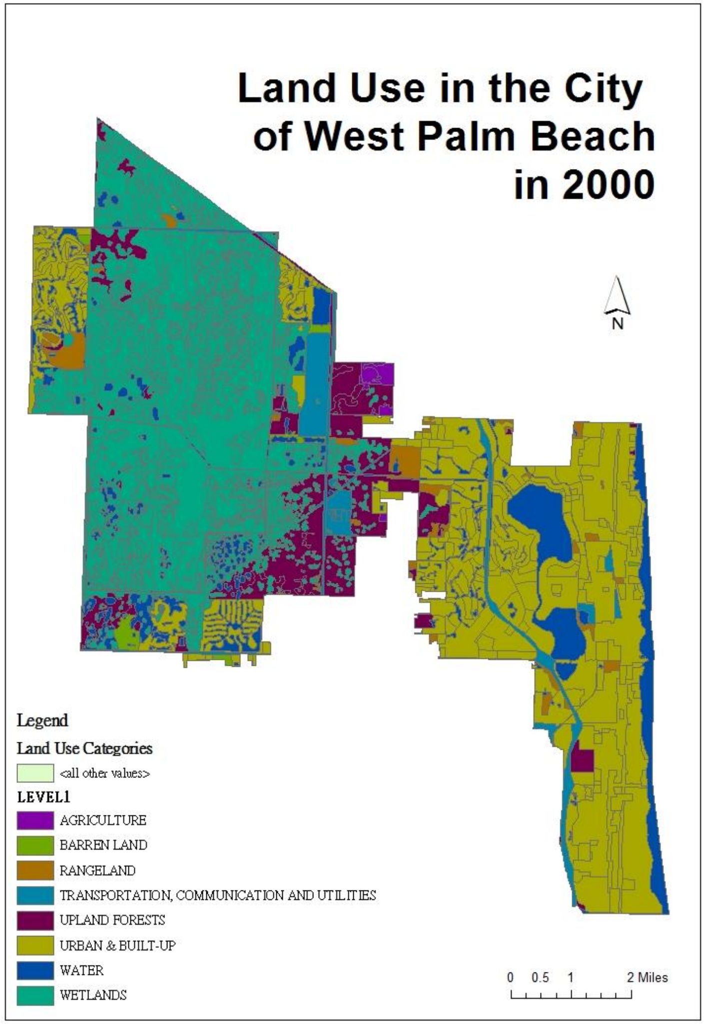

Figure 13: West Palm Beach Land Use 2000

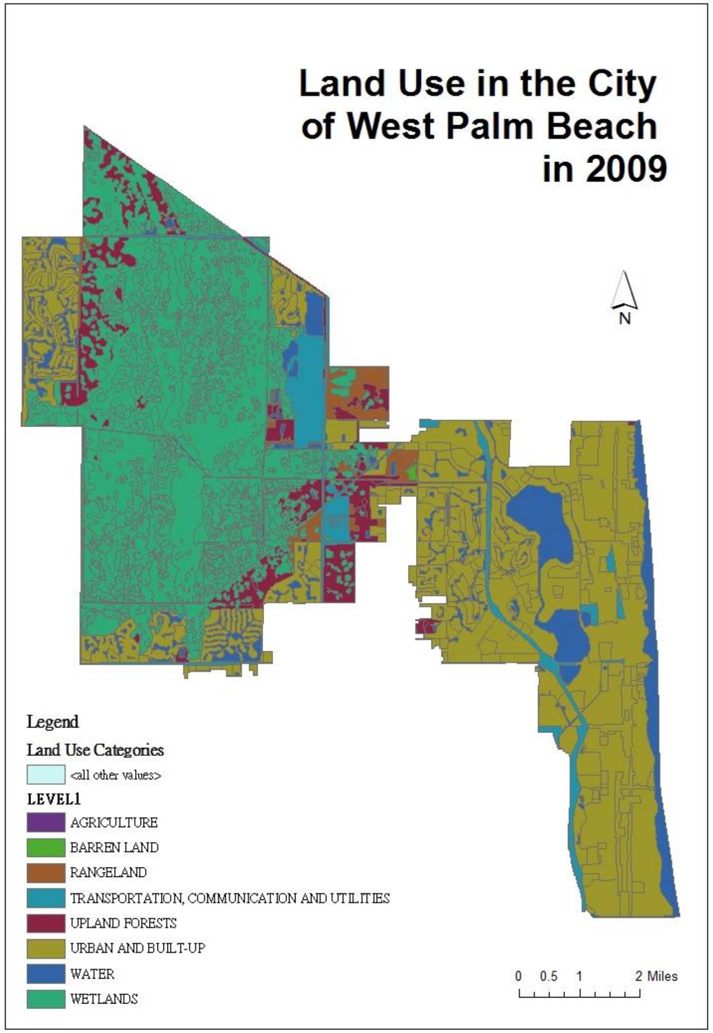

Figure 14: West Palm Beach Land Use 2009

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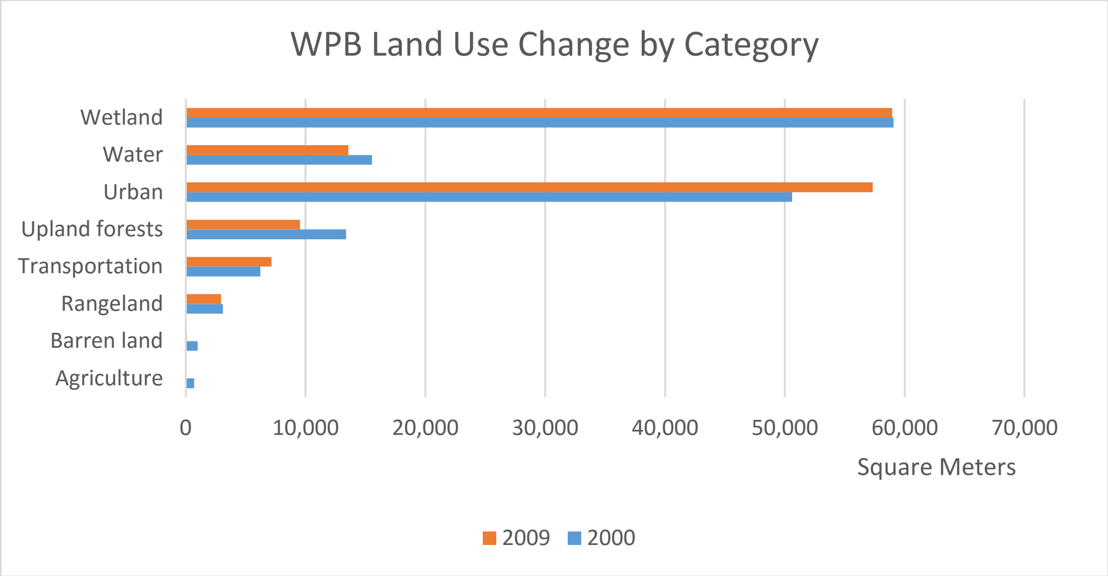

Figure 15: West Palm Beach land use change by category

3.2 Indicator System and Scoring:

With such tumultuous change in the last decade, measuring effects of such change is essential for urban and climate planning, especially on the local level. With climate change, mitigation is more globally focused, but adaptation impacts are highly contextually-specific. Thus, this research aims to compile a set of indicators to measure this change with regards to urbanization and its effect on adaptive capacity on a local scale. Indicators chosen are based on IPCC frameworks and previous literature on vulnerability and adaptive capacity (Brooks & Adger 2004, Sietchiping 2005, Acosta et al 2013, Smit et al 2001). Generic, rather than hazard-specific, indicators are used for comparison to allow for a wider range of possibilities. This research scores climate

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adaptation capacity indicators for years 2000 and 2010 using land use percentages to act a baseline and uses this data to predict indicator values to future time slices along land use change scenarios. Data for indicators were sourced from government census data and reports, land use surveys, and historical documents of each case study site.

Many studies have used similar indicators to measure vulnerability and adaptive capacity, as noted in the literature review. Indicators in this study were chosen based on relationship with urbanization, previous literature, scalar suitability, and data availability, and they are show below in **Tables 1** and **2**.

Table 1: Biophysical Indicators

i	Indicator	Measure
1	Storm water and Runoff	Percent Impervious surface
2	Temperature Variance	Temperature difference in Celsius
3	Surface Water Stability	Percentage of forest/wetland coverage

**Note on biodiversity indicator: in the original index design, a biodiversity indicator was included, as the literature indicates that it would be an important factor. But lack of data or a reliable proxy resulted in its exclusion. A biodiversity indicator would be highly recommended for further research.*

Table 2: Socioeconomic Indicators

j	Determinant	Indicator	Measurement
1	Networks	Occupancy rate	Percentage
2	Networks	Trust level	Percentage
3	Economic Resources	Gross Domestic Product	Dollars
4	Economic Resources	Median household income	Dollars/year
5	Information and Skills	Education level	Percent with high school level education and above

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6	Equity	Inequality	Gini Coefficient
7	Management and Institutions	Government effectiveness	Existence of government plans (i.e. disaster, climate adaptation), yes or no
8	Technology and Infrastructure	Internet access	Percentage

The UACI is calculated using the equation below:

$$\text{UACI} = \sum_{i=1}^{3} B_i + \sum_{j=1}^{8} S_j \quad \textbf{(2)}$$

where i represents the specific biophysical indicator, j represents the specific socioeconomic indicator, B_i equals the biophysical indicator score and S_j equals the socioeconomic indicator score, and $0 < B_i < 10$ and $0 < S_j < 10$.

The indicators were compiled and scored on a scale from 0-10 points, with 10 points representing high adaptive capacity and 0 points representing low adaptive capacity. Socioeconomic scores negatively correlated with urbanization are normalized using the equation below:

$$S_i = \frac{10(S_{max} - S_x)}{S_{max} - S_{min}} \quad \textbf{(3)}$$

where S_x represents the indicator value. Scores positively correlated with urbanization are normalized using this equation:

$$S_j = 10 - \frac{10(S_{max} - S_{x)}}{S_{max} - S_{min}} \quad \textbf{(4)}$$

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Biophysical indicators are calculated similarly. An exception is governance, which is scored as a binary (existent or non-existent). S_{3max} , S_{4max} , S_{5max} , and S_{8max} (GDP, income, education, and internet) are 100 billion (USD), 100 thousand (USD), 95 (percent), and 95 (percent), respectively, all others are 100. A GDP of 100 billion would be in the top 5 GDPs by state in the US, a generous figure for a sub-national scale (Broda and Tate 2015) and an income of 100,000 USD is a common high income cutoff in the US, known as a "six-figure income." 95% secondary education completion and internet access are also exceptionally high achievements (The World Bank 2014, OECD 2011).

Future time slice index values were calculated using built-up land surface percentages predicted by the land use scenarios, which will be further elaborated in the following subsection. Indicator scores were linked to urban land ratio from 2000 and 2010, and the calculated trend was extrapolated using urban land ratio expected in future time slices for each scenario, assuming a linear relationship.

3.3 Land Use Scenarios and *What If*

3.3.1 Data

Geographic data for Tamsui was obtained for years 1995 and 2006 provided by request from the Ministry of the Interior and for West Palm Beach 2000 and 2009

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through the Florida Geographic Data Library. Land use change of both case study sites were analyzed in ArcGIS, and three land use change scenarios were generated based on physical and socioeconomic drivers. Slope, flood area, and soil data layers were combined in ArcGIS as predictive factors, then transferred to *What if?*, a planning support system software used to analyze and predict land use change.

3.3.2 Scenarios

The scenarios are as follows: 1) Business As Usual (BAU), 2) Economically Driven (A) and 3) Environmentally/Socially Driven (B). Scenarios will be pushed to year 2030 and 2050 to align with IPCC emission scenario timelines (2000).

Table 3: Scenario Assumptions/Factors

Scenario	Assumptions
BAU – Business As Usual	Medium level growth
A – Economically Driven	Increased urban build up, high population growth rate,
B - Environmentally and Socially Driven	Urban build up limitations, increased conservation of forest/agriculture, slower population growth

3.3.3 What If?

In order to simulate land use change, this study utilized a planning support system software called *What if?*. *What if?* uses GIS mapping software and integrates it with predictive modelling to generate land use scenarios based on accepted planning

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methods using demographic and economic trends and developmental constraints. Several studies have been done using *What If?*, for example, a case study on Dorood, Iran was conducted to show the process and benefits of *What if?* results to planners (Asgary et al 2007).

There are many different methods for predicting land use, such as Markov Chain models, Cellular Automata (CA), or artificial neural networks (ANN) (Lin et al 2011, Lin and Tseng 2010), but *What If?* is a "relatively simple, rule-based model" chosen for its simplicity and lower data requirements (Pettit 2005). Different land uses are associated with population and different employment sectors, and thus social and demographic changes are the basis for which land use changes. For example, if population grows, residential land use types also grow. If there are fewer industrial workers over time, the land devoted to industrial uses will be converted to other uses with higher demand. Using these trends, *What if?* can calculate how much different land use areas should grow or contract. The steps taken in the process are shown in the figure below.

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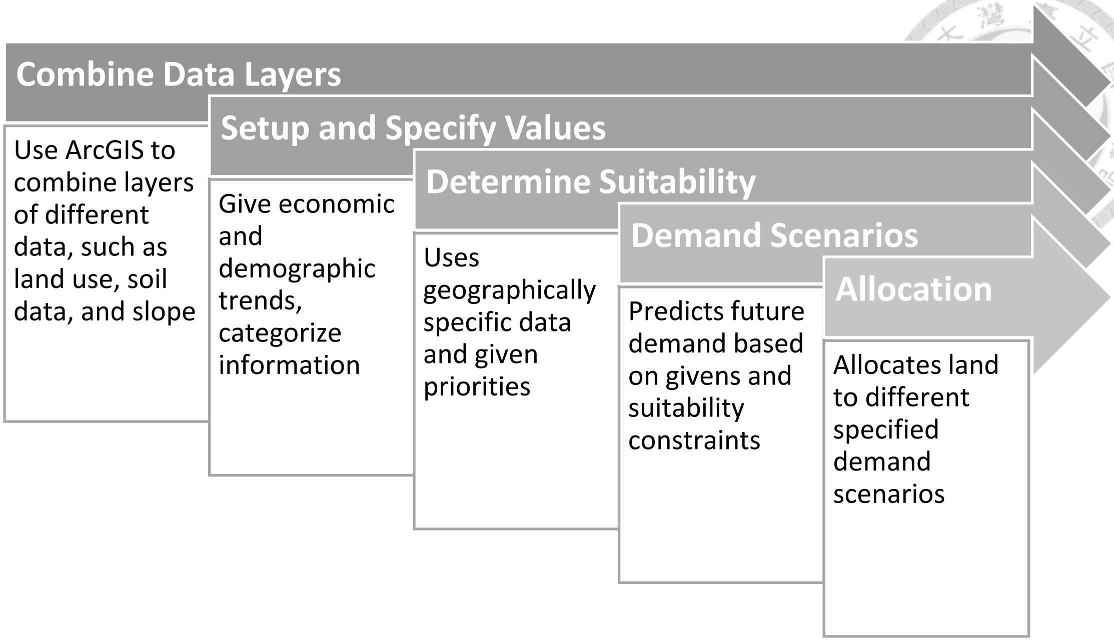

Figure 16: *What If?* Steps

In the program *What If?* various data inputs and assumptions must be set to calculate future land use. After a union file is created in ArcGIS combining different suitability layers, such as soil suitability, slope, and flood zones, it is imported into the *What If?* setup, shown in **Figure 17**. The setup program allows users to specify which data columns correspond to what factors, what units to use, employment categories, what kinds of outputs are desired and more. For this research, the land use option was chosen over the suitability, population, and employment prediction options.

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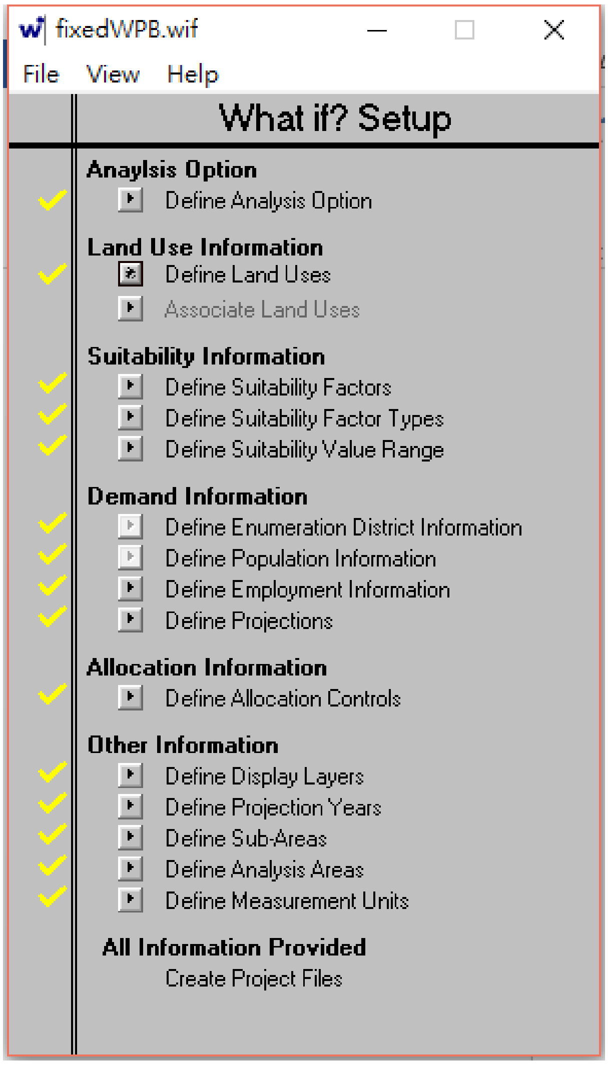

Figure 17: *What If?* setup

Once a project is finalized in the setup, it can be opened in *What If?*. More detailed values can be entered, such as current and project population, as well as current and projected employment information for high, medium, and low growth scenarios that were set. **Figure 18** and **19** show examples of the *Specify Values* windows. West Palm Beach population projections are based off of projections by Palm Beach County and the Bureau or Economic and Business Research, employment projects are based off of census data and reports from the Bureau of Economic Analysis. Tamsui population and

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employment projections are based off of New Taipei City reports. See Appendix A for projection calculations and assumptions.

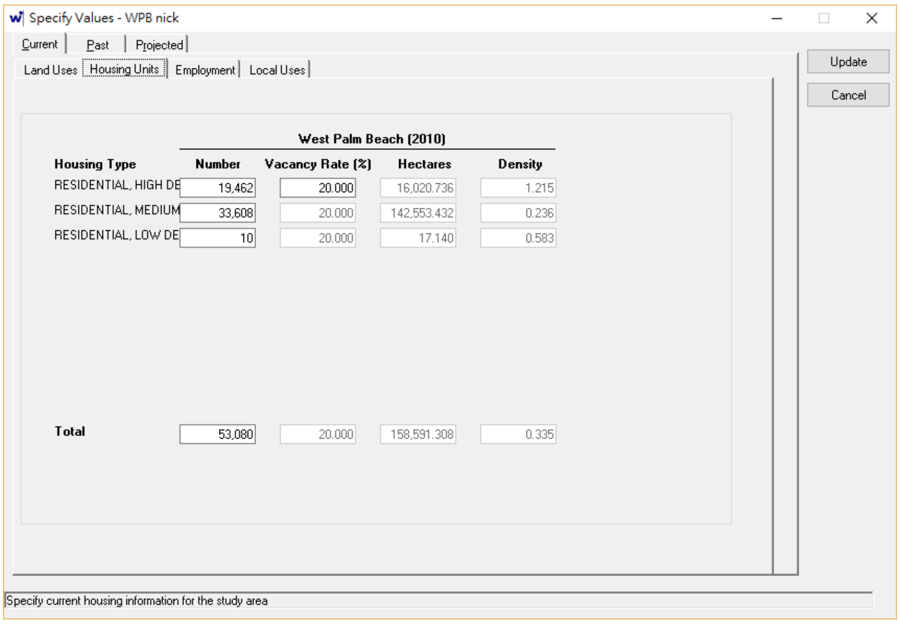

Figure 18: *What If?* Specify Values window

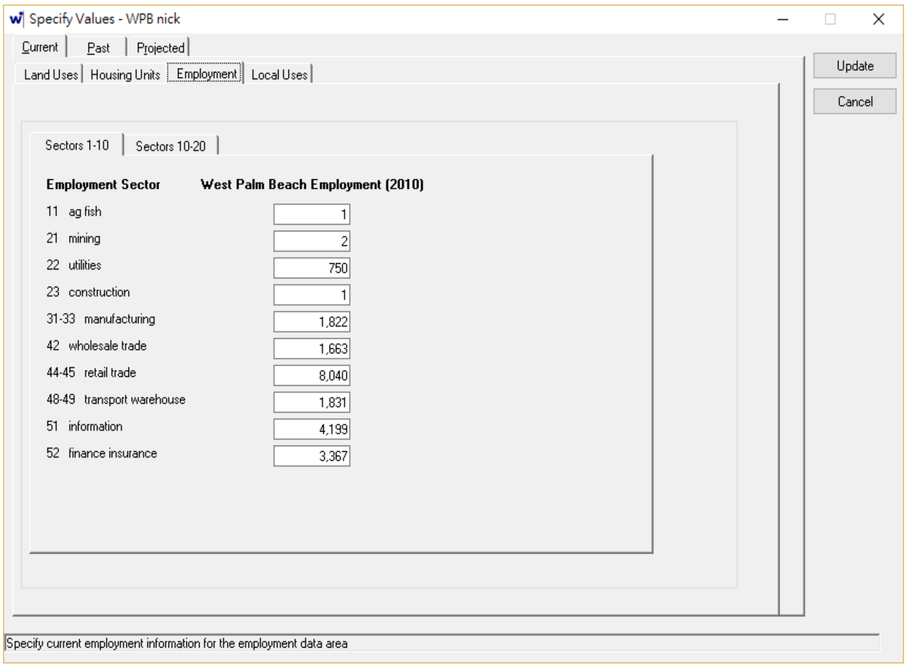

Figure 19: *What If?* Specify Values window (2)

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After these values are set, at least one suitability scenario must be created. Suitability options allow users to dictate which areas are more suitable for development, for example depending on soil types or existing zoning laws. Suitability is based on the suitability factor data embedded in the data layers embedded from GIS files. Suitability for each factor on each land use type is set using scroll bars, as shown in **Figure 20**.

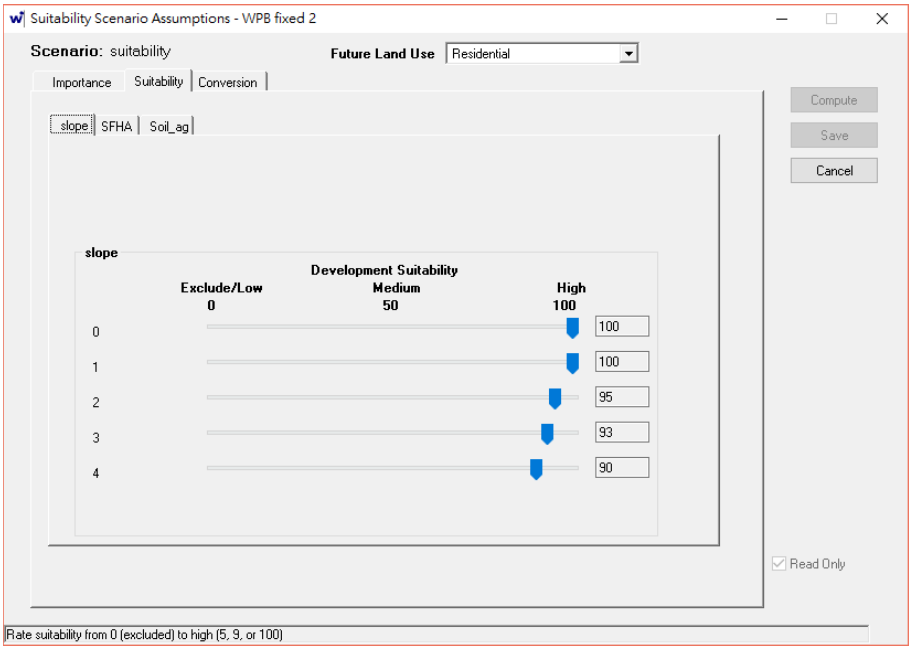

Figure 20: *What If?* Suitability Scenario Assumptions window

Demand scenarios are set after suitability is determined. The demand scenarios utilize the high, medium, and low growth scenario data set in the “specify values” step. Lastly, allocation links a suitability scenario with a specified demand scenario and creates an allocation map and report for the combined scenario.

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Chapter IV: Results and Discussion

The results discussed in this section show the effect of urbanization on adaptive capacity, shown via the UACI scores which are calculated using predicted land use changes. To reiterate, in this research adaptive capacity is considered equal to capacity of response, which is a component of vulnerability to global environmental change. This section will describe the results in the two subsections: *What if?* Allocation Maps and UACI Results. *What if?* Allocation Maps will cover the predicted land use of each scenario for 2030 and 2050 and discuss some of the changes over time. UACI Results will show the score calculations and their implications across the three different scenarios over time.

4.1 *What if?* Allocation Maps

Using the demographic and economic trends and suitability factors given, *What if?* computes different land use scenario results for both case study sites. Maps of the results are shown in **Figure 21** and **22**. Please see Appendix B for the *What if?* allocation output reports for more detailed categories and change totals.

Because each site varies in the land use categories used (i.e. West Palm Beach has several wetland land use categories that are absent in Tamsui) they were simplified

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in the legend for **Figures 21** and **22** for the sake of comparison. Patterns in urbanization can be seen across the three scenarios over time. In Tamsui, development in the southwestern section along the Tamsui River continues to intensify but the LULC change is most dramatic in the northern region of the district, where land was primarily agricultural or forest cover at the baseline time slice. The inland southeast portion of the district experienced the least vegetated-to-urban transition. An important note is that projected transportation projects in Tamsui, such as the light rail project and a proposed road widening, were not considered in these scenarios but are likely to influence development throughout the district.

In West Palm Beach, one primary assumption in the scenarios was that the Grassy Waters Preserve, located in the western portion of the city, was opened up for development. This would be highly unlikely considering the current conservation policy in Florida, but this allows the scenarios to show the influence of land use change and highlight the preserve's ecological value. And as with all environmental protection efforts, the possibility of favoring economic gain over preservation efforts remain. In fact, there is a planned extension of a state road immediately adjacent to the preserve, which may adversely affect the area and is currently a great source of controversy (Capozzi 2015). Thus, for the purposes of this research, the *What If?* projections illustrate the continued development of preserved lands following the non-preserved

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land lying to the east and the center of the city. **Figure 22** shows that development first occurs near the eastern borders of the preserve, then moving into the preserve itself with varying intensity across the different scenarios.

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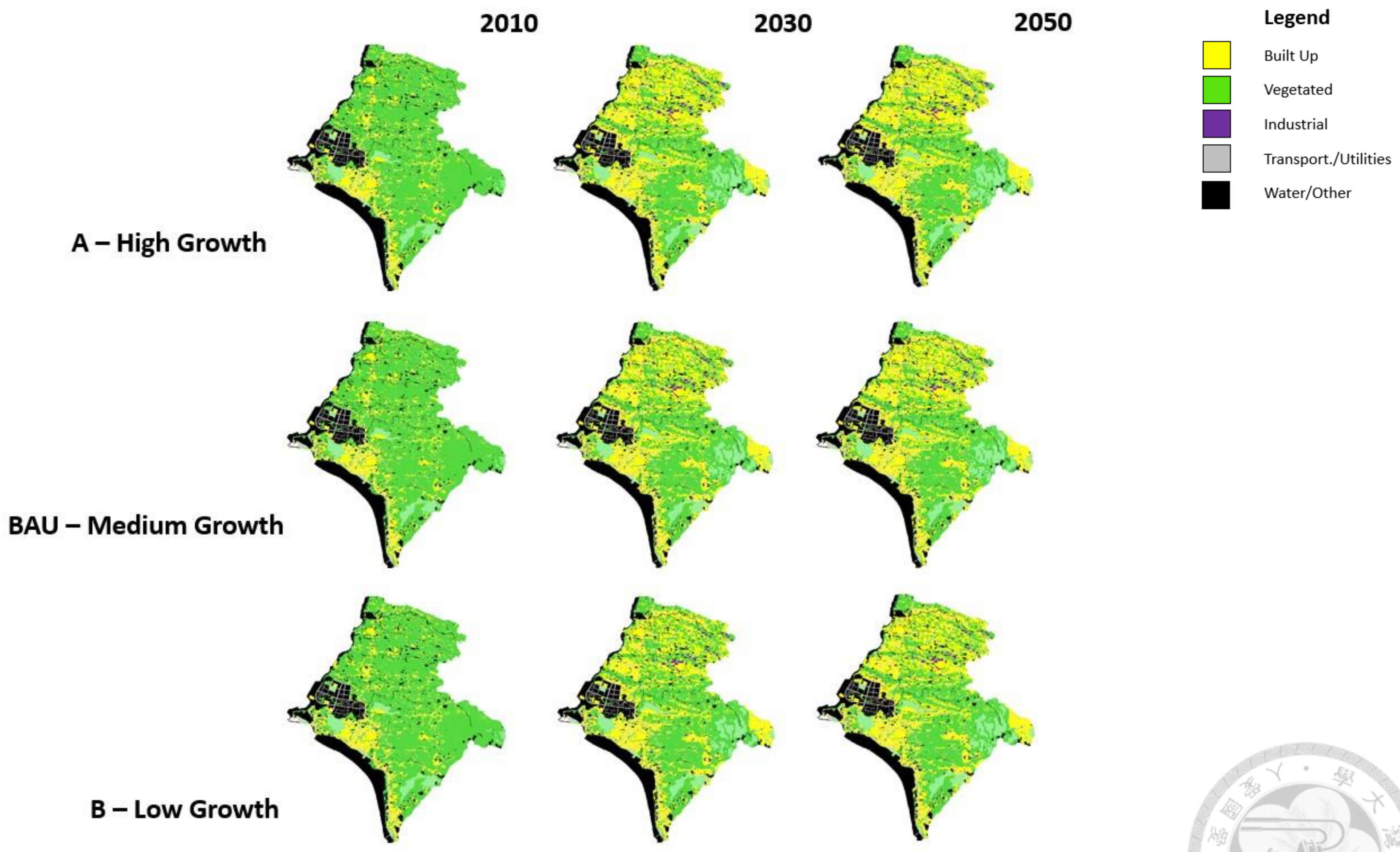

Figure 21: Tamsui land use maps for Scenarios A, BAU, and B

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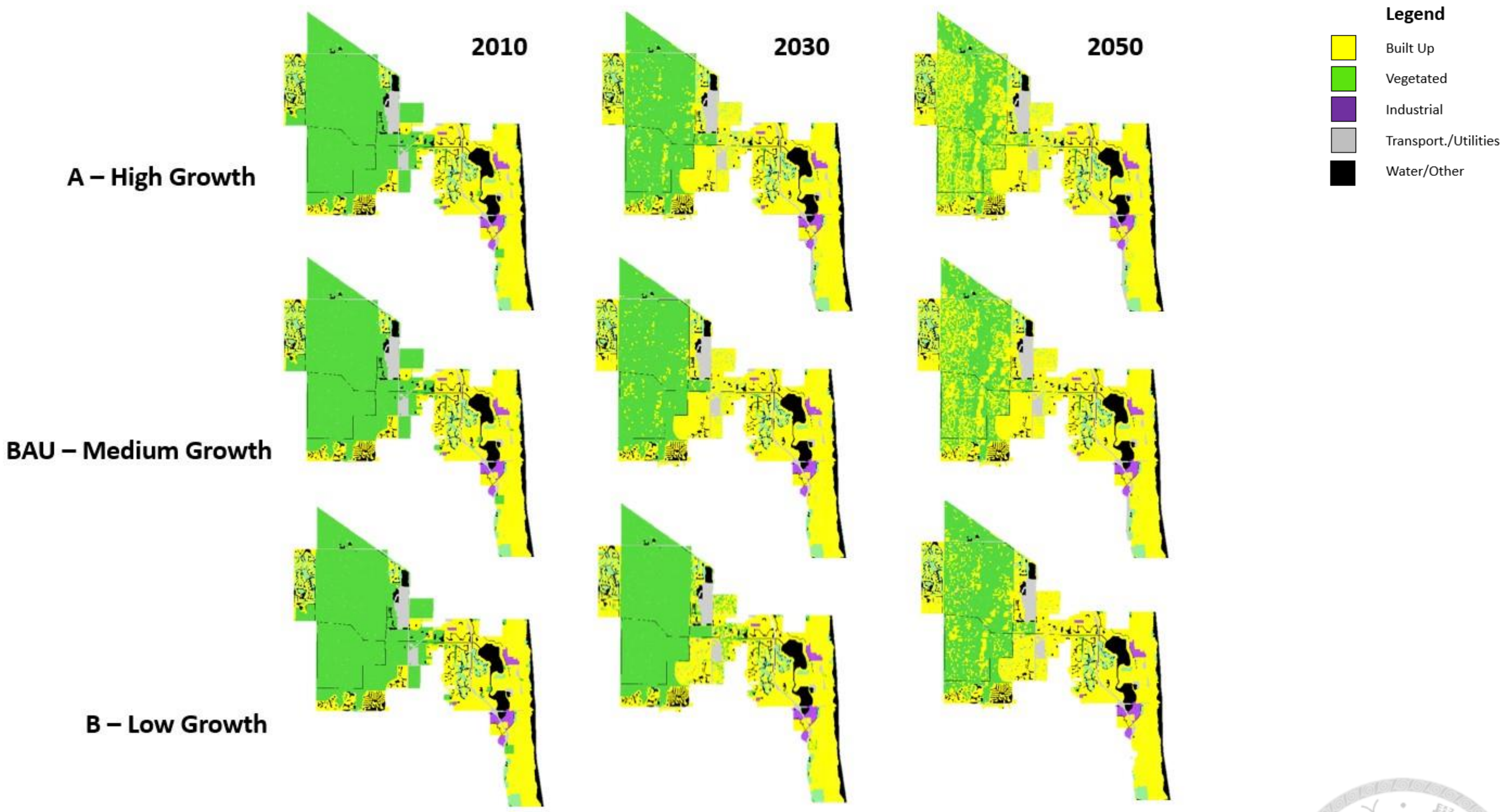

Figure 22: West Palm Beach land use maps for Scenarios A, BAU, and B

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4.2 UACI Scores

The urban and vegetated land area totals from the *What if?* results were used to calculate adaptability scores for each time slice in each scenario for both Tamsui and West Palm Beach. The baseline indicator scores, change over time, and data sources are shown in **Tables 4-7** and **Figure 23** and **24**; calculated scores for time slices 2030 and 2050 are shown in **Tables 8** and **9**; and results are summarized in **Figure 25**. Note that adaptability scores are theoretically out of 110, however the index design made a score of 110 is impossible, and a score lower than 30 is highly unlikely.

4.2.1 Tamsui UACI Results

4.2.1.1 Baseline

From 2000 to 2010, Tamsui showed a substantial increase in adaptive capacity scores going from 65.5 to 74.9, as shown in **Table 5** and **Figure 23**. The urban surface indicator decreased, while forest coverage and temperature variance showed a slight increase. Urban surface and forest coverage are both directly related to the LULC changes that occurred over the decade that reflect economic changes in the area.

In the socioeconomic indicators, 5 out of 8 showed an increase. GDP was the most significant difference, followed by internet access and education. Income,

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occupancy, and trust were the socioeconomic indicators that showed decreases through the decade.

These baseline trends were then extrapolated using the urban built up land percentage and forest land percentage calculated from the *What If?* output report numbers to find the predicted scores for 2030 and 2050.

Table 4: Tamsui baseline indicators, sources, values, and scores for 2010

Indicator	Value	Unit/Measure	Score	Source
impervious surface	18	percent area	8.2	Land Use Data
temperature	7.37	daily average difference in deg C	9.6	Weather Bureau
forest coverage	40	percent area	40	Land Use Data
vacancy	14.75	percent	8.5	Construction & Planning Agency
GDP	8.21E+11	USD	8.2	Index Mundi
income	23900	USD/year	2.4	99 NTC Family Revenue Report
education	63.1	percentage of population with high school level education and above	6.3	NTC Dept of Budget, Accounting and Statistics
trust	30	percentage of people who believe "most people can be trusted"	3	World Values Survey
inequality	0.2958	Gini index score	7	100 Family Income Report
government plans	1	existence of government emergency/disaster plans (binary)	10	District and City website
internet	77.43	percentage with internet access	7.7	100 Family Income Report
TOTAL			**74.9**	

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Table 5: Tamsui baseline score change from 2000 to 2010

	Indicator	2000	2010	% change
biophysical	urban surface	8.6	8.2	-4.7
	temp difference	9.1	9.6	5.5
	forest	3.7	4	8.1
subtotal		*21.4*	*21.8*	*1.8*
socioeconomic	occupancy	8.6	8.5	-1.2
	GDP	3.9	8.2	110.3
	income	2.5	2.4	-4.0
	education	3.9	6.3	61.5
	trust	3.7	3	-18.9
	inequality	6.9	7	1.4
	government plans	10	10	0.0
	internet access	4.6	7.7	67.4
subtotal		*44.1*	*53.1*	*20.4*
total		**65.5**	**74.9**	14.4

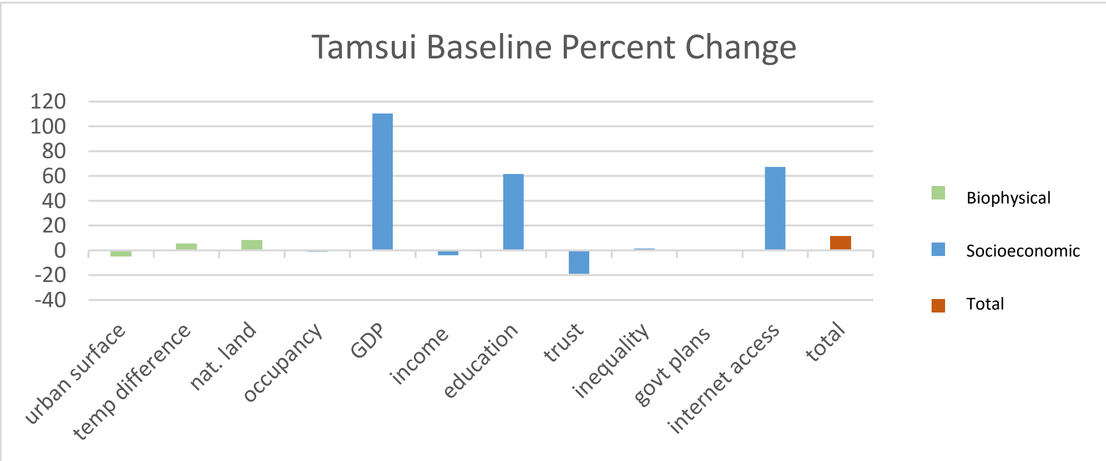

Figure 23: Tamsui baseline percent change

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4.2.1.2 Predicted

In Tamsui, the adaptive capacity score for Scenario A was 67.9 for 2030 and 65.4 for 2050. For Scenario BAU, 2030 had an adaptive capacity score of 69.8 and 2050 scored 68.1. In Scenario B, 70.3 was the score for 2030, and fell to 69 for 2050. The most striking implication is that no matter which scenario, adaptive capacity is predicted to decrease from the baseline year score. All scores in 2050 are lower than their 2030 counterparts, which are all lower than the baseline score of 74.1. Scenario B has the highest score in 2030, followed closely by BAU and then Scenario A with the lowest score of 67.9. In 2050, B is the scenario with the highest score by a larger margin, at 69, compared to 68.1 for BAU at 2050.

The UACI scores for Tamsui reflect several serious issues facing Taiwanese society which affects its communities' ability to adapt to climate change. The biophysical indicators show that Tamsui does particularly poorly with temperature changes. Due to the large temperature changes that occurred between 2000 and 2010, further urbanization pushed scores low across all scenarios.

Stagnating wages and a sharp decrease in trust were two big social factors expressed in the indicators leading to the future decline of AC. As incomes did not rise sharply along with urbanization in the baseline time period, further urbanization would not drive scores upward. And with increasing urbanization

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resulting in higher populations and tourism, trust decreased significantly in future time slices, reflecting a breakdown in community ties. GDP, education, and internet access all reach their maximum scores by 2030 regardless of scenario, thus providing little difference between the scenarios and the time slices. With so many of the social benefits of urbanization having maxed out, the negative aspects of urbanization start to show in the end scores.

4.2.2. West Palm Beach UACI Results

4.2.2.1 Baseline

From 2000 to 2010, West Palm Beach's UACI score went from 67.9 to 72.4 as shown in **Table 7** and **Figure 23**. This baseline trend increase was not quite as high as the Tamsui baseline trend, but still reflected the many benefits of urbanization. The biophysical indicators all showed decreases, but they were not as sharp as the decreases in Tamsui.

There were three socioeconomic indicators which showed a decrease between 2000 and 2010, and they were vacancy, trust and inequality. As with Tamsui, trust decreased with inflow of new residents. But GDP, income, and internet access all showed strong growth with the intensifying urbanization.

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Table 6: West Palm Beach baseline indicators, sources, values, and scores for 2010

Indicator	Value	Unit/Measure	Score	Source
impervious surface	43	percent area	5.7	Land Use Data
temperature	8.5	daily average difference in deg C	9.8	FL St. Uni. Climate Center
wetland coverage	39	percent area	3.9	Land Use Data
vacancy	20.8	percent	7.9	US Census
GDP	7.30E+11	USD	7.3	Fed Reserve Bank St. Louis
income	44905	USD/year	4.5	US Census
education	82.9	percentage of population with high school level education and above	8.3	US Census
trust	35	percentage of people who believe "most people can be trusted"	3.5	World Values Survey
inequality	0.503	Gini index score	5	US Census
government plans	1	existence of government emergency/disaster plans (binary)	10	City website
internet	64.8	percentage with internet access	6.5	US Census
TOTAL			**72.4**	

Table 7: West Palm Beach baseline score change from 2000 to 2010

	Indicator	2000	2010	% change
biophysical	urban	6.2	5.7	-8.1
	temp difference	10	9.8	-2.0
	wetland	4	3.9	-2.5
subtotal		*20.2*	*19.4*	*-4*
socioeconomic	occupancy	8.6	7.9	-8.1
	GDP	4.6	7.3	58.7
	income	3.7	4.5	21.6
	education	7.6	8.3	9.2
	trust	3.6	3.5	-2.8
	inequality	5.4	5	-7.4
	government plans	10	10	0.0
	internet access	4.2	6.5	54.8
subtotal		*47.7*	*53*	*11*
Total		**67.9**	**72.4**	6.6

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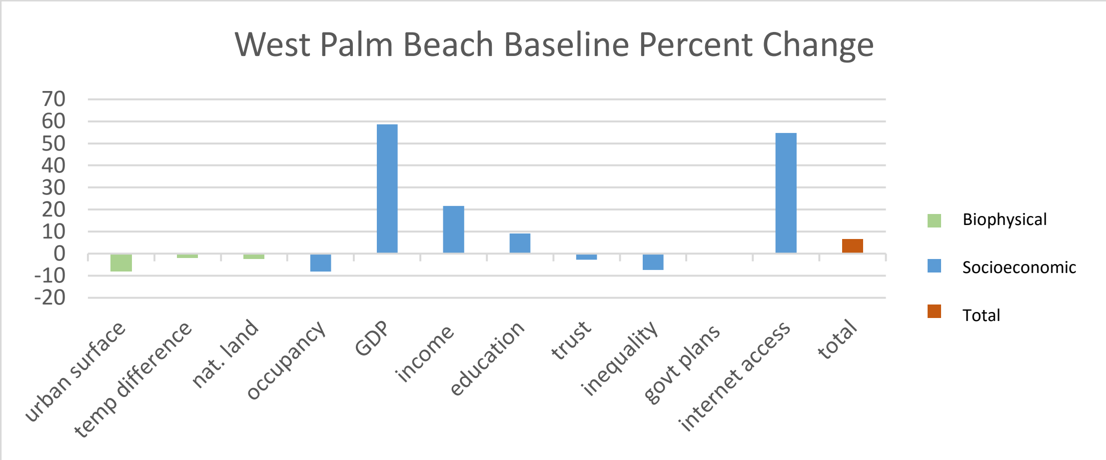

Figure 24: West Palm Beach baseline percent change

4.2.2.2 Predicted

In West Palm Beach, the scores show different trends than in Tamsui. Scenario A scores go from 78.4 to 77.2 in 2030 and 2050, respectively. Scenario BAU scored 76.2 in 2030 and 77.7 in 2050. Scenario B scored 72.1 in 2030 and 78.7 in 2050.

As land is developed, the biophysical adaptive capacity declines steadily. The biophysical indicators in the time slice 2030 were all fairly similar, though Scenario B had the higher scores. But by the year 2050, each of the scenarios had diverged much more in terms of biophysical scores, with Scenario B holding the highest score by a larger margin.

In the year 2030, the results show that Scenario A had the highest adaptive capacity score, at 78.4. This is mostly due to the greater economic benefits that come

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with high growth, such has high GDP and income. But, in the final predicted time slice, 2050, Scenario A's score decreases from its 2030 peak down to 77.2. Scenario BAU also declines in 2050.

Despite its lower score in 2030 relative to the other scenarios, Scenario B has the highest adaptive capacity score in the end. Through 2010, 2030, and 2050, the scores for B are continuously increasing, unlike the other scenarios. The UACI scores for Scenarios A and BAU increase more quickly, peak at 2030, and start to decrease in 2050. This is due to the relatively smaller benefit of economic good of urbanizing after 2030 due to several indicators reaching maximum, while suffering increasing damages from falling environmental and social indicator scores, such as surface water runoff and inequality. Internet access is one measure of infrastructure that is more or less ubiquitous in urban areas, and by the time of the first predicted time slice all of West Palm Beach would be firmly urban "enough" to achieve high internet access in all scenarios.

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Table 8: Tamsui UACI scores for all scenarios

Scenario A - high growth		Indicator	Value	Score
2030	biophysical	urban	39.7	6
		temp difference	12.01	3.2
		forest	22.5	2.3
	subtotal			*11.5*
	socioeconomic	occupancy	83.9	8.4
		GDP	3.23E+12	10
		income	20090	2
		education	95	10
		trust	-8.7	0
		gini	0.2	8
		government plans	1	10
		internet access	95	10
	subtotal			*58.4*
total				**69.9**
2050	biophysical	urban	41.7	5.8
		temp difference	12.43	2.6
		forest	21.1	2.1
	subtotal			*10.5*
	socioeconomic	occupancy	83.8	8.4
		GDP	3.45E+12	10
		income	19747	2
		education	95	10
		trust	-12.68	0
		gini	0.39	6.1
		government plans	1	10
		internet access	95	10
	subtotal			*56.5*
total				**67.0**

Scenario BAU - med growth		Indicator	Value	Score
2030	biophysical	urban	36.4	6.4
		temp difference	11.29	4.1
		forest	24	2.4
	subtotal			*12.9*
	socioeconomic	occupancy	84.2	8.4
		GDP	2.85606E+12	10
		income	20683	2.1
		education	95	10
		trust	-3	0
		gini	0.22	7.8
		government plans	1	10
		internet access	95	10
	subtotal			*58.3*
total				**71.2**
2050	biophysical	urban	39.9	6
		temp difference	12.04	3.1
		forest	22.5	2.3
	subtotal			*11.4*
	socioeconomic	occupancy	83.9	8.4
		GDP	3.2465E+12	10
		income	20067	2
		education	95	9.9
		trust	-9	0
		gini	0.2	8
		government plans	1	10
		internet access	95	10
	subtotal			*58.3*
total				**69.7**

Scenario B - low growth		Indicator	Value	Score
2030	biophysical	urban	35.9	6.5
		temp difference	11.19	4.3
		forest	25.6	2.6
	subtotal			*13.4*
	socioeconomic	occupancy	84.23	8.4
		GDP	1.80618E+12	10
		income	20762	2.1
		education	95	10
		trust	-2	0
		gini	0.22	7.8
		government plans	1	10
		internet access	95	10
	subtotal			*58.3*
total				**71.7**
2050	biophysical	urban	38.5	6.2
		temp difference	11.74	3.5
		forest	23.7	2.4
	subtotal			*12.1*
	socioeconomic	occupancy	84.04	8.4
		GDP	3.08894E+12	10
		income	201316	2
		education	95	10
		trust	-7	0
		gini	0.21	7.9
		government plans	1	10
		internet access	95	10
	subtotal			*58.3*
total				**70.4**

doi:10.6342/NTU201600887

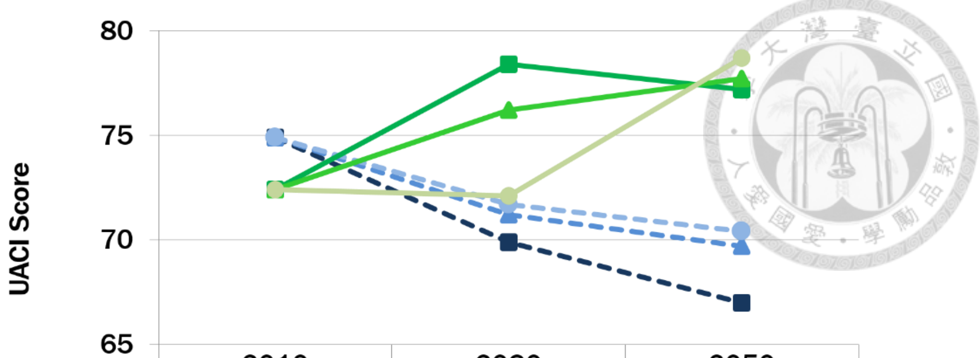
Table 9: West Palm Beach UACI Scores for all

Scenario A		Indicator	Value	Score
2030	biophysical	urban	49.7	5
		temp difference	8.39	9.6
		wetland	31.9	3.2
	subtotal			*17.8*
	socioeconomic	occupancy	70.5	7.1
		GDP	1.08E+12	10
		income	55436	5.5
		education	92	9.2
		trust	33.7	3.4
		gini	0.46	5.4
		government	1	10
		internet access	95	10
	subtotal			*60.6*
total				78.4
2050	biophysical	urban	60.7	3.9
		temp difference	8.14	9.2
		wetland	18.9	1.9
	subtotal			*15*
	socioeconomic	occupancy	56.1	5.6
		GDP	1.66E+12	10
		income	72987	7.3
		education	95	10
		trust	31.6	3.2
		gini	0.39	6.1
		government	1	10
		internet access	95	10
	subtotal			*62.2*
total				77.2

Scenario BAU - med		Indicator	Value	Score
2030	biophysical	urban	47.3	5.3
		temp difference	8.45	9.6
		wetland	32.9	3.3
	subtotal			*18.2*
	socioeconomic	occupancy	73.7	7.4
		GDP	9.55025E+11	9.5
		income	51646	5.2
		education	89	8.9
		trust	34.2	3.4
		gini	0.48	5.2
		government	1	10
		internet access	84	8.4
	subtotal			*58*
total				76.2
2050	biophysical	urban	58.1	4.2
		temp difference	8.2	9.3
		wetland	22.3	2.2
	subtotal			*15.7*
	socioeconomic	occupancy	59.5	6
		GDP	1.52574E+12	10
		income	68811	6.9
		education	95	10
		trust	32.1	3.2
		gini	0.41	5.9
		government	1	10
		internet access	95	10
	subtotal			*62*
total				77.7

Scenario B - low growth		Indicator	Value	Score
2030	biophysical	urban	43.4	5.7
		temp	8.54	9.7
		wetland	35.4	3.5
	subtotal			*18.9*
	socioeconomic	occupancy	78.8	7.8
		GDP	7.45597E+11	7.5
		income	45347	4.5
		education	83	8.3
		trust	35	3.5
		gini	0.5	5
		government	1	10
		internet access	66	6.6
	subtotal			*53.2*
total				72.1
2050	biophysical	urban	51.9	4.8
		temp	8.34	9.5
		wetland	28.5	2.9
	subtotal			*17.2*
	socioeconomic	occupancy	67.7	6.8
		GDP	1.19686E+12	10
		income	58919	5.9
		education	95	10
		trust	33.3	3.3
		gini	0.45	5.5
		government	1	10
		internet access	95	10
	subtotal			*61.5*
total				78.7

doi:10.6342/NTU201600887



	2010	2030	2050
Tamsui A	74.9	69.9	67
Tamsui BAU	74.9	71.2	69.7
Tamsui B	74.9	71.7	70.4
West Palm Beach A	72.4	78.4	77.2
West Palm Beach BAU	72.4	76.2	77.7
West Palm Beach B	72.4	72.1	78.7

Figure 25: Index scores of each scenario at each case study site over time

4.3 Discussion

The results show that Tamsui starts off with a slightly higher adaptive capacity, but West Palm Beach ends up with higher scores regardless of scenario or time slice. However, there are several uncertainties to consider with an index measuring such a wide range of items, and human systems are complex, non-linear, and difficult to measure and predict. For example, social capital and networks are particularly difficult to measure. The source used here, World Values Survey has measured trust at 30% in Taiwan, yet another domestic source measured at 54% using the same question (Chang 2009). This huge margin of difference is troubling when it could make 2.4 points difference in the assessment, and thus ±5% overall for the total score from 2010 for this

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indicator alone. Temperature differences are difficult to measure and thus extrapolate as well. In considering climate is a long term concept, a baseline of 10 years may be too short to extrapolate on, and weather conditions have many factors which may or may not cover urbanization effects. One other large uncertainty is the indicator of government plans. The quality and efficacy of government institutions and disaster planning deserves a research project of its own including both quantitative and qualitative investigation but here is simplified to a binary of existent or nonexistent. The focus of this research was not to evaluate government efficacy; however, since up to ±10% uncertainty in this indicator can vastly affect the adaptive capacity of a place, a more rigorous model of government plans remains a gap in this study and further work should be done to better describe variances in this indicator.

GDP and internet access were the most sensitive indicators in the UACI as the indicators that changed most dramatically during the baseline period. These two indicators grew quickly within the range of the 10 point scores, and were also responsible for the fall in UACI scores after time, as they quickly maxed out as land became more urbanized, meaning their benefits peaked earlier in the timeframe in these two particular sites.

Another weakness of this study is the question of extrapolation. With several indicators urbanization is correlated with a positive or negative trend, but as it is often

doi:10.6342/NTU201600887

stated, correlation does not equal causation. Many of the factors may not have a linear relationship with urbanization, or the relationship curve may change as time goes on.

Despite these flaws the results do reflect, on a larger level, several trends associated with urbanization and land use change. Taiwan has seen very clear climatic changes linked to global climate change which are more severe than in many other larger or inland countries. The changes in LULC have direct impacts on the adaptive capacity of Tamsui, particularly in terms of surface water stability. These are shown clearly in the biophysical indicator results of the UACI. The government and public are both growing in awareness of the precarious nature of the island's ecosystems to further disturbance, and hopefully will enact more protections.

In terms of the socioeconomic aspects, Tamsui –in fact all of Taiwanese society –is indeed affected by wage stagnation despite the fact that urban areas of Taiwan do have higher incomes than rural areas. It is still true that there remains an urban-rural disparity in wages, however, further development in cities or suburban areas may not necessarily lead to proportional increases in income in Taiwan. Unless there is major policy change in the near future, urbanizing will not necessarily bring the expected benefits to individuals and households, which will limit adaptive capacity.

West Palm Beach, on the other hand, is a more development-driven community and its public is much less likely to believe that climate change is occurring, potentially

doi:10.6342/NTU201600887

weakening political will to address climate-related issues. But the indicators showed that it is less affected by temperature changes than Tamsui, which may partially account for the complacency. Its weaknesses in adaptive capacity lie in high inequality and a larger impervious surface ratio which are likely to be exacerbated by further urbanization, but West Palm Beach also stands to benefit from more urbanization with internet, GDP, and income indicators. These socioeconomic indicators are ones that increase more steeply with urban change. But to rely too heavily on technological or economic growth for AC would be unwise in the long term, and could be considered a kind of maladaption.

Another question of maladaption would be the increased developmental density near the water. Both sites are coastal, and development is concentrated near the ocean and will only intensify across all scenarios. This higher population density may alleviate the expansion of urban sprawl but simultaneously increases risk of health and economic loss in the event of a hurricane or typhoon or other flooding events. This tension is a difficult challenge for planners and policy makers and these different risks will need attention.

doi:10.6342/NTU201600887

Chapter V: Conclusion and Recommendations

Adaptive capacity is an understudied yet is conceptually and practically important for the future as the consequences of climate change progress. Using Gallopin's review (2006), this study created an adaptive capacity index to assess a local area's socioeconomic and biophysical ability to adapt, where adaptive capacity is the capacity of response and thus a subset of vulnerability in the context of global environmental change. This set of indicators was compiled into the Urbanization Adaptive Capacity Index, or UACI. Its contribution to the literature is the consideration of urbanization (primarily the transformation of vegetated land cover to build up urban land cover), as urbanization is intricately tied to climate change. The goal with the UACI is to help small locales assess their adaptive capacity and identify strengths and weaknesses. This research had the additional goals of illustrating the effect of land use change on social and environmental factors, as well as making an international comparison between two case study sites.

Using predicted land use change, we predicted changes in adaptive capacity under three different scenarios through 2 time slices, 2030 and 2050. To do this, we chose indicators correlated with LULC change and applied it to years 2000 and 2010 to find a baseline trend, each as a function of LULC change. Land use scenarios were developed based on IPCC literature.

doi:10.6342/NTU201600887

Under all scenarios, both Tamsui and West Palm Beach lost vegetated natural land cover to development. But in Tamsui, all the UACI scores declined after the baseline year, whereas in West Palm Beach, Scenario B had an increasing score through 2030 and 2050. The results tell a general, familiar narrative-- that there are increased social and economic benefits as a place urbanizes, such as higher levels of education or income, but at some point the benefits peak and urban cons begin to overtake its benefits, particularly the environmental costs. According to our results, Tamsui has already reached that point, although this does not necessarily suggest that Tamsui is more vulnerable to climate impacts, as adaptive capacity is only a part of the equation. West Palm Beach and the rest of southern Florida are susceptible to saltwater inundation, which is a sensitivity and exposure issue, and is not linked to urbanization and thus not represented in this study. Nonetheless, it seems its adaptive capacity will decrease into the future.

For the two sites considered in this study, urbanization is shown to bring socioeconomic benefits at the cost of environmental quality. Sustainable development is a concept which aims to separate these trends and provide a way to decouple growth from environmental degradation. It is imperative that Tamsui follow a more conscientious path than a BAU approach, as even a slower growth scenario will not be sufficient to maintain a high level of adaptive capacity. Drastic measures are necessary

doi:10.6342/NTU201600887

to adapt to the impacts resulting from climate change. Policy changes will have to be holistic and consider wellbeing in the long term in a number of different sectors, such as health, economy, transportation, energy and more.

Considering these results, we recommend that Tamsui maintain natural land cover by limiting urban sprawl and development in the mountainous areas to maintain the benefit-over-detriment balance as seen in the baseline score. While preserving the ecosystems of higher altitudes is a high priority in all of Taiwan, this model shows that total natural land cover is of great importance to adaptive capacity in the area, and thus Tamsui should be especially cautious considering its large resident and tourist population. At the same time, maintaining higher population densities can help prevent further land use change. As far as other socioeconomic strategies, fosters stronger social networks and build trust among those in the community can be beneficial for increasing adaptive capacity.

Nationwide initiatives will also be important. As Taiwan has a more centralized government and active climate change policies, national level strategies will also be necessary, especially in terms of bringing up median incomes through labor legislation or keeping inequality low through social programs and regulation.

West Palm Beach falls earlier on this urbanization curve, giving the community more leeway to keep adaptive capacity higher. But as many residents in Florida, and

doi:10.6342/NTU201600887

more broadly across the country, do not find climate change to be a salient issue, framing adaptive capacity issues in a viable way is key. Often encouraging risk reduction and disaster preparedness more generally can be more effective than emphasizing climate change.

The maintenance of Grassy Waters Preserve in West Palm Beach has positive effects on adaptive capacity, as well as in a number of other aspects, especially since the city draws its water from the wetland. West Palm Beach is unlikely to completely open up the preserve to development, as done in our scenarios, but should take care to prevent any ecological degradation like urban encroachment, which can lead to water and air pollution. The existence of the preserve was a key factor in the outcome of the index scores.

West Palm Beach should also focus on mitigating social strain of urbanization, as the region is expecting increased demographic change, especially with regards to immigration. Some demographic groups can be at higher risk and limited access to resources, which will adversely affect indicators such as inequality, internet access, and median household income. Integrating and supporting these populations justly will be key to lowering inequality and increasing social capital.

This research presents the UACI as an introductory model that can be easily elaborated in several aspects, as future data will inevitably be available in finer scales

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as well as more frequent, detailed collection. Ideally, this index would include biodiversity and other land-related indicators as data availability and access improves. Additionally, studies on different geographic locations can reveal different findings and are key to providing a richer picture of climate adaptive capacity.

The major benefits of the UACI is that it is an easy-to-use and -understand index, ideal for small scale, quickly-urbanizing communities to see different potential trends in their adaptive capacity. This index is especially suited to assess districts in a city for comparison or other similar situations. Its importance lies in its ability to provide policy makers and planners with concrete information on which to make decisions to improve adaptive capacity.

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Appendices

Appendix A: *What If?* Projection Calculations and Assumptions

What If? needs inputs for current and future population and employment for all prediction years. Not all of this information is readily available, and thus other figures were used to calculate the required inputs based on assumptions. Bolded numbers are given, via reports or other government documents, and the regular numbers are final inputs into *What If?*.

A.1 Population Projections

A.1.1 Tamsui

Only high and low growth projections are made for 2030 and 2050 for a combined district including Tamsui (one of 5 northern districts). Tamsui's population is 46.5% of the combined district population, and it was assumed that this proportion would remain the same in the future. Thus, the high and lows were multiplied by .465 to get high and low (A and B) projections, and the BAU projection used the midpoint between the two calculated scores.

Table A1: Tamsui population project calculations

	2030 (combined)	2050 (combined)	2030	2050
High	**511,000**	**571,000**	23.8	26.6
Med	**X**	**X**	23.0	25.1
Low	**477,000**	**519,000**	22.2	24.1

Source: 新北市發展預測報告/The New Taipei City Development Projection Report

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A.1.2 West Palm Beach

For scenario BAU, take population difference from 2020-2030 (12,683 people) in West Palm Beach and add to get projection for 2050.

Table A2: West Palm Beach population projection calculation for Scenario BAU

Year	2020	2030	2050
Population	**114,718**	**127,401**	152,767

Source: WPB Jurisdiction Population Projections

For Scenarios A and B, High, Medium, and Low projections are given for year 2030 for the whole county. It is assumed that WPB would grow at the same rate as the county as a whole. BAU for 2030, calculated in the step shown above, is then multiplied by .89 to get a low projection, and by 1.09 to get a high projection using the percent differences from the three county projections to get 2030 projections. The 10 year difference from BAU is doubled, then multiplied by the .89 and 1.09 again to get projections for 2050.

Table A3: West Palm Beach population projection calculations for Scenarios A and B

2030 (county)		2030	2050
Low – 1,441,500		113,387	135,961
Med – 1,624,000	11% growth		
High – 1,785,000	9% growth	138,867	166,514

Source: BEBR County Projections

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A.2 Employment Projections

A.2.1 Tamsui:

doi:10.6342/NTU201600887

Table A4: Tamsui employment projection calculations (gray = final input numbers, in thousands) *Tamsui's population is 3.54% of NTC

type	NTC 2007	NTC 2010	NTC 2014	2014-2007	X2*.0354	BAU	2010 TAM	2030 TAM	2050 TAM	B (10% less)	2030	2050	A(20% more)	2030	2050
A	**8**	**8**	**11**	3	0.2124		**0.28**	**0.50**	**0.71**		**0.45**	**0.64**		**0.55**	**0.78**
B	**0**	**0**	**0**	0	0		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**		**0.00**	**0.00**
C	**492**	**479**	**498**	6	0.4248		**16.96**	**17.38**	**17.81**		**15.64**	**16.03**		**19.12**	**19.59**
D	**5**	**5**	**5**	0	0		**0.18**	**0.18**	**0.18**		**0.16**	**0.16**		**0.19**	**0.19**
E	**14**	**15**	**15**	1	0.0708		**0.53**	**0.60**	**0.67**		**0.54**	**0.61**		**0.66**	**0.74**
F	**150**	**153**	**165**	15	1.062		**5.42**	**6.48**	**7.54**		**5.83**	**6.79**		**7.13**	**8.29**
G	**334**	**334**	**354**	20	1.416		**11.82**	**13.24**	**14.66**		**11.92**	**13.19**		**14.56**	**16.12**
H	**88**	**87**	**95**	7	0.4956		**3.08**	**3.58**	**4.07**		**3.22**	**3.66**		**3.93**	**4.48**
I	**116**	**125**	**137**	21	1.4868		**4.43**	**5.91**	**7.40**		**5.32**	**6.66**		**6.50**	**8.14**
J	**54**	**56**	**71**	17	1.2036		**1.98**	**3.19**	**4.39**		**2.87**	**3.95**		**3.50**	**4.83**
K	**89**	**95**	**89**	0	0		**3.36**	**3.36**	**3.36**		**3.03**	**3.03**		**3.70**	**3.70**
L	**17**	**15**	**23**	6	0.4248		**0.53**	**0.96**	**1.38**		**0.86**	**1.24**		**1.05**	**1.52**
M	**57**	**68**	**82**	25	1.77		**2.41**	**4.18**	**5.95**		**3.76**	**5.35**		**4.59**	**6.54**
N	**43**	**58**	**68**	25	1.77		**2.05**	**3.82**	**5.59**		**3.44**	**5.03**		**4.21**	**6.15**
O	**51**	**57**	**57**	6	0.4248		**2.02**	**2.44**	**2.87**		**2.20**	**2.58**		**2.69**	**3.15**
P	**83**	**84**	**93**	10	0.708		**2.97**	**3.68**	**4.39**		**3.31**	**3.95**		**4.05**	**4.83**
Q	**45**	**53**	**58**	13	0.9204		**1.88**	**2.80**	**3.72**		**2.52**	**3.35**		**3.08**	**4.09**
R	**15**	**16**	**15**	0	0		**0.57**	**0.57**	**0.57**		**0.51**	**0.51**		**0.62**	**0.62**
S	**92**	**89**	**91**	-1	-0.0708		**3.15**	**3.08**	**3.01**		**2.77**	**2.71**		**3.39**	**3.31**

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A.2.2 West Palm Beach

The number of employees in each industry are available for years 2002, 2007, and 2012. These numbers, along with the trends shown in the Bureau of Labor Statistics for West Palm Beach are used to estimate the projected number of laborers in each sector. Figures for 2012 are taken for the baseline (2010).

Table A5: West Palm Beach employment projections (1/6)

Projection: High Growth

Sectors 1-10 | Sectors 11-20

Employment Sector	2010	2030	2050
11 ag fish	1	2	2
21 mining	2	1	1
22 utilities	750	850	900
23 construction	1	1	1
31-33 manufacturing	1,822	1,700	1,600
42 wholesale trade	1,663	2,000	2,200
44-45 retail trade	8,040	11,000	13,000
48-49 transport warehouse	1,831	2,200	1,400
51 information	4,199	5,000	6,500
52 finance insurance	3,367	4,500	6,000

doi:10.6342/NTU201600887

Table A5: West Palm Beach employment projections (2/6)

Projection: High Growth

Sectors 1-10 | Sectors 11-20

Employment Sector		**2010**	**2030**	**2050**
53	real estate	1,144	2,200	3,400
54	professional	7,455	9,000	10,000
55	management	1	1	1
56	admin	10,840	12,000	15,000
61	educational services	203	600	900
62	health care	12,742	16,000	18,000
71	arts entertain	1,695	2,500	3,500
72	accommodation food	6,424	9,000	11,000
81	other	768	1,300	2,000

Table A5: West Palm Beach employment projections (3/6)

Projection: Med Growth

Sectors 1-10 | Sectors 11-20

Employment Sector		**2010**	**2030**	**2050**
11	ag fish	1	2	2
21	mining	2	1	1
22	utilities	750	800	850
23	construction	1	1	1
31-33	manufacturing	1,822	1,700	1,600
42	wholesale trade	1,663	1,700	1,800
44-45	retail trade	8,040	10,000	12,000
48-49	transport warehouse	1,831	2,500	2,800
51	information	4,199	5,000	6,000
52	finance insurance	3,367	5,000	5,500

doi:10.6342/NTU201600887

Table A5: West Palm Beach employment projections (4/6)

Projection: Med Growth

Sectors 1-10 | Sectors 11-20

Employment Sector	2010	2030	2050
53 real estate	1,144	2,200	3,000
54 professional	7,455	8,500	9,200
55 management	1	1	1
56 admin	10,840	12,000	15,000
61 educational services	203	500	700
62 health care	12,742	15,000	17,000
71 arts entertain	1,695	2,500	3,500
72 accommodation food	6,424	7,500	8,200
81 other	768	1,000	1,500

Table A5: West Palm Beach employment projections (5/6)

Projection: Low Growth

Sectors 1-10 | Sectors 11-20

Employment Sector	2010	2030	2050
11 ag fish	1	2	2
21 mining	2	1	1
22 utilities	750	775	800
23 construction	1	1	1
31-33 manufacturing	1,822	1,700	1,600
42 wholesale trade	1,663	1,600	1,600
44-45 retail trade	8,040	9,000	10,000
48-49 transport warehouse	1,831	2,000	2,100
51 information	4,199	5,000	6,000
52 finance insurance	3,367	4,000	5,000

doi:10.6342/NTU201600887

Table A5: West Palm Beach employment projections (6/6)

Projection: Low Growth

Sectors 1-10 | Sectors 11-20

Employment Sector		2010	2030	2050
53	real estate	1,144	2,000	2,500
54	professional	7,455	8,000	9,000
55	management	1	1	1
56	admin	10,840	12,000	14,000
61	educational services	203	500	800
62	health care	12,742	14,000	15,000
71	arts entertain	1,695	2,100	3,000
72	accommodation food	6,424	7,000	8,000
81	other	768	1,000	1,500

Source: US Census and Bureau of Labor Statistics

doi:10.6342/NTU201600887

Appendix B: What If? Allocation Output Reports

B.1 Tamsui

What if? Allocation Report

Scenario: suitability - BAU - med growth - control

Project: Tamsui Nick

Report Printed: March. 29, 2016 7:38 AM

Scenario Computed: Mar. 28, 2016 9:18 PM

Failure Message: None

Location: C:\Users\Chuey\Downloads\Tamsui_Nick\Tamsui_Nick\Allocation\suitability - BAU - med growth - control

Area(s): Study Area

Tamsui

LAND USE INFORMATION

				Hectares
Land Use	2006	2030	2050	Buildout
PUBLIC	133.39	1,002.39	1,048.54	1,048.54
WATER	468.91	468.91	468.91	468.91
TRANSPORTATION	412.57	591.80	621.74	621.74

doi:10.6342/NTU201600887

OTHER	674.68	674.68	674.68	674.68
BUILT UP	746.11	1,125.16	1,199.65	3,737.62
FOREST	2,849.59	1,729.72	1,620.19	34.58
AGRICULTURE	1,597.12	1,016.95	952.89	0.53
RECREATIONAL	273.24	494.60	517.61	517.61
MINING	0.79	52.20	52.20	52.20

			Change (Hectares)	
Land Use	2006-2030	2030-2050	2006-2050	2006- Buildout
PUBLIC	869.00	46.15	915.15	915.15
WATER	0.00	0.00	0.00	0.00
TRANSPORTATION	179.22	29.95	209.17	209.17
OTHER	0.00	0.00	0.00	0.00
BUILT UP	379.05	74.49	453.54	2,991.50
FOREST	-1,119.88	-109.52	-1,229.40	-2,815.02
AGRICULTURE	-580.17	-64.06	-644.23	-1,596.59
RECREATIONAL	221.36	23.00	244.37	244.37
MINING	51.41	0.00	51.41	51.41

What if? Allocation Report

Scenario: suitability - A - high growth - control

doi:10.6342/NTU201600887

Project: Tamsui Nick

Report Printed: March. 29, 2016 7:37 AM

Scenario Computed: Mar. 28, 2016 8:26 PM

Failure Message: None

Location: C:\Users\Chuey\Downloads\Tamsui_Nick\Tamsui_Nick\Allocation\suitability - A - high growth - control

Area(s): Study Area

Tamsui

LAND USE INFORMATION

				Hectares
Land Use	2006	2030	2050	Buildout
PUBLIC	133.39	1,089.72	1,140.08	1,140.08
WATER	468.91	468.91	468.91	468.91
TRANSPORATION	412.57	609.08	642.40	642.40
OTHER	674.68	674.68	674.68	674.68
BUILT UP	746.11	1,161.56	1,217.09	3,594.97
FOREST	2,849.59	1,622.99	1,521.32	34.58
AGRICULTURE	1,597.12	955.32	891.67	0.53
RECREATIONAL	273.24	516.66	542.76	542.76
MINING	0.79	57.49	57.49	57.49

doi:10.6342/NTU201600887

				Change (Hectares)
Land Use	2006-2030	2030-2050	2006-2050	2006- Buildout
PUBLIC	956.33	50.36	1,006.69	1,006.69
WATER	0.00	0.00	0.00	0.00
TRANSPORTATION	196.51	33.32	229.83	229.83
OTHER	0.00	0.00	0.00	0.00
BUILT UP	415.44	55.54	470.98	2,848.86
FOREST	-1,226.60	-101.67	-1,328.27	-2,815.02
AGRICULTURE	-641.80	-63.65	-705.45	-1,596.59
RECREATIONAL	243.42	26.10	269.52	269.52
MINING	56.70	0.00	56.70	56.70

What if? Allocation Report

Scenario: suitability - B - low growth - control

Project: Tamsui Nick

Report Printed: March. 29, 2016 7:38 AM

Scenario Computed: Mar. 28, 2016 9:28 PM

Failure Message: None

doi:10.6342/NTU201600887

Location: C:\Users\Chuey\Downloads\Tamsui_Nick\Tamsui_Nick\Allocation\suitability - B - low growth - control

Area(s): Study Area

Tamsui

LAND USE INFORMATION

Land Use	2006	2030	2050	Buildout
				Hectares
PUBLIC	133.39	915.63	1,033.50	1,033.50
WATER	468.91	468.91	468.91	468.91
TRANSPORTATION	412.57	573.90	601.06	601.06
OTHER	674.68	674.68	674.68	674.68
BUILT UP	746.11	1,088.78	1,134.37	3,801.84
FOREST	2,849.59	1,841.55	1,707.01	34.58
AGRICULTURE	1,597.12	1,073.31	995.57	0.53
RECREATIONAL	273.24	471.98	493.63	493.63
MINING	0.79	47.68	47.68	47.68

Land Use	2006-2030	2030-2050	2006-2050	2006- Buildout
				Change (Hectares)
PUBLIC	782.24	117.87	900.11	900.11
WATER	0.00	0.00	0.00	0.00
TRANSPORTATION	161.32	27.17	188.49	188.49
OTHER	0.00	0.00	0.00	0.00

doi:10.6342/NTU201600887

BUILT UP	342.67	45.59	388.26	3,055.72
FOREST	-1,008.05	-134.54	-1,142.59	-2,815.02
AGRICULTURE	-523.81	-77.74	-601.55	-1,596.59
RECREATIONAL	198.74	21.65	220.39	220.39
MINING	46.89	0.00	46.89	46.89

B.2 West Palm Beach

What if? Allocation Report

Scenario: suitability - A - high growth - control

Project: WPB fixed 2

Report Printed: March. 10, 2016 10:55 PM

Scenario Computed: Mar. 10, 2016 9:29 PM

Failure Message: None

Location: C:\Users\Chuey\Downloads\WPBNick_Fixed - 2\Allocation\suitability - A - high growth - control

Area(s): Study Area

West Palm Beach

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doi:10.6342/NTU201600887

LAND USE INFORMATION

Hectares

Land Use	2010	2030	2050	Buildout
COMMERCIAL AND SERVI	1,216.95	1,914.92	2,553.06	2,553.06
COMMUNICATIONS	9.20	9.20	9.20	9.20
DISTURBED LAND	9.51	9.51	9.51	9.51
HERBACEOUS (DRY PRAI	164.40	1.00	0.34	0.00
INDUSTRIAL	220.67	220.67	220.67	220.67
INSTITUTIONAL	328.23	647.23	1,293.72	1,293.72
LAKES	382.70	382.70	382.70	382.70
MIXED RANGELAND	64.09	0.00	0.00	0.00
NURSERIES AND VINEYA	0.27	0.27	0.27	0.27
OPEN LAND	125.28	27.34	25.13	0.00
RECREATIONAL	676.57	984.97	1,072.66	1,072.66
RESERVOIRS	510.25	510.25	510.25	510.25
RESIDENTIAL, HIGH DE	735.68	913.14	1,086.68	4,128.26
RESIDENTIAL, LOW DEN	3.58	3.58	3.58	3.58
RESIDENTIAL, MEDIUM	2,422.56	3,004.10	3,574.65	3,574.65
SHRUB AND BRUSHLAND	67.53	3.80	1.90	0.00
SPECIALTY FARMS	0.01	0.01	0.01	0.01
STREAMS AND WATERWAY	462.39	462.39	462.39	462.39
TRANSPORTATION	346.66	346.66	346.66	346.66
UPLAND CONIFEROUS FO	437.57	271.14	140.94	0.00

doi:10.6342/NTU201600887

UPLAND HARDWOOD FORE	517.31	86.86	40.76	0.00
UTILITIES	359.45	379.01	388.38	388.38
VEGETATED NON-FOREST	3,453.88	2,760.82	1,544.15	0.00
WETLAND CONIFEROUS F	1,129.36	1,054.22	649.90	0.00
WETLAND FORESTED MIX	560.47	339.88	225.96	0.00
WETLAND HARDWOOD FOR	751.41	622.30	412.49	0.00

	Change (Hectares)			
Land Use	2010-2030	2030-2050	2010-2050	2010- Buildout
COMMERCIAL AND SERVI	697.97	638.14	1,336.11	1,336.11
COMMUNICATIONS	0.00	0.00	0.00	0.00
DISTURBED LAND	0.00	0.00	0.00	0.00
HERBACEOUS (DRY PRAI	-163.39	-0.67	-164.06	0.00
INDUSTRIAL	0.00	0.00	0.00	0.00
INSTITUTIONAL	319.00	646.50	965.50	965.50
LAKES	0.00	0.00	0.00	0.00
MIXED RANGELAND	-64.09	0.00	-64.09	0.00
NURSERIES AND VINEYA	0.00	0.00	0.00	0.00
OPEN LAND	-97.94	-2.22	-100.15	0.00
RECREATIONAL	308.40	87.69	396.09	396.09
RESERVOIRS	0.00	0.00	0.00	0.00
RESIDENTIAL, HIGH DE	177.47	173.54	351.01	3,392.59
RESIDENTIAL, LOW DEN	0.00	0.00	0.00	0.00
RESIDENTIAL, MEDIUM	581.54	570.55	1,152.09	1,152.09

doi:10.6342/NTU201600887

SHRUB AND BRUSHLAND	-63.73	-1.90	-65.63	0.00
SPECIALTY FARMS	0.00	0.00	0.00	0.00
STREAMS AND WATERWAY	0.00	0.00	0.00	0.00
TRANSPORTATION	0.00	0.00	0.00	0.00
UPLAND CONIFEROUS FO	-166.43	-130.19	-296.63	0.00
UPLAND HARDWOOD FORE	-430.46	-46.09	-476.55	0.00
UTILITIES	19.55	9.37	28.92	28.92
VEGETATED NON-FOREST	-693.07	-1,216.67	-1,909.73	0.00
WETLAND CONIFEROUS F	-75.14	-404.31	-479.46	0.00
WETLAND FORESTED MIX	-220.59	-113.92	-334.51	0.00
WETLAND HARDWOOD FOR	-129.10	-209.81	-338.91	0.00

What if? Allocation Report

Scenario: suitability - BAU - med growth - control

Project: WPB fixed 2

Report Printed: March 10, 2016 11:01 PM

Scenario Computed: Mar. 10, 2016 10:17 PM

Failure Message: None

Location: C:\Users\Chuey\Downloads\WPBNick_Fixed - 2\Allocation\suitability - BAU - med growth - control

Area(s): Study Area

West Palm Beach

doi:10.6342/NTU201600887

LAND USE INFORMATION

Hectares

Land Use	2010	2030	2050	Buildout
COMMERCIAL AND SERVI	1,216.95	1,914.81	2,340.51	2,340.51
COMMUNICATIONS	9.20	9.20	9.20	9.20
DISTURBED LAND	9.51	9.51	9.51	9.51
HERBACEOUS (DRY PRAI	164.40	1.00	1.00	0.00
INDUSTRIAL	220.67	220.67	220.67	220.67
INSTITUTIONAL	328.23	808.69	1,132.10	1,132.10
LAKES	382.70	382.70	382.70	382.70
MIXED RANGELAND	64.09	0.00	0.00	0.00
NURSERIES AND VINEYA	0.27	0.27	0.27	0.27
OPEN LAND	125.28	27.34	26.46	0.00
RECREATIONAL	676.57	809.95	897.45	897.45
RESERVOIRS	510.25	510.25	510.25	510.25
RESIDENTIAL, HIGH DE	735.68	880.34	1,082.34	4,686.38
RESIDENTIAL, LOW DEN	3.58	3.58	3.58	3.58
RESIDENTIAL, MEDIUM	2,422.56	2,898.32	3,560.59	3,560.59
SHRUB AND BRUSHLAND	67.53	3.80	2.99	0.00
SPECIALTY FARMS	0.01	0.01	0.01	0.01
STREAMS AND WATERWAY	462.39	462.39	462.39	462.39
TRANSPORTATION	346.66	346.66	346.66	346.66

doi:10.6342/NTU201600887

UPLAND CONIFEROUS FO	437.57	272.14	175.94	0.00
UPLAND HARDWOOD FORE	517.31	87.86	56.93	0.00
UTILITIES	359.45	388.25	393.70	393.70
VEGETATED NON-FOREST	3,453.88	2,881.82	1,824.56	0.00
WETLAND CONIFEROUS F	1,129.36	1,066.22	774.74	0.00
WETLAND FORESTED MIX	560.47	344.88	264.33	0.00
WETLAND HARDWOOD FOR	751.41	625.30	477.08	0.00

	Change (Hectares)			
Land Use	2010-2030	2030-2050	2010-2050	2010- Buildout
COMMERCIAL AND SERVI	697.87	425.70	1,123.56	1,123.56
COMMUNICATIONS	0.00	0.00	0.00	0.00
DISTURBED LAND	0.00	0.00	0.00	0.00
HERBACEOUS (DRY PRAI	-163.39	0.00	-163.39	0.00
INDUSTRIAL	0.00	0.00	0.00	0.00
INSTITUTIONAL	480.46	323.41	803.88	803.88
LAKES	0.00	0.00	0.00	0.00
MIXED RANGELAND	-64.09	0.00	-64.09	0.00
NURSERIES AND VINEYA	0.00	0.00	0.00	0.00
OPEN LAND	-97.94	-0.89	-98.82	0.00
RECREATIONAL	133.38	87.50	220.88	220.88
RESERVOIRS	0.00	0.00	0.00	0.00
RESIDENTIAL, HIGH DE	144.66	202.00	346.66	3,950.70
RESIDENTIAL, LOW DEN	0.00	0.00	0.00	0.00

doi:10.6342/NTU201600887

RESIDENTIAL, MEDIUM	475.77	662.27	1,138.03	1,138.03
SHRUB AND BRUSHLAND	-63.73	-0.81	-64.54	0.00
SPECIALTY FARMS	0.00	0.00	0.00	0.00
STREAMS AND WATERWAY	0.00	0.00	0.00	0.00
TRANSPORTATION	0.00	0.00	0.00	0.00
UPLAND CONIFEROUS FO	-165.43	-96.19	-261.62	0.00
UPLAND HARDWOOD FORE	-429.46	-30.93	-460.39	0.00
UTILITIES	28.79	5.45	34.25	34.25
VEGETATED NON-FOREST	-572.07	-1,057.26	-1,629.32	0.00
WETLAND CONIFEROUS F	-63.14	-291.48	-354.62	0.00
WETLAND FORESTED MIX	-215.59	-80.55	-296.14	0.00
WETLAND HARDWOOD FOR	-126.10	-148.22	-274.32	0.00

What if? Allocation Report

Scenario: suitability - B - low growth - control

Project: WPB fixed 2

Report Printed: March. 10, 2016 10:59 PM

Scenario Computed: Mar. 10, 2016 10:13 PM

Failure Message: None

Location: C:\Users\Chuey\Downloads\WPBNick_Fixed - 2\Allocation\suitability - B - low growth - control

Area(s): Study Area

doi:10.6342/NTU201600887

West Palm Beach

LAND USE INFORMATION

Hectares

Land Use	2010	2030	2050	Buildout
COMMERCIAL AND SERVI	1,216.95	1,489.50	2,021.27	2,021.27
COMMUNICATIONS	9.20	9.20	9.20	9.20
DISTURBED LAND	9.51	9.51	9.51	9.51
HERBACEOUS (DRY PRAI	164.40	48.67	1.00	0.00
INDUSTRIAL	220.67	241.05	253.96	253.96
INSTITUTIONAL	328.23	808.92	1,132.37	1,132.37
LAKES	382.70	382.70	382.70	382.70
MIXED RANGELAND	64.09	9.61	0.00	0.00
NURSERIES AND VINEYA	0.27	0.27	0.27	0.27
OPEN LAND	125.28	65.46	27.34	0.00
RECREATIONAL	676.57	766.16	825.32	825.32
RESERVOIRS	510.25	510.25	510.25	510.25
RESIDENTIAL, HIGH DE	735.68	836.94	931.65	5,547.80
RESIDENTIAL, LOW DEN	3.58	3.58	3.58	3.58
RESIDENTIAL, MEDIUM	2,422.56	2,754.38	3,067.25	3,067.25
SHRUB AND BRUSHLAND	67.53	28.07	3.80	0.00
SPECIALTY FARMS	0.01	0.01	0.01	0.01

doi:10.6342/NTU201600887

STREAMS AND WATERWAY	462.39	462.39	462.39	462.39
TRANSPORTATION	346.66	346.66	346.66	346.66
UPLAND CONIFEROUS FO	437.57	297.89	236.28	0.00
UPLAND HARDWOOD FORE	517.31	209.42	77.14	0.00
UTILITIES	359.45	371.52	383.42	383.42
VEGETATED NON-FOREST	3,453.88	3,129.54	2,400.34	0.00
WETLAND CONIFEROUS F	1,129.36	1,087.00	978.81	0.00
WETLAND FORESTED MIX	560.47	403.90	313.58	0.00
WETLAND HARDWOOD FOR	751.41	683.38	577.85	0.00

	Change (Hectares)			
Land Use	2010-2030	2030-2050	2010-2050	2010- Buildout
COMMERCIAL AND SERVI	272.55	531.78	804.33	804.33
COMMUNICATIONS	0.00	0.00	0.00	0.00
DISTURBED LAND	0.00	0.00	0.00	0.00
HERBACEOUS (DRY PRAI	-115.73	-47.67	-163.39	0.00
INDUSTRIAL	20.38	12.91	33.29	33.29
INSTITUTIONAL	480.69	323.46	804.14	804.14
LAKES	0.00	0.00	0.00	0.00
MIXED RANGELAND	-54.48	-9.61	-64.09	0.00
NURSERIES AND VINEYA	0.00	0.00	0.00	0.00
OPEN LAND	-59.83	-38.11	-97.94	0.00
RECREATIONAL	89.59	59.16	148.76	148.76
RESERVOIRS	0.00	0.00	0.00	0.00

doi:10.6342/NTU201600887

RESIDENTIAL, HIGH DE	101.27	94.71	195.97	4,812.13
RESIDENTIAL, LOW DEN	0.00	0.00	0.00	0.00
RESIDENTIAL, MEDIUM	331.82	312.87	644.69	644.69
SHRUB AND BRUSHLAND	-39.46	-24.27	-63.73	0.00
SPECIALTY FARMS	0.00	0.00	0.00	0.00
STREAMS AND WATERWAY	0.00	0.00	0.00	0.00
TRANSPORTATION	0.00	0.00	0.00	0.00
UPLAND CONIFEROUS FO	-139.68	-61.60	-201.28	0.00
UPLAND HARDWOOD FORE	-307.90	-132.28	-440.17	0.00
UTILITIES	12.06	11.90	23.97	23.97
VEGETATED NON-FOREST	-324.34	-729.20	-1,053.54	0.00
WETLAND CONIFEROUS F	-42.35	-108.20	-150.55	0.00
WETLAND FORESTED MIX	-156.57	-90.32	-246.89	0.00
WETLAND HARDWOOD FOR	-68.03	-105.53	-173.56	0.00

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