Developing an Urban Ecosystem Resilience Index Using a System Dynamics Approach

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LIST OF ACRONYMS

A&GA	Agriculture and Greenspace Area
ADT	Average Daily Traffic
ADWF	Average Dry Water Flow
AIP	Annual Investment Plan
AL	Available Land
ASEAN	Association of Southeast Asian Nations
BAU	Business-As-Usual
BDRRMC	Barangay Disaster Risk Reduction and Management Committee
BOD	Biological Oxygen Demand
BuA	Built-up Area
C	Run-off Coefficient
CATDO	Cultural Affairs and Tourism Development Office
CATO	Cultural Affairs and Tourism Office
CDIA	Cities Development Initiative for Asia
CDP	Comprehensive Development Plan
CDRRMO	City Disaster Risk Reduction and Management Office
CENRO	City Environment and Natural Office
CES	Cultural Ecosystem Services
CH_4	Methane
CLD	Causal Loop Diagram
CLUP	Comprehensive Land Use Plan
CPDO	City Planning and Development Office
DAO	DENR Administrative Order
DDR	Department of Disaster Resiliency
DENR	Department of Environment and Natural Resources
DOC	Degradable Organic Compound
DPWH	Department of Public Works and Highways
DRRMO	Disaster Risk Reduction and Management Office
ECA	Environmental Compliance Audit
EF	Emission Factor
EMB	Environmental Management Bureau
ER	Ecological Resilience
ES	Ecosystem Services
EWG	Estimated Waste Generated
FMD	Flood Management Division
FNRI	Food and Nutrition Research Institute
GHG	Greenhouse Gas
GUI	Graphical User Interface
HLURB	Housing and Land Use Regulatory Board
IPCC	Intergovernmental Panel on Climate Change

JICA	Japan International Cooperation Agency
KII	Key Informant Interviews
LCCAP	Local Climate Change Action Plan
LDRRMF	Local Disaster Risk Reduction Management Fund
LGU	Local Government Units
Lpd	Liters per Day
MEA	Millennium Ecosystem Assessment
MMDA	Metropolitan Manila Development Authority
MRF	Materials Recovery Facility
MRS	Materials Recovery System
MSW	Municipal Solid Waste
MWSS	Metropolitan Waterworks and Sewerage System
NDRRMF	National Disaster Risk Reduction Management Framework
NDRRMF	National Disaster Risk Reduction Management Fund
NDRRMP	National Disaster Risk Reduction and Management Plan
NFA	National Food Authority
NGA	National Government Agency
NRW	Non-Revenue Water
OCD	Office of Civil Defense
P&RA	Parks and Recreational Area
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PCSL	Population Connected to Sewerage Lines
$PM_{2.5}$	Particulate Matter (under 2.5 microns)
PNCSL	Population Not Connected to Sewerage Lines
PSA	Philippines Statistics Authority
PUB	Public Utility Bus
PUJ	Public Utility Jeep
R	Roads
RDF	Refuse-Derived Fuel
RIDF	Rainfall Intensity Duration Frequency
SD	System Dynamics
SER	Socio-ecological Resilience
STP	Sewage Treatment Plant
SUW	Severely Underweight
SWM	Solid Waste Management
SWMO	Solid Waste Management Office
SWMP	Solid Waste Management Plan
tCO_2e	Carbon Dioxide Equivalents (in tons)
TEEB	The Economics of Ecosystems and Biodiversity
UE	Urban Ecosystem
UER	Urban Ecosystem Resilience
UERI	Urban Ecosystem Resilience Index
UES	Urban Ecosystem Services
UN	United Nations
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UR	Urban Resilience
US EPA	United States Environmental Protection Agency

USDA United States Department of Agriculture
UW Underweight
VKT Vehicle Kilometer Traveled
WW Wastewater

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Abstract

This research assessed Urban Ecosystem Resilience of Pasig and Valenzuela City using a System Dynamics approach. The Urban Ecosystem Resilience Index was developed to serve as a decision-support tool for local governments. The concept of the UERI was formed by applying an ecosystem services approach to categorize city services like natural ecosystem services. Afterwards, systems thinking was applied using the Vensim® software to map out the interrelation of these services and their dynamics to capture feedback and trade-offs found in the system. Quantification of these services was done to measure the resilience of different services forming the overall UERI and was applied to both cities.

Under the Business-As-Usual scenario, structures were made to reflect the current conditions when projecting the resilience of services. The UERI of Pasig under this scenario was sub-optimal all throughout reaching a peak value of 0.73 for the year 2033. As for Valenzuela, the UERI reached a peak value of 0.61 for the year 2023. For both cities, the provisioning resilience score was observed to be highest while the regulating services scored the lowest. The cultural services could not be compared given the difference in the context for land use. Both resilience scores decreased over time given that there was an increase in demand for all services due to population growth. Different scenarios were also introduced to both cities framed in their respective context, but only resulted in a slight increase in the UERI value.

Using the UERI allowed for a more holistic view of resilience for the city given that it tackled more than just the services that are generally prioritized. Therefore, the UERI provides an avenue for capacity building as it allows for the rationalization of long-term city development. Recommendations include collection of additional data for model refinement.

1. Introduction

1.1 Background of the Study

In a rapidly urbanizing world, city systems are highly developed areas that have been built as result of various, indirect and complex effects on the natural ecosystems that surround them (Endlicher, Langer, & Kowarik, 2007). Cities are characterized as dynamic and complex socio-economic and biophysical systems (Pickett et al., 2003). Therefore, understanding city systems becomes an integrated field of study of the coupled relationship of the human-nature system (Alberti & Marzluff, 2004). Unique to this type of system as compared to other systems is the dominance of humans. Implications of this include humans continuously altering the whole system's processes, composition, dynamics and functions (Alberti, 2016) in order to ensure their own survival.

The extent of the disturbance experienced by city systems arises from the processes of urbanization which has driven both demographic growth and land use change in urban areas (Lyu, Zhang, Xu, & Li, 2018). Urbanization is defined to be a process in which cities are formed to become larger due to industrialization and economic development. This encourages urban-specific changes in specialization, labor division, and human behaviors (Uttara, Bhuvandas, & Aggarwal, 2012). The process itself is associated with the idea of modernization as the main goal for both developed and undeveloped countries. Implications to the environment include examples such as increased resource extraction and disturbance to natural environments due to increased built up area which could affect availability of resources. Therefore, without the appropriate city and land use management, commonly seen in the case of developing countries such as the Philippines (Bhattacharya, 2002), growing portions of the population are reduced to poverty given the impacts of urbanization and its major drivers towards services the provided by the city.

Cities have their own set of services to provide for the socio-economic and biophysical needs of the people residing in them similar to the context ecosystem services of natural ecosystems. An ecosystem service is defined as the benefits that people derive from ecosystems (Millenium Ecosystem Assessment Board, 2005). Urban areas provide a wide range of benefits to both sustain and improve human livelihood and quality of life. These services are characterized into four categories mainly provisioning, regulating, supporting, and cultural (Millenium Ecosystem Assessment Board, 2005). With that, there are frameworks that treat city systems as ecosystems with its own set of mechanisms that work to produce services. The purpose of this framework is to help understand the complexities of city systems. Urban Ecosystems (UE)—urban areas as ecosystems—are defined as the dynamic combination of natural, constructed, and social features that are associated within an urban area—refers to the ecology of a city (Brown, 2017).The UE approach, when applied to cities, provides new management opportunities towards meeting the demands set by rapid urbanization by focusing on the services the ecosystem provides based on different city management decisions. It involves assessing the effects of city development on the delivery of Urban Ecosystem Services (UES) divided between four categories based on TEEB (2018): provisioning, regulating, supporting, and cultural. These UES differ from natural ES given that cities are comprised of both natural and human-made areas. Therefore, the scope of UES involves not only ES provided by the natural but also from the artificial such as electricity, cultural elements, mobility, flood regulation, potable and non-potable water management, solid and liquid waste management, and land use.

When cities are conceptualized as a UE, their respective UES can be used as indicators to track down the integrity and sustainability of the respective system. The desired state of the urban ecosystem is one that meets the goals set by the city when it comes to providing UES. This is not only is it an indicator of ecosystem health—as for the case in natural ecosystems—but could also serve as a guide for decision-based management when applied in a UE context given that changes in the city require adjustments for UES delivery. Given continuous population growth, the goal of the UES framework is to determine how management efforts affect the desired state over time therefore, assessing which UES are compromised for future generation. This is in line with sustainability in cities which is defined as the ability to support the quality of life of the current generation without impairing the future generation to meet their needs for well-being (Curwell, et al., 2005).

Cities are also understood to evolve over the long term considering the interactions between socio-economic and biophysical processes (Alberti & Marzluff, 2004; Shane, 2005; Warner & Whittmore, 2012; Hart, 1991). As compared to natural ecosystems, various modifications take place in city systems which, in turn, also affect how the various types of ES provided depending on the priorities of each city development goal. From there, there exist trade-offs between the different UES across short and long-term timescales. Trade-offs are defined as the "increase in one ecosystem service (ES) and the simultaneous decline of another service at the same location" (Haase et al., 2012). These trade-offs are based on relevant stakeholder city management decisions in response demographic changes and socio-ecological changes brought about by urbanization, which is manifested in the different land-use changes and policy implementations for city development.

Aside from pressures associated with urbanization, another factor that could also influence the delivery and prioritization of UES are hazards introduced to the system. Hazards are defined as "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (UNDRR, 2016). These hazards could either be short term with immediate effects or long term whose effects are felt throughout a long timescale. Resilience studies have been introduced to help in city management to contribute to achieving sustainability. Resilience is to be defined in this paper as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2015). Resilience studies have developed to incorporate urban areas following this definition—referred to as Urban Resilience (UR). In developing cities using the UES framework, there is a need to introduce a new term referred to as Urban Ecosystem Resilience (UER) which is a sub-component of overall UR. While Urban Resilience is concerned with overall city resilience including social, infrastructure, economic and ecological, UER is particularly concerned in the development of the ecological aspect by contextualizing ES—used mostly in natural systems—to urban areas, or UES in short. This is in terms of assessing the changes and trade-offs of services derived from human-natural systems. Given this, UER was defined in the study as the ability of a city to adapt and transform in face of socio-economic and demographical changes, as well as long-term hazards, in order to sustain delivery of all four types of UES in the long term to achieve sustainable development.

Cities are always undergoing changes to respond to constant pressures from urbanization and hazards. Given this, it is more appropriate to frame Urban Ecosystem Resilience within a socio-ecological resilience context. With this, socio-ecological resilience (SER) is defined as the capacity of a socio-economic system to adapt and transform in the face of disturbance while undergoing change to retain its function, structure, identity, and feedbacks (Walker et al., 2004). This incorporates a basic definition of resilience concerned with maintaining the ability to adapt to the changes and disturbances introduced in the system while adding the idea that cities are transformative. SER builds on this by looking into how a city's buffering capacity can be increased via the reorganized of UES while considering potential trade-offs between them. (Sanchez et al., 2018).

Developments have been made for tools used to model how the components of socio-ecosystems interact over time. System Dynamics (SD) is a computer—aided approach to policy analysis and design (SDS, 2018). This SD tool was developed by Donella Meadows as an approach to tackling dynamic problems that arise from complex systems (System Dynamics Society, 2019). This involves capturing important feedbacks relevant to the problem observed. The feedbacks are defined by the (System Dynamics Society, 2019) as information loops which travel through a system, potentially influencing future action. The goal of SD is to identify these feedback loops to understand the mechanisms of complex systems to serve as a guide for policy and decision making. Applying the SD approach in UE allows the mapping of important interrelationships between system components therefore, quantitatively representing trade-offs in decisions regarding UES. This helps operationalize said resilience in the long term by providing graphical analyses useful in describing long-term dynamic scenarios and representative of human-nature interactions in the city (Ford, 1999; Meadows, 2008).

Urban settlements located in coastal areas continue to face the pressures brought about by both rapid urbanization and long - term climate hazards. The location of the urban settlement increases exposure to different climate – change related hazards such as flooding, increased precipitation, and sea level rise (Navarro, 2014). These hazards are aggravated over time due to different development schemes as a response to demographic growth and industrial expansion. Therefore, there is a decline in the integrity of ecosystem services provided by the city due to perturbations brought about by long-term hazards with increasing effects due to human actions.

Pasig City and Valenzuela City, both part of the mega-city of Metro Manila, are two such areas experiencing the challenges of urbanization. Both cities undergo population growth which increases the need for more services as well as the infrastructure to produce and distribute them. Therefore, there is an increasing portion of the population without access to basic services such as clean water, electricity, and food (CDIA, 2014). Additionally, urban growth decreases the options for resettlement of people from prone locations given lack of available dedicated for housing. Rapid urbanization in these areas have impacted the quality of services such as flood regulation. This has led to more incidences of flooding due increased built surface from urban development (Robas, 2014).

1.2 Statement of the Problem

The complex and non-linear processes in urban systems make it difficult to achieve a resilient and equitable city in terms of UES management. Developing a more holistic measure of resilience includes identifying feedbacks within a continuously evolving and developing system (Meadows, 2008). Urban ecosystems evolve over time due to the dynamic interactions between socio-economic and biophysical processes over multiple scales (Alberti, 1999). Human actions are continuously modifying the city to create new sets of feedback mechanisms making the ecosystem unstable. Current studies fail to show relationships of the diverse urban processes in urban systems into one coherent model (Alberti and Marzluff, 2004). Crucial feedback mechanisms are often disregarded given that ecologists and social scientists study components of urban ecosystems separately. Current urban ecosystem studies work on the assumption that ecological and human services work on independent ecological and economic processes (Daily et al., 1997).

Feedback mechanisms are seen in different categories of UES depending on which is prioritized in city planning. Different studies that attempt to use the ecosystems framework tend to focus on only one or two categories (mainly regulatory and cultural) rather than all four (Haase et al., 2014). An example of these studies includes assessing effects of urbanization on supporting services, mainly of pollination of bumblebees (Jannson & Polasky, 2015). A few studies have done more than one category such as the study assessing the potential impact of NYC MillionTrees program on both carbon storage and air quality improvements but failed to assess trade-offs or synergies between (Haase et al., 2014). With that, there is still a lack of a holistic and comprehensive understanding for the different interactions and possible feedbacks among the urban ecosystem services themselves. Additionally, understanding how these UES can support or impair each other is crucial in planning to account for possible trade-offs, synergies, or net losses (Rodriguez, et al., 2006).

There is also a need for a more temporal analysis for determining which sets of mechanisms can drive the city to collapse and which can lead to a desired outcome (Alberti, 2016). Currently, there is an abundance of spatial studies to assess changes in UES given land use changes and population growth (Haase et al., 2014; Burkhard et al., 2009). While it considers human-environment systems such as in risk maps, spatial studies fail to examine human-environment systems change over time and how subcomponents interact (Baho, et al., 2017).

To further contextualize to the stated cities, urbanization in both Pasig and Valenzuela City, has resulted into challenges experienced by both cities which hinder them from achieving resilience. For the case of Pasig, there is a lack of integrated and cross-sectoral planning for different sectors (energy, air quality, solid waste management, water management, transportation, ecology, urban agriculture, DRRM, and health). Given this, there exists different stakeholders, most especially the marginalized sector, which face increasing vulnerabilities to climate changed induced hazards (ICLEI, 2018). Additionally, it is the most vulnerable sector that are not able to participate in policy and program planning in the city. Other issues with lack of integrated planning involve solid waste management and the need to integrate it with other urban sectors. Waste is contributed by majority of the sectors in the city which have led to increased incidences of flooding due to clogged waterways. Other issues in the city involve increased smoke pollution, lack of garbage cans in the streets, and lack of urban green spaces to regulate environmental conditions as seen in different barangay reports (Dela Cruz et al., 2017).

In terms of Valenzuela city, main challenges to resilience include increasing exposures and vulnerability to flooding. There are increasing incidences of flooding in the city as a result of the implications associated with rapid urbanization such as improper solid waste disposal, insufficient drainage due to increased built-up, and demographic growth which exposes more people to floods (CDKN, 2015). During flooding, residents are left stranded in their houses with little supply of food and clean water. Additionally, cascading hazards such as water-related diseases occur due to the long reside time of warm and stagnant water given that there is not enough drainage. Other issues to resilience include lack of local food production as a result of land use changes due to urbanization which involves converting farmlands to residential areas to meet housing demand from an increasing population (CDKN, 2015). This in turn results into higher prices for food products given the lack of alternative food production within the city. With that challenges to resilience include integrating environmental concerns to local policies and programs. This involves seeing the interrelationships between a number of factors such as sustainable livelihood practices, land use planning, and implications of increased rainfall which the urban resilience index could provide.

Challenges brought about by urbanization brings about the need to tackle the problem in these cities using a more systemic approach in order to come up with fundamental solutions to complex problems. An SD approach may bridge the gaps that these cities may not easily perceive, such as why alternative methods of water sourcing such as rainwater collection may potentially decreasing flooding incidences. Therefore, relevant stakeholder consultations may prove useful in addressing the problems of these cities.

1.3 Research Objectives

The main objective of the study was to define and assess urban ecosystem resilience using a system dynamics approach. This study aimed to create a decision support tool for relevant stakeholders for development planning. The specific objectives were:

- To apply systems thinking approaches to articulate the feedbacks and trade-offs among the ecosystem services in an urban context;
- To develop a dynamic Urban Ecosystem Resilience Index (UERI) model based on an ecosystem services framework
- To apply the model to explore the impacts of different development scenarios on the UERI of two cities in Metro Manila, Pasig and Valenzuela, as initial case studies.

1.4 Significance of the Study

Urban ecosystem resilience (UER) provides a new perspective to assessing resilience that is not limited to considering the role of natural resources but also the implications of human modifications affecting ecosystem services. It involves further examination into resilience as a long-term phenomenon, spanning multiple spatial and temporal scales (McPhearson, 2014). Specific to this framework is the assessment of trade-offs which uses the socio-ecological resilience definition and a system dynamics approach. This new perspective involves treating human and natural systems as parts of the ecosystem. Therefore, in terms of assessing UES, the Urban Ecosystem Resilience Index can be used to build on overall urban resilience through its contribution by expanding the scope of ecological component to integrate natural and man-made systems. The creation of a new framework is also a step in contributing to new knowledge to the vast resilience literature

Secondly, this urban ecosystem resilience index also serves to augment capacities in partner communities, making this study both theoretical and practical. A concrete outcome of this study is a decision-support tool that LGUs may use for integrating resilience and sustainability considerations into development planning. The study and the model produced provide a way to understand complexities and interdependencies of human-natural systems. Policymakers can base their decisions on the trade-off assessment of urban ecosystem services. Therefore, the framework can help provide a guide towards tackling difficulties of understanding cause and effect relationships inherent in socio-ecological systems (Sanchez et al., 2018). The index provides an overview of overall processes and how they connect rather than a summary report of raw values. The challenge of summary reports is it does not incorporate in long-term planning that requires understanding of feedbacks formed from different changes in the system.

Optimization can then be achieved by analyzing feedbacks and trade-offs over time given that no city is self-supporting (Galderisi, 2014). This analysis was done through a system dynamics approach. This is potentially useful in analyzing the dynamism of an urban ecosystem, as well as to identify critical feedback mechanisms used in scenario testing (Ford, 1999; Meadows, 2008).

1.5 Scope and Limitation

The study focused on assessing Urban Ecosystem Resilience, a component of overall Urban Resilience. Manifestations of urbanization was limited to population growth and land use change. Additional components such as infrastructural, institutional, economic, and social dimensions which are part of a larger urban resilience model in the project, were not included specifically in this study. The UERI was envisioned as a component of overall urban resilience and would have some overlaps with the additional components mentioned to explain different feedbacks in the model but was not discussed as detailed as the ecosystem component. The site of the study was limited to two cities in Metro Manila mainly Pasig and Valenzuela.

Data was obtained from different agencies such as Local Government Units and National Government Agencies. These data mainly constituted of measurable parameters and development plans of the LGUs; soft variables that were difficult to quantify were excluded from this study. Hazards that were hydro-meteorological in nature (e.g. rainfall and flooding) were considered in the model design but geophysical hazards (e.g. earthquakes, landslides) have not yet been integrated in this version.

1.6 Conceptual Framework

The conceptual framework is found in Figure 1 regarding the formation of the UERI. In developing an UERI, there was a need to address rapid and uncontrolled urbanization. This was in the context of certain drivers such as a demographic growth and land-use change. City development plans respond to these changes through the increase in built-up areas and infrastructure which have implications to the natural ecosystems around it as well as the services tied up to these ecosystems. This type of urbanization becomes problematic when city grows too rapidly that it prioritizes expansion and neglects the ES (such as in the constant delivery of UES). Long-term hazards can also perturb the delivery of the UES. Such effects include the cutting of the supply of the basic needs such as water or food when hazards such as typhoons strike. Additionally, changes made in the city can modify the extent of disturbance of these hazards. Demographic growth, for one, increases portions of the population at risk. Additionally, land use elicits changes within the system that could compromise ecosystem services needed to buffer these hazards. Given this, the UERI also looked into trade-offs as well as synergies found between the four UES. Prioritization of one UES as a response to drivers of urbanization may have certain implications with other UES, either positively or negatively. Thus, the UES serve as good indicators for UER, as they determine whether a system is able to support the people, through its services, amidst rapid urbanization and climate-induced hazards. This, in turn, affects the overall well-being of a certain urban area's population.

The goal, then, was to establish a more long-term and holistic approach in city planning towards achieving urban ecosystem resilience through the UERI. The tool was made to serve as a decision-support tool in creating management strategies for the 4 UES. In assessing their interactions via the use of system dynamics, the UERI helps underline their importance to relevant stakeholders, especially in planning for sustainable city development. This addresses the effects of rapid urbanization by ensuring that the delivery of the UES for future generations is sustained. Aside from this, sustainable city development also prepares a city in the long-term, in terms of the ability to adapt and transform in the face of said hazards. In summary, the assessment of these 4 UES and interactions in light of long-term urban resilience can help achieve sustainable management while also considering adaptation and transformation in light of long-term climate induced hazard management. A resilient city is a city able to adapt and transform in order to ensure that services are provided in future generations as well. As such, UERI aims to show how UER is tied up to achieving sustainable development in cities.

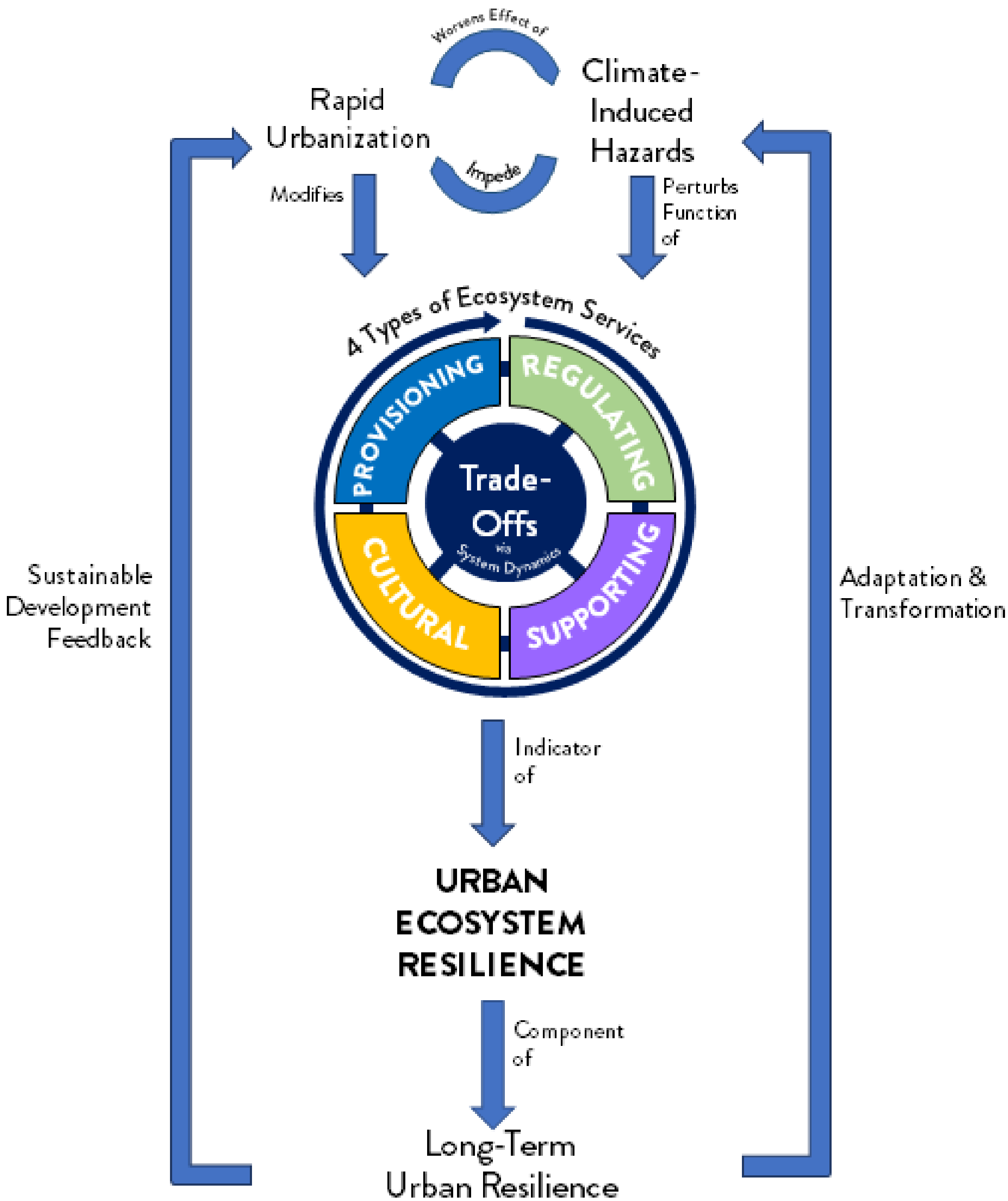


Figure 1. Conceptual Framework

2. Review of Related Literature

2.1 Defining Resilience

Several definitions of resilience have emerged with some being iterations of one another and others being completely different in terms of how the concept is used in different fields. Exemplifying this can be seen in Folke's (2006) analysis which provides a conceptual tension between three main resilience definitions namely: Resilience in Engineering, Resilience in Ecology, and Socio-Ecological Systems. Three major resilience definitions were differentiated based on the aspects of resilience were given focus. These different aspects were then categorized intro three main variations: (1) the system characteristic in response to hazards which could focus on recovery & consistency, robustness & persistence, or even adaptive capacity and transformability, (2) recovery from hazards which could focus on return time or efficiency, buffer capacity - being able to withstand shocks, or reorganization, sustain and develop, and (3) the type of equilibrium of the system analyzed whether single, multiple, or containing integrated systems. In the similarities and differences among the resilience definition, there exists overlaps which may lead to confusion. On the other hand, definitions, when understood, could be integrated and developed similar to the case of the holistic Urban Resilience which is an application of the three major resilience definitions highlighted by Folke (2006) as well as other ones used in city risk management.

Similarly, resilience has also been interchanged with the concept of sustainability. These terms are interchanged because of their similarities given that both are used to describe systems over time (Carpenter et al., 2001). This is attributed to the similarity in approaches given that both deal with system survivability, therefore both often follow common research methodologies such as life-cycle assessment, structural and socio-economic analysis as seen in different researches (Bocchini et al., 2014). The difference lies in what particularly in the system is given focus on with sustainability being the delivery of UES which improves the quality of life in respect to environment, social, and economic considerations for present and future generations (Collier et al., 2013) while resilience pertaining to the response of systems to extreme disturbances and persistent stress (Folke et al., 2016). Knowing the difference between the two allows for ways in which they can be jointly implemented to better understand the system. An example would be resilience being used as component of sustainability as a potential framework for case studies such a city risk management wherein the delivery of services for present and future generations – or city sustainability, is affected by persistent stresses and hazards experience by cities – or city resilience. Given this, rather than being interchangeable, resilience becomes something that is integral to sustainability.

2.1.1 Engineering and Ecological Resilience

The general resilience definition comes from Holling (1973) who was first to use the term to describe natural systems faced with external perturbations. The definition used by Holling for resilience is interpreted as "measure of the ability of a system to absorb changes of state variables, driving variables, and parameters, and still persist" and is defined based on stability as "the ability of a system to return to an equilibrium state after a temporary disturbance" (1973). Therefore, resilience comprised of these two definitions which focuses on an equilibrium centered view (Galderisi, 2014).

Resilience was then differentiated to either engineering resilience or ecological resilience. Holling (1996) characterized engineering resilience to be focused on the stability of systems which was measured by factors of efficiency, constancy, predictability, return time to previous state, and, most importantly, worked on the idea of single, stable equilibrium. The formal definition of "engineering resilience is the ability of a system to return to an equilibrium or steady-state after a disturbance" (Davoudi, Resilience: A bridging concept or a dead end?, 2012). Ecological resilience recognized the existence of multiple equilibrium states, as opposed to engineering resilience, and was defined as the ability of a system to absorb changes based on the system's threshold (Holling, 1996). Ecological resilience is associated with speed of recovery to a state equilibrium (not necessarily the state before disturbance) and the intensity of disturbance that can be absorbed which is referred to as the critical threshold (Davoudi, Resilience: A bridging concept or a dead end?, 2012).

The different resilience definitions were based on the idea of equilibrium with main differences being whether it focused on single or multiple equilibria. The resilience definition proposed by Holling, which is an equilibrium centered view, is considered static and does not provide transient behavior of systems that are not near equilibrium (Galderisi, 2014). Engineering resilience also works on the single equilibrium perspective which works on the central idea of bouncing back to a pre-event normal or equilibrium state (Holling, 1973) identified to be more desirable than the present (Vale, 2014). When applied to urban policy, engineering resilience is measured in the speed of recovery to the system's prior state (Sanchez, 2018) measured in the system's persistence and stability. The criticism under this definition is that it fails to capture the changed reality or new possibilities given that it returns to previous state equilibrium which is more apt for material than human systems (Manyena et al., 2011). Additionally, when translated into policy, engineering resilience focuses on short-term damage and recovery and cannot account for chronic stresses that urban settlements face over time (Sanchez, 2018). Ecological resilience works on a multiple equilibrium perspective. Given different stability domains, this type of resilience focuses on system relationships to maintaining function rather than stability under stress (Adger, Social and Ecological Resilience: Are They Related?, 2000). The problem with ecological resilience is in the nature of cities to be in a state of non-equilibrium given multiple internal and external pressures for urban change (Vale, 2014). Adaptation associated with ecological resilience cannot cope with the complexity of dynamic systems. Lastly, stability of domains becomes a problem if the desired characteristic for long-term survival involves changes or evolution in the system (Adger, 2000).

2.1.2 Socio-Ecological Resilience

Socio-ecological resilience (SER) was developed to strengthen the ecological approach by shifting the perspective from just natural to include as well the socio-ecological aspects in the system which are governed by close relationships between human and natural components (Galderisi, 2014). Holling developed SER to provide a useful framework for understanding how individual, communities, organizations, and ecosystems face both known and not known uncertainties, the challenges it provides, and possible opportunities (Hassler & Kohler, 2014). Therefore, developments of ecological resilience leading to SER have embedded human and cultural ecology in cities (Alexander, 2013). The formal definition for SER for understanding socio-ecological systems is “the capacity of a system to absorb disturbance and organize while undergoing change so as to retain essential same the function, structure, identity, and feedbacks” (Walker et al., 2004). Evolutionary resilience is derived from the SER with an adapted panarchy model (Sanchez, 2018) that deals with adaptive cycles of change inherent in systems. The panarchy model deals with phases of change such as growth, conservation, creative destruction and reorganization of systems (Holling, 2001).

Both resilience definitions deal with disturbances that can either be chronic or rapid shocks (Sanchez, 2018). SER is in understanding how actions to address threat influences the whole SES to achieve a desired system state (Adger, et al., 2011). Therefore, it deals with the system’s capacity to adapt and survive through reorganization of components and not particularly through planned interventions (Davoudi et al., 2016). SER deals with system theories which requires self-organization of sub-systems formed by independent agents interacting at local scales (Sanchez, 2018). The limitation of the definition is in determining what is the desired state of a city (Davoudi et al., 2012). Evolutionary resilience (ER) differs from SER given that SES can change with or without external disturbances (Sanchez, 2018) as seen in the idea that cities are constantly changing systems. Introduced in this resilience definition is the bounce forward (Manyena et al., 2011) which presents resilience as a continually changing process through re-build of city into an optimized system. Therefore, in SES such as cities, it is important to take both definitions given that SER governs reorganization of components while evolutionary resilience focuses on the idea of optimizing systems given a continuously changing city (via urbanization processes) given that it is in a constant state of non-equilibrium requiring constant improvement.

2.1.3 Urban Resilience

Urban resilience (UR) draws its definition from the application of previous resilience definitions mainly, but not limited to, ecological, engineering, evolutionary, and socio-ecological. From the various definitions of UR found in the Urban Resilience review by Meerow et al. (Meerow et al., 2016), the differences among them depends on which resilience definition was used as a basis mainly, differences in which system characteristic is given more focus which could include capacity to absorb, capacity to recover, or capacity to absorb & transform, amidst persistent stress and hazards. UR is holistic in a sense that it covers multiple applications not simply ecological or socio - ecological. Multiple application of resilience is reflected in definition of Urban Resilience formulated by (Meerow et al., 2016), “Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity”. This definition incorporates ER principles of returning to desired functions as well as SER and ER principle of integrating socio-ecological components and the addition of the transformative aspect which allows systems to bounce forward after a disturbance seen in the mention of future adaptive capacity not being limited.

UR applies to the resilience of areas experiencing rapid urbanization and population change (Berkes, 2008; CSIRO Annual Report, 2007). Major disturbances experiences by cities include climate - related hazards. Given this, resilience in an urban system is concerned particularly in three main things mainly: “metabolic flows in sustaining ecosystem functions, wellness and quality of life; governance networks and the ability of society to learn, adapt and reorganize itself to face urban challenges; social dynamics of community and citizens, as users of services, consumers, producers, and their relationship with the built environment defining physical patterns of urban space interaction (CSIRO Annual Report, 2007).

The concept of resilience is crucial in understanding the complex dynamics of urban systems said to “depend on both the social and biophysical ecological patterns and process that are continuously changing under pressure of internal and external drivers” (Pickett et al., 2004; 2010). Using this understanding of resilience, it then becomes a potential tool in achieving sustainable development goals. For a system to be sustainable, consideration must be made for its vulnerabilities to disturbances. Urban resilience addresses how a system can become sustainable from recovering after a disturbance through its adaptive components (Marchese, et al., 2017)). Given this, urban resilience is crucial in achieving sustainable development mainly in framing policies to address vulnerabilities from slow-moving and sudden disturbances.

2.1.4 Urban Ecosystem Resilience

Developing Urban Ecosystem Resilience (UER) as a subcomponent of UR captures components mainly from SER and ER which are evolved from the ER definition in order to capture the adapt and transformative characteristic found in the UR definition. The subcomponent involves focusing the ecological aspect within overall UR.

In the literature review of Rus et al. (2018), the four main components that affect the resilience of urban systems are buildings, open space, infrastructure, and community. This framework focuses on the physical (buildings, open space, infrastructure) and social (the community) as seen in various studies on urban resilience. The proposed framework deals with identifying indicators under four main categories towards having a more holistic approach to resilience. These four components involve leadership & strategy, health and wellbeing, economy and society, and infrastructure and ecosystems (Shah, n.d.). The index itself focuses more on the social and physical contributions to resilience as opposed to the ecological ones. Urban system are often divided between physical and social with very little attention to the ecological aspect present in cities. The study on ecosystem services framework can fill in the gap needed to make the divisions more holistic. Knowledge on ES can be added under the infrastructure and ecosystems portion of the City Resilience Index developed by Rockefeller Foundation.

There have been few studies done in applying the ecosystem service framework for UR under the guidelines of the Millenium Ecosystem Assessment (MEA) and The Economics of Ecosystems Biodiversity (TEEB) classification frameworks (Gómez-Baggethun & Barton, 2013). The basis for using this framework comes from the relationship between urban processes and how it affects the capacity of urban ecosystems to function and provide ecosystem services. Ecosystems have specific metabolic flows which deal with supply and consumption chains in a specific ecosystem (Brand & Jax, 2007). Metabolic flows are linked with the capacity to produce, energy, goods and services for the wellness and life-quality of a community. Under this framework, the city is viewed as an ecosystem and its services (as metabolic flows) are classified under the four categories of provisioning, regulating, cultural, and supporting. A review on the contributions on ecosystem services to urban resilience by Carabine (2015) and Haase (2014) explains that ability of the ecosystem to meet the demands for the different services is linked with increasing resilience.

Alberti and Marzluff (2004) mention the problems of treating human actions as separate (external drivers) of ecosystem dynamics in relation to ES studies. In their paper, they mentioned that one of the main problems in natural resource management stems from the lack of recognition that ecosystems and social systems that depend on them are inextricably linked. As such, assessing the feedback loops among them, considering the interdependent social-ecological systems, will determine the overall dynamics of the system (Folke, et al., 2010). Given this, an urban ecosystem resilient city is seen in being able to continuously provide ecosystem services when faced with changes from urbanization processes. Additionally, it must account for trade-offs from the different prioritization and optimization among services provided based on each cities' development goals. Example of applied the ES framework in urban resilience involves the study of Breuste (2013). Indicators from the ES were chosen based on their contributions to overall human well – being which he defined as a component of resilience. The limitation of the study was that it was limited to natural green spaces as the main source of the ecosystem services. There were no considerations for environment - related services provided by the urban ecosystem.

Challenges in UR studies that apply the ES framework involve the lack of contextualizing ES in the urban setting as well as the lack of temporal studies made. In understanding the dynamics of UES, it is important to assess the relationship between different processes found in an urban ecosystem such as urbanization, environmental impact assessment, and flow of ES. The review paper by Haase (2014) assesses the current state of the ES framework in Urban Resilience studies. Different studies assessing changes in UES were applied at a regional scale while only few at a site or neighborhood scale. Most of these studies focused on spatial analysis relation changes in land use to ecosystem services. Among these studies, half were said to have used historic analysis and minimal studies undertook long term assessment. The only current study to have done a combination of both historic analysis and scenario approach was that of Schetke and Haase (Schetke & Haase, Multi-criteria assessment of socio-environmental aspects in shrinking cities. Experiences from Eastern Germany., 2008). The mentioned study dealt with demographic change and economic decline and how these factors affected urban land use patterns in shrinking cities of Germany. The study used a multi-criteria assessment scheme to quantify socio-environmental impact on urban greenery and residents. Main indicators were again chosen based on how they affect quality of human life. While the study was more integrated, it focused on selected ecosystem services such as urban greenery rather than provisioning, supporting, and cultural.

Given the challenge provided in assessing temporality, majority of the studies that were reviewed used a spatial approach. The spatial approach involved using satellite imagery, maps, and photographs to correlate land cover change to ES. This included studies by Burkhard et al. (2009) and Kroll et al. (2011) which provided an ES assessment through land cover maps and different land use types. The limitation of these studies were that they failed to account for important dynamics such that while land use remained the same, its characteristics were subject to change. The study by Burkhard et al. (2009, 2011) showed how the increase in productivity in farming has been compensated by a loss of farmland as a result of urbanization.

The review mentions another challenge of the method which involves the tendency of different literature to focus on either the natural sources of ecosystem services or the urban services termed as the environment-related services. Among these studies, the most common ones were on regulating services such as carbon sequestration and storage, storm runoff, and air pollution removal (Haase et al., 2014). There are only a few studies which dealt with provisioning services and only one on examining the effects of urbanisation to supporting services mainly on pollination of plants (Jansson and Polasky, 2010). As for changes in cultural ES, only about three papers were mentioned in the review and among those three, two referred to the same study (Schetke and Haase 2008; Schetke et al., 2009).

The Urban Ecosystem Resilience framework contributes to understanding the temporal dynamics of service delivery which does not only consider average delivery over time but also how these services change over time (Birkholfer, et al., 2015). The main limitation of this framework seen in different studies is the tendency to focus on only one category of ES in measuring resilience. Additionally, there are not enough data understand trends needed in temporal studies.

2.1.5 Measuring Resilience

Studies that have conceptualized and modeled resilience have mainly focused on a more static view or a resilience that did not specify the trade-offs between the ecosystem services. There are studies that utilized questionnaires and surveys, demographic and geographic assessments and a few utilized as scorecard approach as a composited and consolidated overall score such as in (Kotzee & Reyers, 2016).

To give some examples, a study by (Shaw & Oikawa, Education for Sustainable Development and Disaster Risk Reduction, 2014) focused mainly on creating spider diagrams to give a more general output on resilience and measured 5 dimensions to capture the overall picture of resilience but using a societal approach in conducting the methodology (Shaw et al., 2010). It is important to note as well that the study was focused on static resilience based on survey and questionnaire results at the time being of the study. A similar study conducted by (Uy et al., 2012) framed the same methodology in Infanta, Quezon, but this time using an ecosystems approach. The study still is a static means of approaching resilience, but this time using the natural processes in ecosystems to quantify resilience. There is a mention as to urban ecosystems may not be ecologically intact but did mention the social dimension in the definition of resilience.

Rus et al. (2018) along with the previously mentioned City Resilience Index by the Rockefeller Foundation also give substantial insight as to the relationships of indicators. However, resilience here is also measured individually for each indicator. The holistic measure mentioned in the study focuses on preparedness, recovery, response, and adaptation. However, while this is mentioned, the study did not focus on the the system as a whole, and that time-dependency and long-term considerations are not factored (Rus et al., 2018).

What is notable with the diagrams made, when put side-by-side with Rus et al. (2018) structure of a city resilience index, is that there needs to be an overlap of the 5 dimensions mentioned to fully encapsulate resilience. While Shaw (2014) configures a more subjective approach to quantify resilience, Rus et al. (2018) introduces a mathematical quantification to normalize each indicator.

Studies that contextualize mathematical assessment such as in Khazai et al. (2018) and (Razafindrabe, et al., 2015) tend to use only questionnaires and geographic assessments to give value to their resilience scores. An insight based on their conclusions say that constant introduction of the questionnaires give a more dynamic perspective on measuring resilience. However, while participants' answers may change, the mechanism which they are recorded does not and remains subject to the participants' experiences.

When synthesizing the studies, Rus et al. (2018) takes into consideration the urban system as a whole, taking into account of the different groups, such as the population, demographics, infrastructure, socio-economic factors, as well as the ecosystem services that it gives. (Asprone et al., 2018) emphasizes what the previous authors tried to integrate into a model called the Hybrid Social-Physical Network (HSPN), bridging engineering resilience and ecosystem resilience. By defining the ecosystem approach, they stress that quantification of resilience needs to be done as a whole, as opposed to engineering resilience (Asprone et al., 2018). Therefore, this implies that given the studies, each has to be integrated to give a more holistic picture of resilience. The dynamism measured in the HSPN catered urban area does not just encompass the socio-economic factors and biophysical factors, but it also includes taking a look at the recovery of an urban system as a whole in terms continuous measurements, and not just static updates.

2.1.6 Ecosystem Services

2.1.6.1 Ecosystem Services Framework

The ecosystem services framework is an example of a more holistic approach to measure socio-ecological resilience. Measuring SER then follows a hybrid definition including environment - related services defined as "the underlying capacity of an ecosystem to maintain desired ecosystem services in the face of a fluctuating environment and human use" (Folke, et al., 2002). The framework takes into consideration feedbacks between human behavior, environmental conditions, ecosystem services, and human well-being (National Research Council, 2013). The Ecosystem Services approach provides us a way for understanding the complexities and interdependencies of human-natural systems (Alberti, Marzluff, 2004)

There are also certain relationships between resilience and delivery of ecosystem services that are given emphasis under this framework. Some ecosystem services are said to increase the resilience of social - ecological systems. The changes brought about by different drivers and the ability of a system to absorb these disturbances are measured through its delivery recovery. What makes the system resilient is in the speedy recovery of the ecosystem services after a system was subject to a periodic disturbance. High recovery rate allows a continuous delivery of desired ecosystem services matching their respective demand. Therefore, the resilience in social-ecological systems depends on the feedback between the ecological and human communities in regard to ES delivery.

Quantifying ecosystem services was first done using a hierarchical typology made by TEEB. The typology separates the ecological processes from the actual benefits that are dependent upon these processes (Balmaford, et al., 2008). Ecosystem services benefit was defined as the end product used directly by humans and therefore, also desired by humans (Elmqvist et al., 2011).

Ecosystem services are categorized into four types based on their functions as defined by MEA (2005). The first category is provisioning services which is defined as the goods that can be extraction or consumed from ecosystems or can be valued in markets such as water, food, wood, and biofuels. The second category is regulating services which refers to benefits derived from ecosystem processes that modulate conditions experienced such as regulation of climate, soil fertility, or flood regulation. The third category are the cultural services or the intangible benefits that emerge from interactions between humans and ecosystems such as spiritual, aesthetic, and cognitive development. The fourth category refers to the supporting services which permit the delivery of the first three categories and is considered the fundamental ecosystem processes such as photosynthesis, nutrient cycling, habitat provisioning, and evolution.

2.1.6.2 Provisioning Services

TEEB (2018) defines provisioning services as the material and energy outputs in the system. The typology of TEEB lists four main materials under the provisioning service which include food, raw materials, freshwater, and medicinal resources. In assessing the provisioning services in the context of urban ecosystem services, studies mostly focused on food, water, and energy (Haase et al., 2014; Sieber & Pons, 2015). Out of all these, energy supply appears most frequently in different literature compared to the rest (Haase et al., 2014). The study done by Balvanera (2016) lists down other key services such as crops, livestock, aquaculture, fisheries and harvested wild goods but majority are often not found in urban ecosystems. Provision of goods constitute the basic needs for human sustenance contributing to their overall well-being, therefore increasing resilience. The problem with current literature is the lack of a standardized approach for the provisioning and demand assessment given that the demand side has yet to be fully studied, therefore multiple proxies and methods are needed (Haase et al., 2014). Additionally, meeting urban demands for ES delivery such as food, water, and energy can only be fulfilled under a geographic scope that goes beyond the cities' boundary (Folke et al., 1997, Gómez-Baggethun and Barton, 2013) which adds further complexity as to how demand can be measured. Major materials under the provisioning services that have a wide array of literature involve food, water and electricity.

In terms of food production, the use of peri-urban farm fields, rooftops, backyards, and gardens (Andersson et al., 2007) as well as urban agriculture and urban farming services (Sieber, Pons, 2015) is mentioned in most literature. When it comes to measuring food production, the biophysical indicator used for food supply is tons per year (Gómez-Baggethun and Barton, 2013). Studies to determine potential food production include land use data to determine changes in urban forest and green urban area cover over time given that they are food sources for the city (Grunewald & Bastian, 2017). Aside from analyzing food production services associated with land use change, there are also studies that focus on food security specific to households which are measured using food consumption and nutritional status over time (Jones, Singels, & Ruane, 2013). Studies on food supply are minimal given that cities produce only a small share of the food that they consume and majority are obtained from other areas to meet their demands (Folke et al., 1997; Ernston et al., 2010) thus, requiring the use of proxy indicators to assess food provision such as food security indicators. In the Philippines, the food threshold is measured as the minimum expenditure needed for a family/individual to meet their nutritional requirements of about 843 – 1,195kcal (FAO,nd) which is estimated to be 1,266P on average monthly (PSA, 2015).

In terms of water production, common indicators for freshwater provisioning include groundwater recharge (Haase, 2009) and demand and provisioning of freshwater (Fitzhugh & Richter, 2004). Other indicators used involve water use per sector divided between water withdrawals from different natural water supplies such as surface water and groundwater and water demand such as public use, agricultural use, livestock water use, energy use, and water consumption per capita (Karabulut et al., 2015). These indicators were applied in studies that contained watersheds or nearby ecosystems with sources of freshwater such as the study done by on the New York City Watershed and that of Karabulut on the water provisioning of the Danube river Basin (Karabulut et al., 2015). For cities found in Metro Manila where there are no nearby watersheds, proxies are needed to assess water provisioning. The National Water Resource Board (NWRB, 2012) enumerates indicators associated with water production development such as withdrawal rates, location and consumptive use, conveyance rate & losses, and reclaimed wastewater. Water supply is dependent on surface water, groundwater, and water budget which falls under biophysical data (NWRB, 2012). Water demand is based on household demand reflected in data provided by the MWSS (Inocencio & David, Understanding Household Demand for Water: The Metro Manila Case, 2019). Therefore, in choosing indicators for different literature, water provisioning was divided into two main parts one for quality and one for quantity as each have varying pressures brought about by urbanization (Grizzetti et al., 2016). The proposed basic water requirement per household for an estimated 6 per family is 54 l/c/d in the Philippines (Inocencio et al., 1999).

In terms of energy, there are literature that deal with energy flows closer to how they are framed in natural ecosystems (Brunner, 2007; Zhang et al., 2012). Other studies have focused on a supple and demand ratio for electricity consumption (Kroll et al., 2011; Lundy & Wade, 2011). There is a lack for the second type of study given that the goal of most energy ecosystem services study is to assess the ecological footprint of energy flows (as material productions) in cities. In another study using electricity consumption, sustainable goals were associated with energy through the its efficiency and demand, which is why indicators are chosen based on these two concepts (Bai, 2016). This can be applied when framing electrical consumption in the context of its end-users such as how electricity is supplied to power and transport which are crucial for cities to function. In terms of lifeline rate and levels, the Energy Commission Regulatory board sets a maximum consumption of 15 kWh for the marginalized sector and 75 kWh for small-big industries (Energy Regulatory Comission, 1998).

2.1.6.3 Regulating Services

Regulating services are defined by the TEEB (2018) as the services that maintain the quality of air, soil, providing flood and disease control, and pollination of crops. Under the TEEB typology, services include local air climate quality, carbon sequestration, moderation of extreme events, waste-water treatment, erosion, biological control, regulation of water flow, and pollination. These services modulate the conditions which people experience (Balvanera, 2016). As such, this type of ES includes all the benefits obtained from the regulation by ecosystem processes: the regulation of climate, water management, and human diseases associated with flooding, air pollution, and wastewater (Gómez-Baggethun and Barton, 2013).

When collating literature on the various ES in this category, the MEA classifies these ES intro four major categories: climate regulation, water purification, pollination and erosion control. However, this might not be enough to describe the extent of what cities may actually provide. Balvanera (2016), Bolund and Hunhammar (Bolund & Hunhammar, Ecosystem services in urban areas, 1999), and TEEB also include urban temperature regulation, moderation of climate extremes, drainage, flood regulation, and solid and water waste treatment. (Gómez-Baggethun and Barton, 2013). Given these, there seems to be similarities with some of the indicators of ES applied in the natural ecosystems with that of the man-made services in the city. Similar indicators include the extent flood management using changes land cover data and amount of wastewater treated from greenspace to treatment plants.

Firstly, climate regulation services are crucial in maintaining conditions that are conducive to life on Earth. This talks about the influence this type of ES has on global climate change, measured by the concentration of greenhouse gases (GHGs) in the atmosphere (MEA, 2005; UNEP, 2004). The types of ES described by Balvanera (2016) and Gómez-Baggethun and Barton, (2013) that enumerate ES such as urban temperature regulation and moderation of climate extremes fall under this category in terms of how they deal with global climate change. The indicators mentioned in the literature gathered from TEEB, the Common International Classification of Ecosystem Services (CICES) and Kiel University point to the reduction and regulation of carbon and other GHGs in the atmosphere (Muller, et al., 2016). Kiel University measure this regulating service through carbon sequestration in vegetation. These indicators were chosen for all the sub-categories in climate regulation because of how the concentration of GHGs in the atmosphere produced by urban ecosystems directly influence how much heat is trapped in. In the long term, the reduction of GHGs may also influence the reduction of climate extreme such as extreme global warming which may cause sea-level rise. Studies on urban green spaces and forests utilize indicators and concepts like these and talk about the ability of these to purify or reduce emissions in an area (Baró, 2017); (Pataki et al., 2011). While there are no minimum standards for GHG emissions, there is an encompassing agreed made by the Philippine Climate Change Commission to reduce emissions by 70% (USAID, 2016). GHG mitigation goals would vary from city but the protocol often includes setting a fixed level goal by a set year (WRI, nd)

Second, water regulation services describe the “influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge,” particularly in terms of the water storage potential of the ecosystem or landscape (Bolund & Hunhammar et al., 1999), 1999, MEA, 2005). In that sense, what this regulates is not the provision of water per se, but the capacity to provide for quality potable water resources available such as water retention and water purification via waste management as well (Grizzeti et al., 2016). Another function of water-related regulating services also determines the functionality of other ES such as removal of pollution (Coates, et al., 2013). In the context of coastal cities, these types of systems deal with faulty drainage due to poor solid waste management that hinders water flow, which should serve as pollution removal and flood buffers in lieu of natural vegetation and soils (Robas, 2014; UNEP, 2010). That being said, this service is influenced by the amount of flow (both in and out) of water and the waste it carries. Balvanera (2016) uses the natural indicators such as flood volume that is naturally buffered by said vegetation, however, this would require understanding various flood models as well. Water quality standards and effluent standards subscribe to the guidelines set by the Environmental Management Bureau (Gonzales & Cleofas, 2016).

Third, air quality regulation refers to the service provided by the ecosystem to influence local climate and air quality (TEEB, 2018). The industrial processes and anthropogenic sources of air pollutants which end up in the atmosphere, bodies of water or vegetation serve as the sink to the sources which these air quality regulation targets (Bolund and Hunhammar, 1999, MEA, 2005). Air quality is mainly influenced by the inflow and outflow of air in terms of air change rate within a system and as well as the amount of “filtration devices” it has that help in the outflow of pollutants. Additionally, the capacity of an ecosystem to regulate air quality is also influenced by the inflow of pollutants which occur from the industrial and mobile processes in city systems. In the urban context, main contributors to emissions and pollutants include the transport sector (European Comission, nd). Much like in climate regulation, indicators used focus on carbon sequestration as well (Müller et al., 2016; (Kiss et al., 2015)). Like in the previous section, vegetation is key in this filtration and sequestration because the area of urban forests is a useful indicator for the possibility of regulating air quality. Green spaces also have a part to play in air purification (Baró et al., 2014; Pataki et al., 2011). Bolund and Hunhammar (1999) stress the importance of tree cover and that rapid growths of urbanization may result in higher rates of deforestation as well. In the Philippines, standards subscribe to the guideline set in the National Ambient Air Quality Guideline Values (NAAQGV) which sets the values for Total Suspended Particles, PM10, PM2.5, Sulfur Dioxide, Nitrogen Dioxide, Ozone, Carbon Monoxide, and Lead (EMB, 2015).

2.1.6.4 Cultural Services

The cultural ecosystem services (CES) account for the non-material benefits obtained from nature that are essential for human health and well-being (MEA, 2005). CES is formally defined as non-material and/or socio-ecological benefits people obtain from a contact with ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (MEA 2005; TEEB 2018). Recreation accounts for reducing stress, thereby improving human health and well-being (Grunewald & Bastian, 2017). Aesthetic benefits target the psychological benefits that enrich human life (Haase et al., 2014). Cognitive development helps promote environmental stewardship by promoting stronger recognition for different ecosystem services. This may fall under education which improves resilience by increasing adaptive capacity through continuous learning. Place value and social cohesion refers to attachments which promote preservation to different green spaces.

Out of all the ecosystem services, Limited attention has been given to (CES)–particularly in urban contexts (Hernández-Morcillo et al., 2013; Tengberg et al., 2012). In the review of La Rosa et al. (2015), literature on CES have four general categories such as social values, constituents of wellbeing, public goods, and contribution of peri-urban woodlands to well-being. The review by La Rosa (2014) mentioned the lack of CES indicators that are relevant to the urban contexts given that urban environments play a minor role within current ES assessments. There is currently only one study which looks at tourism as a potential indicator under cultural services.

Most parameters for cultural service use educational value and communication as indicators (Lundy and Wade 2011). Other indicators involve measure of greenspace, number of tourists, willingness - to - pay, human health, recreation, real estate value, and money flow (Haase et al. 2014). These indicators were chosen based on the underlying elements of the ecosystem (cognitive benefits obtained) as well as services used by humans. Additionally, there were chosen based on their contributions to social capital and social well-being (MEA, 2005). Correlation can be seen with areas with green space (serving as recreation) to having a high density of visits as in the case study of Sieber, Pons (2015) which explains why it was chosen as an indicator for both aesthetic and recreation. The review of La Rosa et al. (2016) collates different literature which contain a set of indicators and among them, common ones involve park visitations, area for greenspace, willingness to pay, ecotourism and recreational potential, and accessibility to parks.

The review of Haase et al., (2014) mentions that there exists a knowledge gap for both cultural and provisioning services. Rarely considered parameters include aesthetic, inspiration for culture, regional identity, and spiritual awareness given that they are intangible and difficult to measure. The review by (Milcu et al., 2013) looks into alternative methods for valuating ecosystem services such as monetary valuation, land percentage of protected area, and donations to conservation agencies. The problem of monetary valuation is the use of noneconomic deliberative techniques such as surveys which was argued to be appropriate as they reflect the relationship between users and the specific cultural service (Milcu et al., 2013).

2.1.6.5 Supporting Services

Supporting services ensure the continuous production of all the other types ecosystem services. How they differ from the other services is that impacts are either indirect or occur over long periods of time (MEA, 2005). Supporting services are concerned with landscape connectivity and habitat delivery offered by cities (Milliken, 2018). The review of Haase et al. (2014) mentions that there is only one study that examines the effects of urbanization on supportive service mainly, the pollination of plants by bumble bees done by Jansson and Polasky (2010). Strategies for urban sustainability deal with increasing biodiversity which is associated with increasing ecosystem functions (Milliken, 2018) to increase resilience to environmental change. Given this, the supporting services deal with how configuring the urban landscape to a higher degree of heterogeneity can therefore increase the delivery of different types of habitats (Andersson et al., 2007). The only study that mentions human habitation is from the MEA (2005) regarding the different categories of which includes urban described as built environments with high human density.

Currently, studies done on this type of ES are focused more on habitat delivery and biodiversity rather than land space (Haase et al., 2014). Urban biodiversity incorporates urban approach in assessing supporting services. Thus, supporting services often go together with cultural services given that infrastructure and recreational opportunities must reconcile with preservation of green space and biodiversity (Grunewald and Bastian, 2017).

Land space allows for the delivery of other ecosystem services as well as for economic, commercial activities, and housing. Studies in urbanization look into urban soils and nutrient cycling as one of the key services provided under this category (MEA, 2005). The study done by the USDA looks into soil data such as soil types, soil properties, spatial distribution and relationship with social, hydrological and vegetation (2013). In the urban context, land space can be separated between land cover of the surface and built up area. Land cover of the surface includes surface types whether it is agricultural, greenspace, or built up (cemented). Built up area can be divided between industrial, commercial, residential, and recreational.

Water balance is another supporting service associated with meeting the demands of water provisioning. It deals with accounting for transpiration, interception, and water run-off as indicators for assessing the supporting process (Pataki et al., 2011). A better understanding of balance water regulation ES can come from the current state of waste management in the city and the amount of urban land cover coupled with the regular water flow in the context of the city, as this tells the amount of waste and infrastructure. When contextualized in the urban setting, water balance could refer to alternative water sources for both potable and non-potable water sourced locally. These include groundwater, surface water, rainwater, and greywater which involve appropriate treatment facilities to be made available for household use and consumption.

Urban biodiversity describes not only the biodiversity of the different fauna that can be found in the urban setting but also how it affects its constituent human population. This coupled interaction underpins many of the other ES because of how it affects all the other services; that is, biodiversity can affect the processes of the other ES which contribute to the well-being of the human population (CBD, 2010; Zari, 2018). In most cases, this means the health of the human being. Biodiversity then becomes the backbone of life-sustaining goods and services which provisioning, regulating and cultural services provide (UN CBD, 2010). That being said, changes in biodiversity have impacts, whether through explicit, synergistic links or implicit, less-direct links, on human physical and psychological health, as well as cultural health (Zari, 2018). Much of biodiversity have been studied to be appear in urban cities but in an altered state due to various anthropogenic activities such as land-use change and biotic exchange which contributes to introduction of invasive species.Various indicators deal with the amount of green spaces that preserve biodiversity (Zari, 2018). However, this also entails use of more land space (Grunewald and Bastian, 2017).

2.1.6.6 Urban Ecosystem Services and Urbanization

In ecosystem services studies, the general practice would be to classify the different services of the selected system into the four categories defined by the Millennium Ecosystem Assessment (2005), mentioned in the previous subsections.

Contextualizing ES as UES or in the urban setting has been analyzed in the review by Gómez-Baggethun and Barton., (2013). Framing of ES from pooled literature is contextualized in the urban setting by first defining the extend of an urban ecosystem as well as the scope of its services. The classification of UES follows the same framework as ES wherein relevant ones were placed under the respective typology proposed TEEB. The difference is how the ES were adapted to include contribution to services specifically provided by urban ecosystems namely man-made services such as urban cooling, peri-urban agriculture, noise reduction, and runoff mitigation. To further illustrate the difference, an example would be in the changes in population have certain effects on the delivery of ES. Increase in population would require a higher demand for food, water, and energy supply under provisioning service (MEA, 2005).

These services address problems specific as well to the urban setting such as impermeable surfaces leading to increased water runoff, increase noise, higher temperatures and air pollution from increased emissions, and waste from urban effluents. What is lacking in the article is the consideration for services that do not consider ecological infrastructure such as treatment plants and powerplants as well as crucial supporting services such as land use management.

2.1.6.7 Ecosystem Disservice and Sustainable Indicators

There is a lack of consideration for sustainability in majority of the indicators used especially those under provisioning (Haase et al., 2014). Found in (National Academies of Sciences, Engineering & Med, 2016) is a metareview of the different urban sustainability indicator sets and metrics such as The North American Green City Index, Urban Sustainability Indicators, Sustainable City Index and Sustainability and Urban Development Indicators. Among the different indicators used in the indices, environmental indicators chosen could be framed under the different types of ecosystem services such as provisioning, regulating, and supporting mostly for the mentioned indicators of land, air quality, water, greenhouse gas emissions, and waste. Sustainability was then operationalized by collecting consumption data for the provisioning type of indicators, emissions data for the regulating type of indicators and production plus land use for supporting indicators. These were then compared to standards as there were mentions of greenhouse protocols, air quality standards, water quality, percentage of waste produced and recycled, and rate of urban sprawl. The goal of the indicators in terms of sustainability were to make them integrated to city sustainability goals and objectives by addressing actionable issues in the city when it comes to development.

In framing ecosystem services as indicators of sustainability or the sustainability of ecosystem service yields, it is crucial to consider the trade-offs between them. Trade-offs exist because it is impossible to manage ecosystems to simultaneously maximize all its services (King et al., 2015). In the study of King et al. (2015), most trade-offs occur within the provisioning services as it requires modifying the ecosystem to provide the needed material which could result in a decline of regulating services due to declining ecological integrity. As such, considering trade-offs can serve as guides for resource management development, and planning which are a crucial in city systems. Contextualizing the trade-off situation in an urban setting, land use management associating with urbanization serve as the main altering driver ecosystem change and therefore, certain changes also occur with the services they provide. Increasing studies are now being made on ecosystem services and their trade-off analysis in association with land use given that specific trade-offs arise from particular land use management decisions (Deng et al., 2016). While providing various opportunities for management and policy, there are few studies that explore trade-off analysis given the complex interactions between ecosystem services as they are not interdependent of one another (Deng et al., 2016).

2.2 Systems Thinking and Resilience

2.2.1 System Dynamics

A system is a set of variables that are interconnected. Each of the variables has influences on the other variables which help make a system functional (Meadows, 2008). Like anything that has a relation to another thing, if a system were to run for a time being, whether driven by outside constraints or within the system itself, changes can be noticed in the behavior of the system. This is why, when looking at a system, it is important to look at the interconnections: the system is not just a sum of its parts but a collective system function over time Meadows, 2008; Ford, 1999). From this, the term system dynamics is derived.

With that, modeling systems can serve to represent aspects of these real systems in a more substitutable way such as miniaturization or through computed-generated modelling (Ford, 1999). Specifically, computer-generated models help represent these interconnections of systems by simulating descriptive graphical analyses which generates behavior over time. This can map out the interactions of the variables given various feedback using mathematics as its language (Ford, 1999; Martin, 1997). This feedback is defined as the information gained about system performance after various parameter configurations (Ramaprasad, 1983). These mechanisms test the integrity of the systems, whether through reinforcing (or contributing) an initial variable or balancing (or stabilizing) its amount, in how it responds given various feedback (Meadows, 2008). These feedback mechanisms, whose behaviors are measured in the long term along with the entire system serve to work as an entire system, then, and not just the sum of its parts. This means to say that while system dynamics has the ability to track and describe changes in system behavior over time, this behavior can only be measured accurately depending on how the model was structured.

Furthermore, the components of these models comprise of the stock, or the variable that accumulates over time, the flows, or the variables that take away or add to the stocks, and the auxiliaries, or the variables that influence that flows, which all can be affected by feedback.

All these contribute to a better understanding of how a system works—not only in its inputs and outputs, but in other trade-offs and drivers that may hinder or facilitate system performance (Meadows, 2008; Ford, 1999; Maxwell et al., 2016). As an effect, modelling helps people understand complex systems as a whole (rather than just one individual phenomenon) that are also dynamic.

2.2.2 Using System Dynamics to Model Resilience

From an overview of modelling from Ford and Meadows, the environment is also another system that can be modeled. Paying attention to the natural environment or even to just the surroundings, contain a lot of things that can be seen as systems (Ford, 1999). A TV is system of all its working parts from its plug which provides it with an inflow of electricity to the output which is the display. Systems can also be political in nature such as the justice system and the like, or even economic such as resource allocation and distribution. With that, the definitions of resilience provided by Alberti, Marzluff, Holling and Gunderson help solidify that arguments on resilience and the environment involve complex dynamics that change over time. From this, it can also be seen how urban resilience can be treated as systemic and dynamic in nature. Such system includes the complex interactions between the socio-economic and biophysical factors which should not be taken separately, studied by Alberti and Marzluff (2004).

Identifying feedback mechanisms within these critical interactions is key for assessing the factors within the system that affect itself as well as for early detection of possible effects that may happen in the future (Martin, 1997; Maxwell et al., 2016). Failure to recognize and understand feedback mechanisms for detection restricts success and proliferation of systems to thrive in a management perspective (Maxwell et al., 2016). On the level UER, then, feedback can help modelers depict the trade-offs accounted for in an urban ecosystem, especially in the delivery of their services (Balvanera, 2016). In the construction of such type of models, modelers should consider these especially when talking about the drivers that affect the balance in the 4 UES such as rapid population growth or in impermeability of spaces due to floor change.

As such, the challenge despite considerations is that defining, and modelling resilience in terms of these four UES is not the only hurdle but the way to do so also varies per context and is observer-dependent (Helfgott, 2018). While resilience is a pressing topic globally, across disciplines and sectors, definitions do not come to a universal agreement (Helfgott, 2016). Many studies have treated ecosystems and social systems independently, which is why there needs to be something that unifies these systems in a way that accounts for the definition of urban ecosystem resilience over vast literature. As such, Helfgott (2016) and Rus' et al. (2018) definitions in framing resilience seem to come to an agreement in that many types of behavior describe resilience such as robustness/resistance, stability/recovery and adapting/benefitting. It stresses that if a system is able to withstand impacts, recover and adapt and transform in the face of a disturbance, it can be classified as a resilient system (Walker et al., 2004; Helfgott, 2016).

This means that UER needs to be given more attention, especially in characterizing the changes behavior of the city systems. Contextualizing resilience according to the local area such as a city may also give rise to specific feedback mechanism other city system may not have. Developing an umbrella model for multiple city systems may come into conflict with another modelers definition on how to construct such model, not to mention the local people who may also not agree. Thus, aside from vast literature, there needs to be careful consultation with the communities or bodies that might end up adapting such models. In summary, then, framing UER using system dynamic modelling should describe the nature of how the 4 UES's responds and reacts to certain feedback over time.

To give more concrete examples, there have been several studies that tried to frame resilience using system dynamics. One that used such to model a city's risk management to a flooding hazard was conducted by Josol (2014) who modeled evolving and cascading physical hazards. This study focused on creating an index to model the impact of cascading hazards. However, insights may be drawn from this when considering all the different hazards a city may have and how their development plans may counteract these to become more resilient. To develop the physical hazard index model, what was considered besides the hazards were also the interactions between the hazard and the drivers of the human-environment systems when it came to climate-and-weather-related events. More specifically, this same model was used to track the delivery of the what can be considered UES in relation to environmental quality when faced with hazards (Josol, 2014). This implies that the UES are sourced from multiple sectors within the city which can also be affected hazards or disasters strike.

In the previous sections, Shaw's (2010) focused more on a social science lens to assess risk reduction, utilizing questionnaires. Josol (2014) approach, on the other hand, focused more on analyzing risk through a physical science lens, assessing environmental processes using a system dynamics approach. While Shaw's (2010) resilience assessment using spider diagrams may be more static, using a system dynamics approach like in Josol's (2014) helps describe future scenarios. This also proves that resilient systems are dynamic: observation and studies conducted on them in the short run do not capture the entire picture (Meadows, 2008). Both studies also agree that the idea of development defined in the previous sections stress the importance of sustainability and that this affects the quality of life in a city (Shaw, 2010; Folke et al., 2002). When comparing to the other tools for resilience in the previous sections, both Shaw's (2010) and Josol's (2014) theses prove useful in assessing resilience because they consider two perspectives needed in modelling resilience using a system dynamics approach. Josol's (2014) approach also proves to be useful in tracing the movement of the hazards through a system and how they modify the system. This is useful to see if a certain system can be graphically seen to transform or adapt when faced with a shock.

Other studies that used a system dynamics approach such as Simonovic & Peck (2013) modeled various spatial and temporal dynamics using their space-time dynamic resilience measures (ST-DRM) that considered a normalizing value for a city, from a range of 0 to 1 or higher, with 1 being an indicator of a resilient city. The considerations of the model also considered multiple disciplines such as economic, health, organizational and environmental (physical impact) however, modeled them separately.

Gotangco et al. (2016) adapted this general model that considered adaptive capacity. It introduced a variable called RHO which was defined as the "change in the system performance during a specific period based on the adverse impact and the adaptive capacity factors present to help cope with and recover from them" (Gotangco et al., 2016; Simonovic and Peck, 2013). This RHO was measured as a function of time to see its overall effects on a system's resilience. This study focused also on flood as the main hazard and served as the damage profile. This damage profile is defined as the variable that represents the amount of adverse impacts that would reduce a certain key stock. Both theses also focused on flooding as the main hazard, but described the hazard only. Combining both could give a greater context as how the interplay of the hazard and risk can define resilience, especially as to where the impact of this hazard would enter the system. Furthermore, Joakim et al., (2016) also derived their model using Simonovic and Peck's studies. This study focused on social vulnerability and social resilience which considered population and various drivers to quantify this social resilience.

Overall, a multi-disciplinary approach considering various interactions is still needed to understand the depth of the issue to be able to simulate non-static scenarios much like Josol's thesis (Simonovic and Peck, 2013; Alberti and Marzluff, 2004). Simonovic and Peck (2013) and Helfgott (2016) agree in a sense that looking at the system as a whole also means that resilience thinking should be comprehensive given the broadness in literature spanning both the biophysical and socio-economic processes. With the understanding of UER and the 4 ES, then, the interplay of UES using a historic and meta-analysis analysis and a long-term assessment can be modeled. This can be done using the other UES as variables instead, such as in the framing of the trade-offs prioritizing water provisioning over agricultural spaces, and not just urban greenery or social factors (Schetke and Haase, 2008).

That being said, if UES can be expressed as a combined synthesis of vast literature with the approaches in system dynamics of Gotangco et al., Simonovic and Peck, Joakim et al., Josol, Shaw and other studies in the way that Haase, Alberti and Marzluff (2004) define UES, then a more holistic model can be constructed. Attributing a scoring system such as in Rus' (2018) study to quantify trade-offs in a way that behave to affect each other can be used to capture which specific city functions may or may not be working in the long term. Model construction, coupled with contextualization and communication with relevant stakeholders, such as Helfgott (2016) suggests also plays an important role in localizing the issues of urbanizing cities. Finally, the concept of Urban Resilience such as in the City Resilience Index by the Rockefeller Foundation can also be used as a basis on how to further link the variables in the UES together as it describes an urban area to be interconnected to factors outside the ecosystem functions.

2.3 Urban Development Trends

2.3.1 Global Trends

Urban expansion, previously characterized as a slow process affecting cities, has suddenly seen an increase in the last thirty years (Angel, 2011). The phenomenon of urban population growth occurs on a global scale but recent studies have revealed that the bulk of urban expansion and associated land-cover changes is concentrated on a few select regions such as Asia, mainly in China and India (Seto et al., 2011; Seto K. , 2012). Urban population densities are observed to be four times higher in low income countries based on their averages (Seto, et al., 2014). As for urban land cover, Africa was expected to have the highest rate of increase of around 590% from 2000 to 2030 which are concentrated in areas near river bodies such as the Nile, coast of West Africa, and Northern shores of Lake Victoria. Currently, the largest change in total urban land extent has occurred in North America. Overall, the minimum global increase in land area is expected to be 58,000 km^2 between the years 1970 to 2000 (Seto et al., 2011). While urban land area – area for urban cities - covers a relatively small fraction of the Earth's surface, these urban areas are considered main drivers to global environmental change (Grimm, et al., 2008).

Mentioned in the study by Seto et al. (2012) regarding urban expansion, common drivers mentioned involve population growth and GDP, as well as associated demand by the growing population, serve as dependent variables for probabilistic studies (Seto et al., 2012). The relationship observed from global trends was that higher the population growth and economic growth rates were expected to lead to higher rates for urban expansion. These indicators were chosen based on how they contribute to the need for expansion; population growth requires increase in residential and supporting activities and economic growth is often coupled with the need for productive land and increased consumption of goods and services for those belonging to the higher income group (Seto et al., 2012). Therefore, uncertainties associated with globalization trends are due to the different trajectories for both economic development and population growth (Seto et al., 2014).

Urban development poses both benefits and risks depending on whether it is regulated. When urbanization is managed well, it can facilitate economic growth given that 80% of GDP is contributed by cities (Wallace, 2014). Additionally, efforts in urbanization studies have led towards attributing sustainability as a goal promoting innovation from ideas such as saving energy, proper land use, and resource management. The problem comes in the idea of rapid urbanization, especially in developing countries, as unregulated expansion leads to a growing fraction of the population without access to basic services (Florida, 2016). Additionally, due to the demands of the growing population, environmental resources are being depleted at faster rates.

2.3.2 Philippine Context

Urbanization in the Philippines is measured using the barangay classification system which follows three guidelines enumerated by PSA; (1) population has grown to 5,000 inhabitants or more (2) if it has at least one establishment with a minimum of 100 employees (3) has five or more establishments (2013). Proportion or urban population to total population was 43.5% (PSA, Urban Population in the Philippines, 2013). United Nations projections for Philippine Urbanization in 2030 and 2050 will be close to the rates found in countries within the Southeast Asia region (Navarro, 2014). Metro Manila along with Central Luzon and CALABARZON ranks among the most populous agglomerations in the world of about 24.6 million and is 100% urbanized (Ojastro, 2016).

Problems associated with rapid urbanization involve lack of appropriate service to match city expansion. Key problems involve shortage of potable water, inadequate sanitation, frequent flooding (lack of flood regulation services), poor solid waste disposal, and inefficient urban transport (Asian Development Bank, 2010). What serves to be the main driver according to different literature is the increasing population which in turn, causes certain long-term effects such as rising cost of production, limited access to land, and low affordability levels (Ojastro, 2016). Another study mentions that urbanization in Metro Manila is also driven by income inequality (higher income in urbanized regions) which has caused an increase in migration from rural to urban areas (Costello, 1996). Therefore, increasing urbanization requires major adjustments mainly in housing and employment provision, consumption patterns, and social interactions (Navarro, 2014).

Assessing the different development plans over the history of the Philippines serves to show the difficulties faced by the government in addressing urbanization. Different studies use the historical approach as a theoretical framework for studying urbanization trends which is commonly done for countries in the ASEAN region (Osteria, 1987). In the context of the Philippines, attention has been focused on licensing activities rather than strategic urban planning (Navarro, 2014). The basis for strategic planning comes from a mandated Comprehensive Land Use Plan CLUP which tends to focus on specific areas such as resident/commercial area development rather than the connectivity of the overall plan. Therefore, there is a need to frame CLUP in such a way that it allows for a long-term vision along with cohesive strategies towards interconnectivity of infrastructure going beyond political boundaries of cities (possible regional connectivity). The CLUP tends to be lacking in coherence given that it is articulated in such a way that development is fragmented and lacking in complementarity (Navarro, 2014).

2.3.3 Resilience Planning and Governance for Philippine Cities

The Act Creating the Department of Disaster Resilience was proposed under many different bills in order to uphold the population’s right to life by reducing the root causes of vulnerability through a Disaster Risk and Vulnerability Reduction Plan in a more science-based approach, including sensitivity when it comes to gender and culture (Salceda, 2017). However, this bill has yet to be approved. It has since been undergoing consultations and major revisions on it being passed as an actual government department, the Department of Disaster Resiliency (DDR). The bills, such as in the revisions of HB No. 195 and HB No. 6075, are said to be established as an agency that is clearly mandated to lead in the planning, monitoring, oversight and implementation of disaster-risk and vulnerability reduction and management, with focus on risk transfer and insurance. Patajo-Katipunan (2019) and HB No. 30 introduced also by Salceda stressed the importance of a collective action on capacity building in the long-term in rehabilitation and reconstruction, and development of risk-reduction plans. The proposed creation of the DDR was also pushed because of how outdated RA 10121 is in terms of management when faced with large-scale typhoons or calamities. HB No. 6075 incorporates a more science-based approach using tools such as GIS in improving the country's resilience and even includes ecosystem management and restoration (Salcedo, 2017 (Patajo - Kapunan, 2019).

At present, cities are mandated by the Philippine Disaster Reduction and Management Act (RA 10121) to mainstream disaster risk reduction and climate change adaptation in national and local development planning. RA 10121 shifts from a response-based approach to a preparedness in response paradigm. The first approach focused on short term relief such as post-disaster action and forecasting, and evacuation while the latter emphasized mitigation, post disaster support, and recovery. Under the law, cities are mandated to develop a local disaster risk reduction and management plan, which is aligned to the National Disaster Risk Reduction and Management Framework (NDRRM framework) and Plan (NDRRMP). The NDRRMP developed by the National Disaster Risk Reduction and Management Council (NDRRMC) provides for strategies and guidelines in dealing with disasters and emergencies. Implementation of the NDRRMP falls under the Office of Civil Defense which sets out goals to integrate the Local DRRM plans into the local Comprehensive Development Plans (CDP) and Comprehensive Land Use Plans (CLUP) that are also required in every city (NDRRMC, n.d). However, the OCD does not have a specific mechanism to ensure that this is followed. There is a need to strengthen capacity building in CLUP given that members of the planning team are not equipped with the skills to tackle issues in CLUP formulation such as analyzing different sectors (Salazar & Orale, 2016).

Aside from a national plan, the law also promotes development of capacities in disaster management at individual, organizational, and institutional levels (LSE, 2010). Strategies to increase capacity involve mainstreaming disaster risk reduction into physical and land-use planning, budget, infrastructure, education, housing, health and environment, and other sectors (LSE, 2010). A related document to the CLUP and the CDP is the Annual Investment Plan (AIP) which programs and allocates annual budgets to programs, projects, and activities identified in the CDP. Other documents an LGU must provide includes the Local Climate Change Action Plan (LCCAP), which is required by the Climate Change Act of RA 9729. The plan is deliberated and evaluated by the Climate Change Commission when LGUs apply for the People's Survival Fund to finance climate change adaptation measures.

Other requirements mandated by RA 10121 include having a Disaster Risk Reduction and Management Office (DRRMO) in every province, city, and a municipality as well as a Barangay Disaster Risk Reduction and Management Committee (BDRRMC). Benefits derived from said act also include the advantage of having a National and Local Disaster Risk Reduction Management Fund (NDRRMF and LDRRMF). The NDRRMC advises the Office of the President in calamity fund allocation and oversees management operations (RA 10120, 2010). Budgets to the Office of Civil Defense and the NDRRMC then also need to be correctly allocated, lest the misuse of resources.

2.3.4 Pasig City

Geographically, Pasig City is flat, and is intersected by the Pasig River and the Marikina River. These two are facilitated by the Napindan Channel and Manggahan Floodway, respectively. With these 4, Pasig City serves a catch basin from all these bodies of water. Pasig is dependent of the different tidal estuaries and river systems located near the area to help in flood mitigation and drainage (Pasig City Government, 2015). Pasig River, considered as a tidal estuary, is dependent on the level of water in Manila Bay and Laguna de Bay. Marikina River serves as a tributary to Pasig River and helps control water levels via the Manggahan Floodway.

Pasig, deemed as the “Green City,” is bordered on the west by Quezon City and Mandaluyong, situated at the eastern border of Metro Manila as seen in Figure 2. Pasig is primarily residential, but with the Ortigas Center established in the 1930s being the central business district of the city, it has slowly grown more commercial. The accessibility and that the central business districts provides to its population and as well as those who want to work there have given rise to the high rates of urbanization in terms of migration. The rapid development that this incurs has made Pasig City one the most highly developed cities in Metro Manila (Robas, 2014).

Development plans have considered towards disaster risk reduction due to its experience with typhoon such as Ondoy which incurred massive economic loss as well as high casualties (Pasig City Government, 2014). The city constantly faces damage from deadly floods brought about by the *Habagat*, Despite having the Manggahan Floodway and Napindan Channel, climate change-related hazards such as flooding are exacerbated due to the lack of efficient drainage systems, asphalt and concrete paving, and deforestation (Robas, 2014). This is also worsened because a lot of houses were built along the riverbank, effectively blocking water flow in and out of the Laguna de Bay (Pasig City Government, 2015).

With regard to the disasters experienced, the city’s development plans have been more tied to addressing climate change. Considering stakeholders such as PWDs, senior citizens, informal settlers and the like (Robas, 2014). Management and policy plans include lowering GHG emissions, implementing a solid waste management plan in the other sectors of the city. The city’s focus is also on energy efficiency and conservation, solid waste management, water management, ecology, urban agriculture, health and safety, transportation, and air quality (Robas, 2014).

Certain services were also mapped based on the classification of the 4 UES. This was based on the collected maps from the Comprehensive Land Use Plan (CLUP), the Local Climate Change Action Plan and the Risk Profile. These include the overall administrative map as seen in Figure 2, the land use map as seen in Figure 3 and the flood susceptibility map as seen in Figure 4. The land use map indicates the different categories of which land was used in Pasig City. The administrative map depicts the boundaries of Pasig, as well as the west and east banks of the city. Lastly, the flood susceptibility map refers to the area in Pasig City which were most prone to flooding.

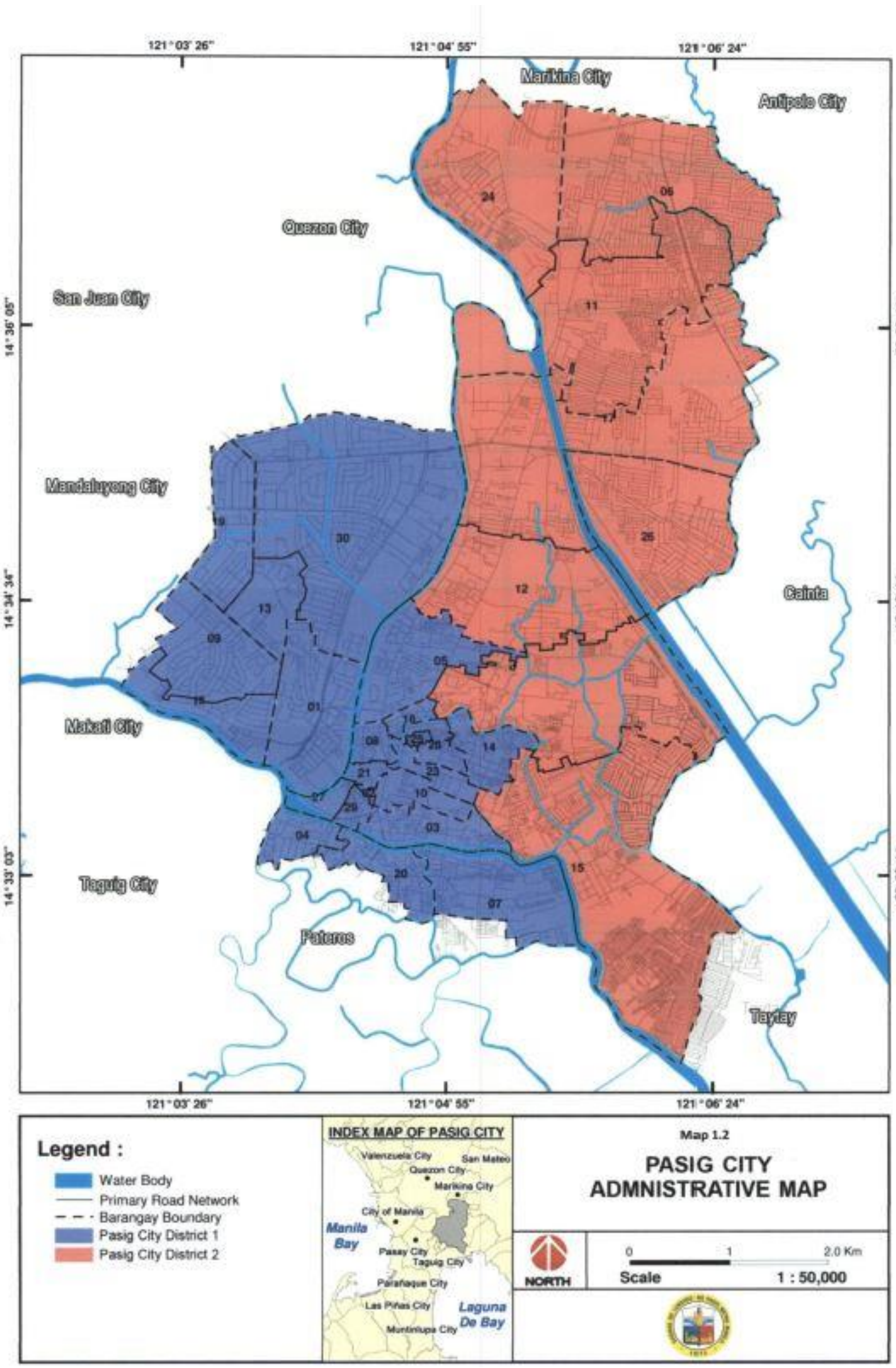


Figure 2. Map location of Pasig City in reference to Metro Manila. Taken From Pasig City CLWUP *(2015)*

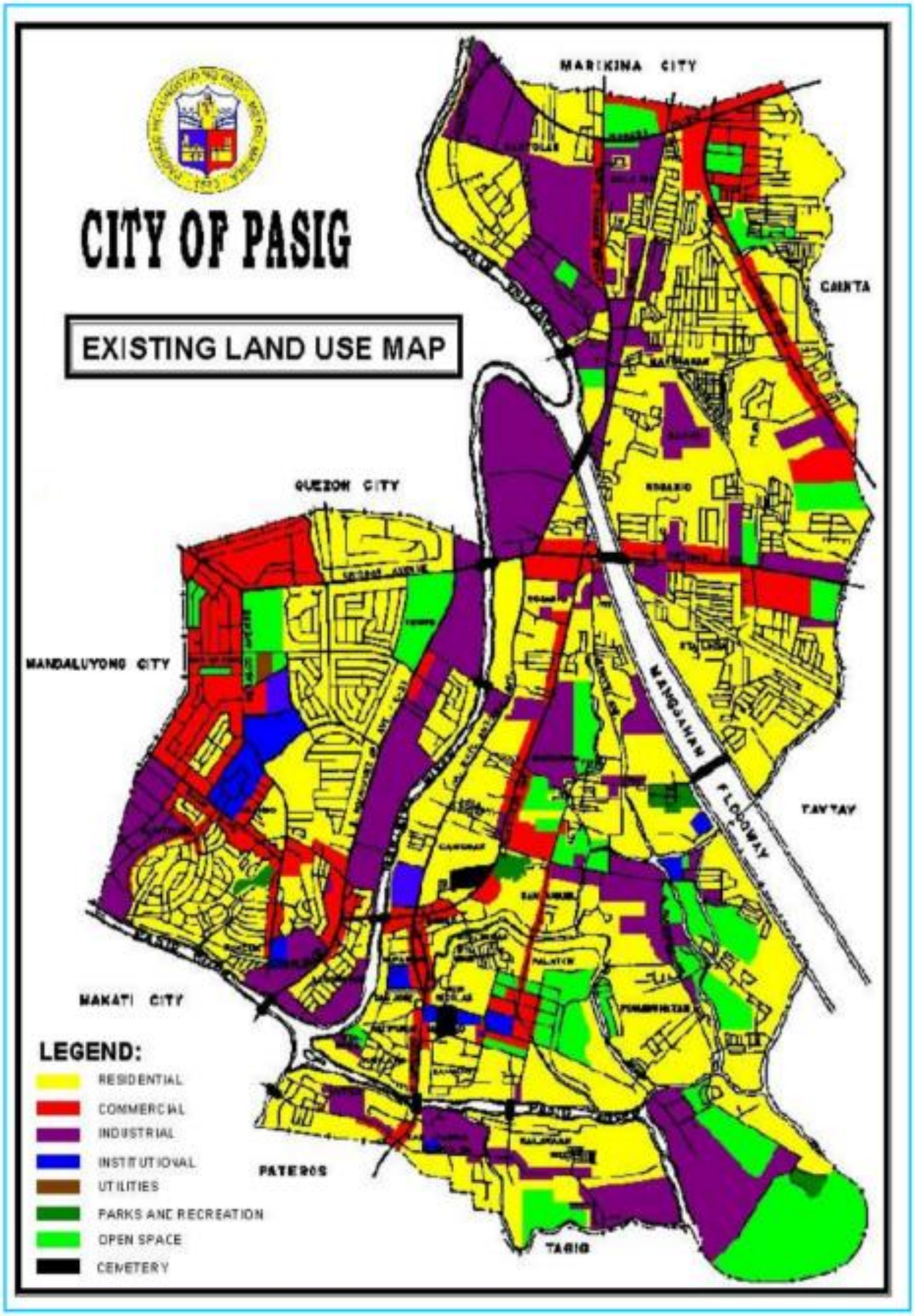


Figure 3. Pasig City Land Use Map. Taken from: Pasig City CLWUP (2015)

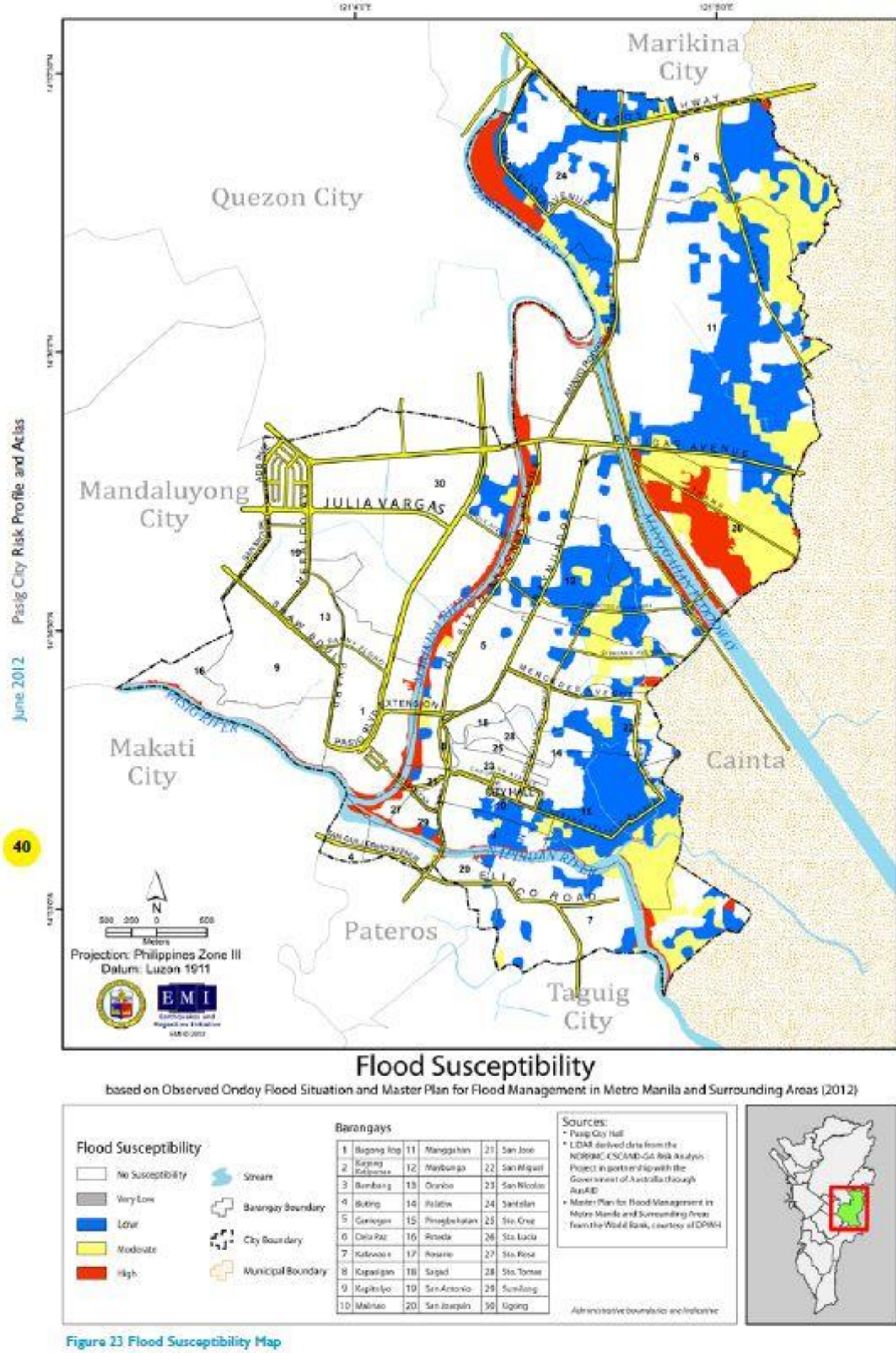


Figure 4. Pasig City Flood Susceptibility Map; Taken From Pasig City CLWUP (2015)

2.3.5 Valenzuela City

Geographically, Valenzuela is located north of the Philippine's city capital, Manila. It is a landlocked city composed of gentle slopes. The city is separated from Malabon by the Tullahan River, one of the major river systems in the city which is part of the Marilao-Meycauayan-Obando river system and considered biologically dead along with the Meycauayan River (CDIA, 2014). There are 3 river basins that contribute to the flooding situation in Valenzuela. As the city consists of a lot of low-lying areas, these river basins and other adjacent urbanized portions are exposed and are very vulnerable to rainfall and floods even if the effects of climate change are not considered. These basins and other bodies of water have several stressors such as uncontrolled land occupation or urban expansion, which potentially worsens aggravates the basins' condition (CDIA, 2014).

In terms of socio-demographic aspect, Valenzuela City, a highly urbanized area, which was once rural, is located on the northwest portion of Metro Manila, alongside Caloocan, Malabon and Navotas as seen in Figure 5. Aside from the high-density city with a population of around 625,000, the city also contains a large number of industrial establishments.

As a highly urbanized city, and being the 13th most populous city, the city has identified 3 major hazards namely, fire, flood and liquefaction (Valenzuela City Government, 2017). Existing flood protection plans consist of drainage, sewerage, and physical means of mitigation such as flood walls. Drainage experiences a lot of plastic trash especially at the intakes and a lot of the sluice gates are dilapidating. This contributes in clogging as well as a slower rate of pumping and discharging. Sewerage is recent and installation of sewage treatment plants will rely on the existing drainage system (CDIA, 2014). Additionally, there are also city processes that exacerbates hazards which include water pollution in the nearby waterways due to run-off of wastewater from both the industrial and residential. These waterways often overflow during storms or moderate-to-heavy rainfall, posing health and public risks. The waterways and rivers discharge water into Manila Bay. This also means that the city has a lot of low-lying areas (CDIA, 2014).

In response to the hazards and risks, recent resilience plans have focused on relocation of informal settlers off the riverside, as these are the areas that are most prone to flooding. The health sector and social welfare are also two things that this city looks, especially when talking about partnering with the private sector (Valenzuela LGU, 2019). Additionally, as of 2014, the Local Climate Change Action Plan (LCCAP) and the Comprehensive Land-Use Plans (CLUP) of the city both stress the importance of how land-use affects the impact of flooding. In the 2009-2018 CLUP, there has been an increase industrial zoning (Acurentes, 2009). Low-lying areas are an important part of water resource management and flood retention which is why conversion or perturbation must be kept at a minimum (Acurentes, 2009). To add, sewerage in the area is relatively new, and should be looked into as not to add to the disruption of water flow.

Certain services were also mapped consistent with the classification used in the study for the 4 UES. This was based on the collected maps from the Comprehensive Land Use Plan (CLUP), the Local Climate Change Action Plan and the Greenspace Report. The maps taken from the CLUP were seen in Figure 5, Figure 6, Figure 7, and Figure 8. Figure 9 was taken from the city's Waste Management Division. The land use plan indicates the different categories of which land was used in Valenzuela City. The greenspace and recreation spaces map show which parts of

Valenzuela City are of the respective land type. The flood susceptibility maps depicts those prone to flooding and their location on the map, and lastly, the existing MRF locations show where in Valenzuela the existing MRFs are located in.

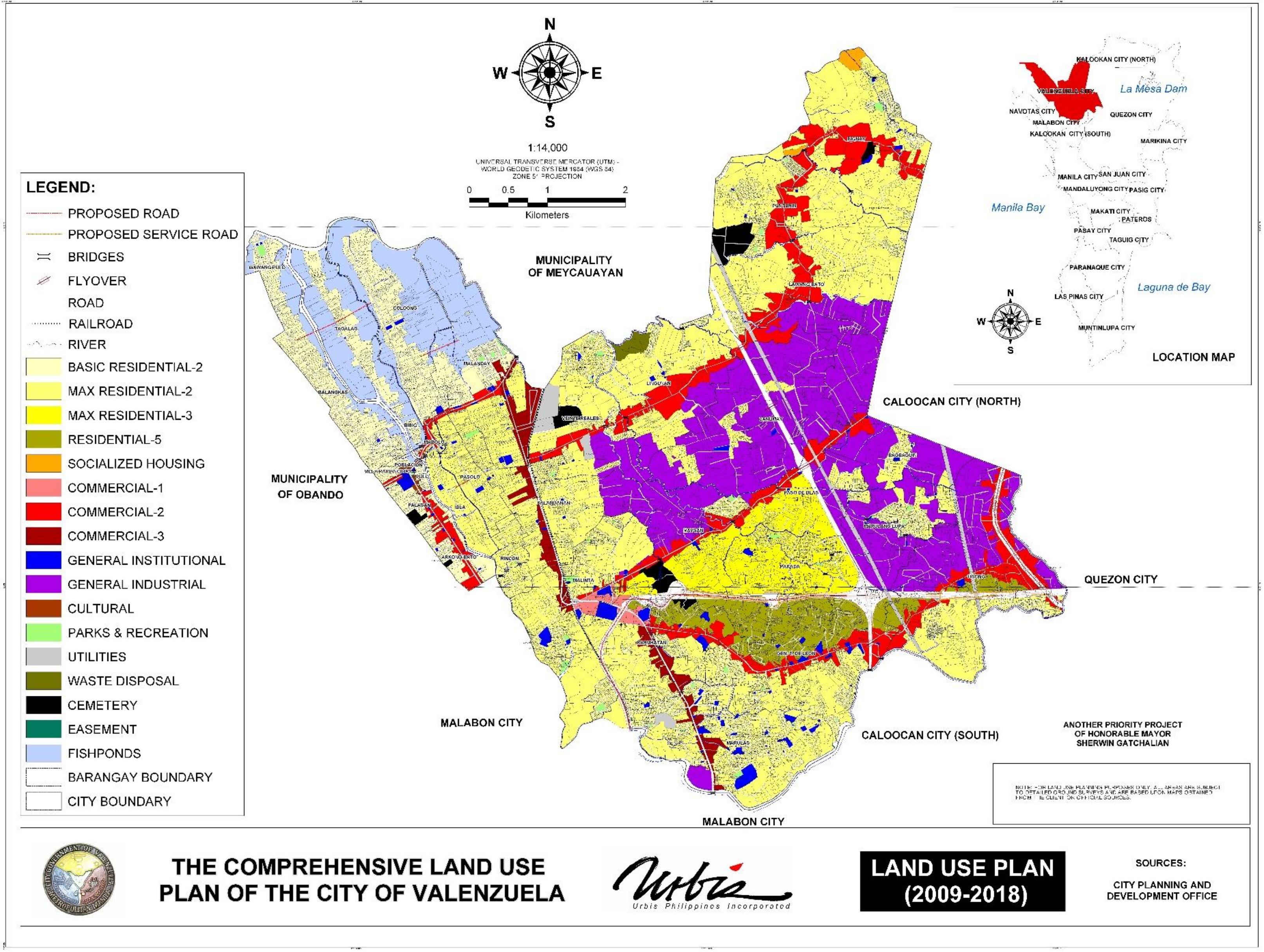


Figure 5. Existing Land Use Map of Valenzuela City; Taken from: Acurentes *(2009)*

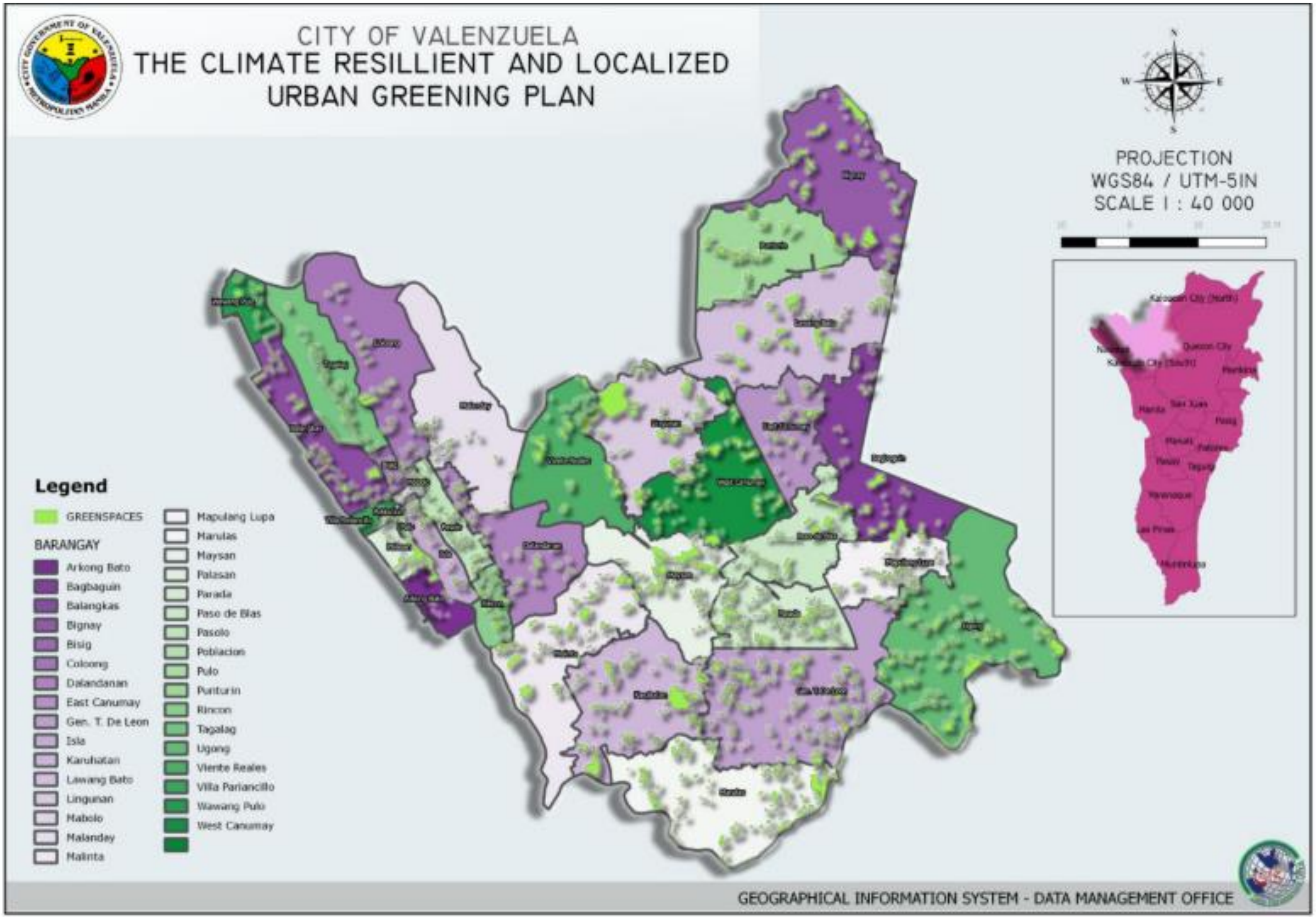


Figure 6. Greenspace Map of Valenzuela; Taken from Urban Greening Plan of Valenzuela City *(Valenzuela City Government)*

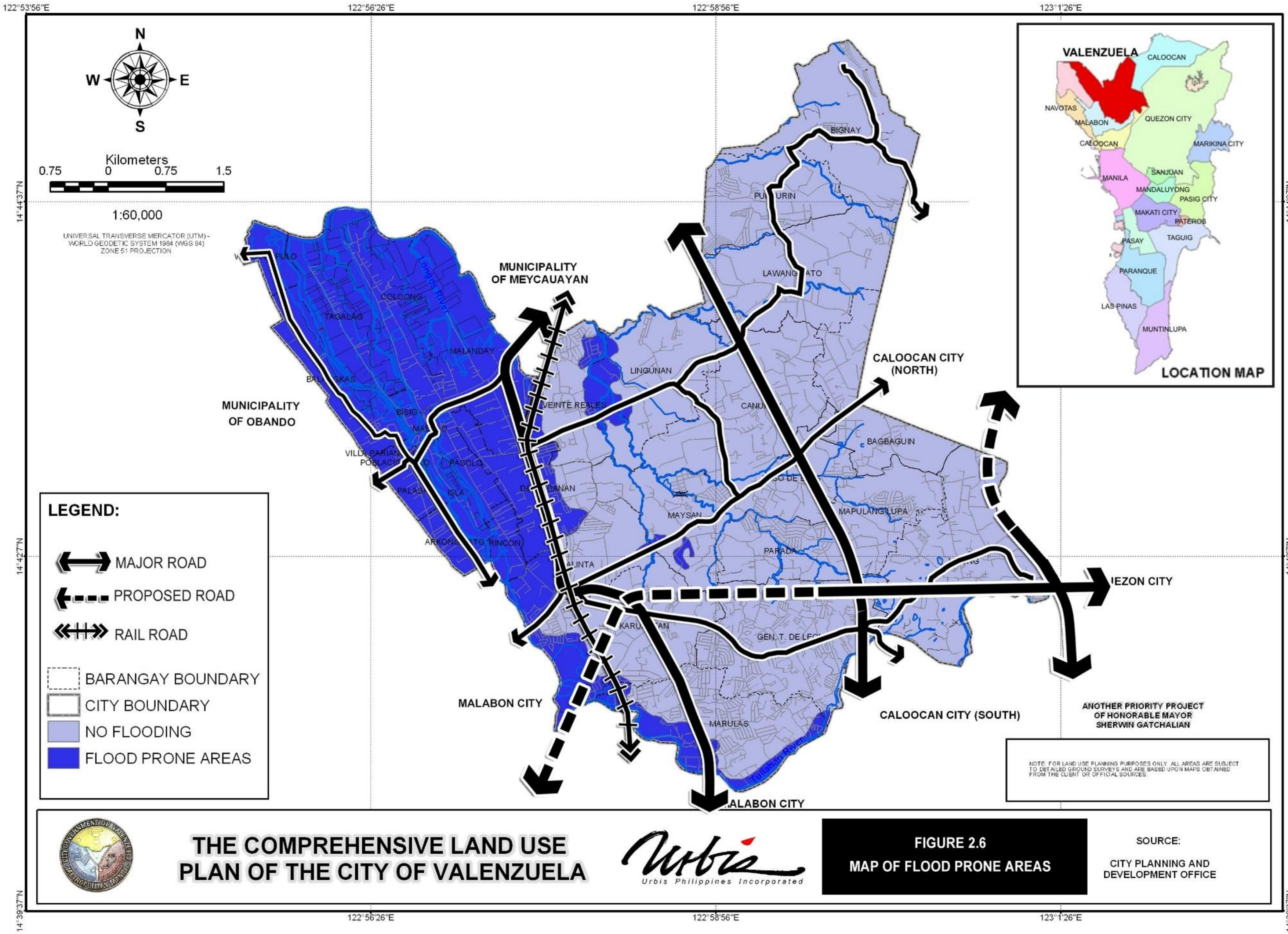


Figure 7. Flood Susceptibility Map of Valenzuela City; Taken from: Acurentes *(2009)*

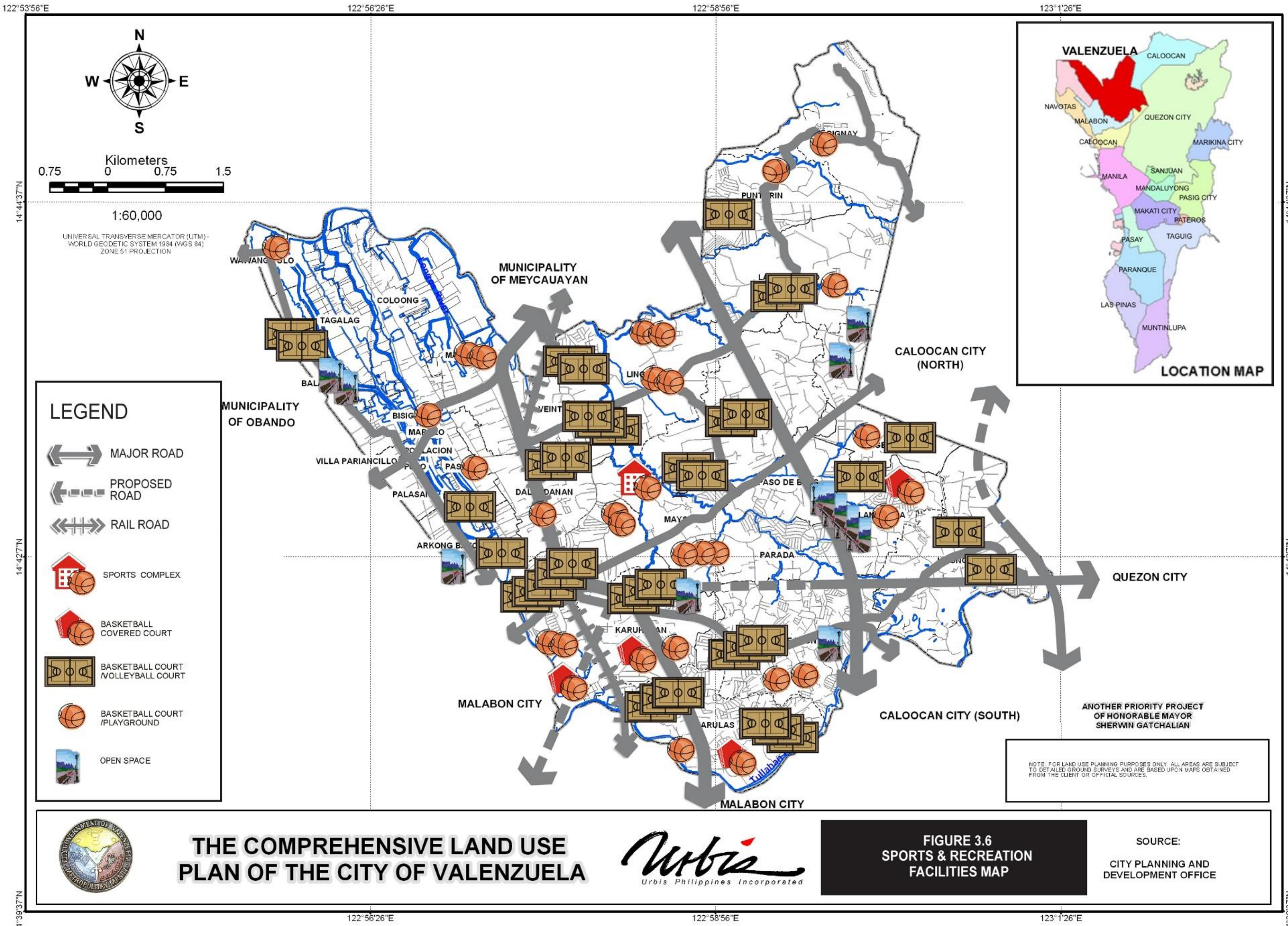
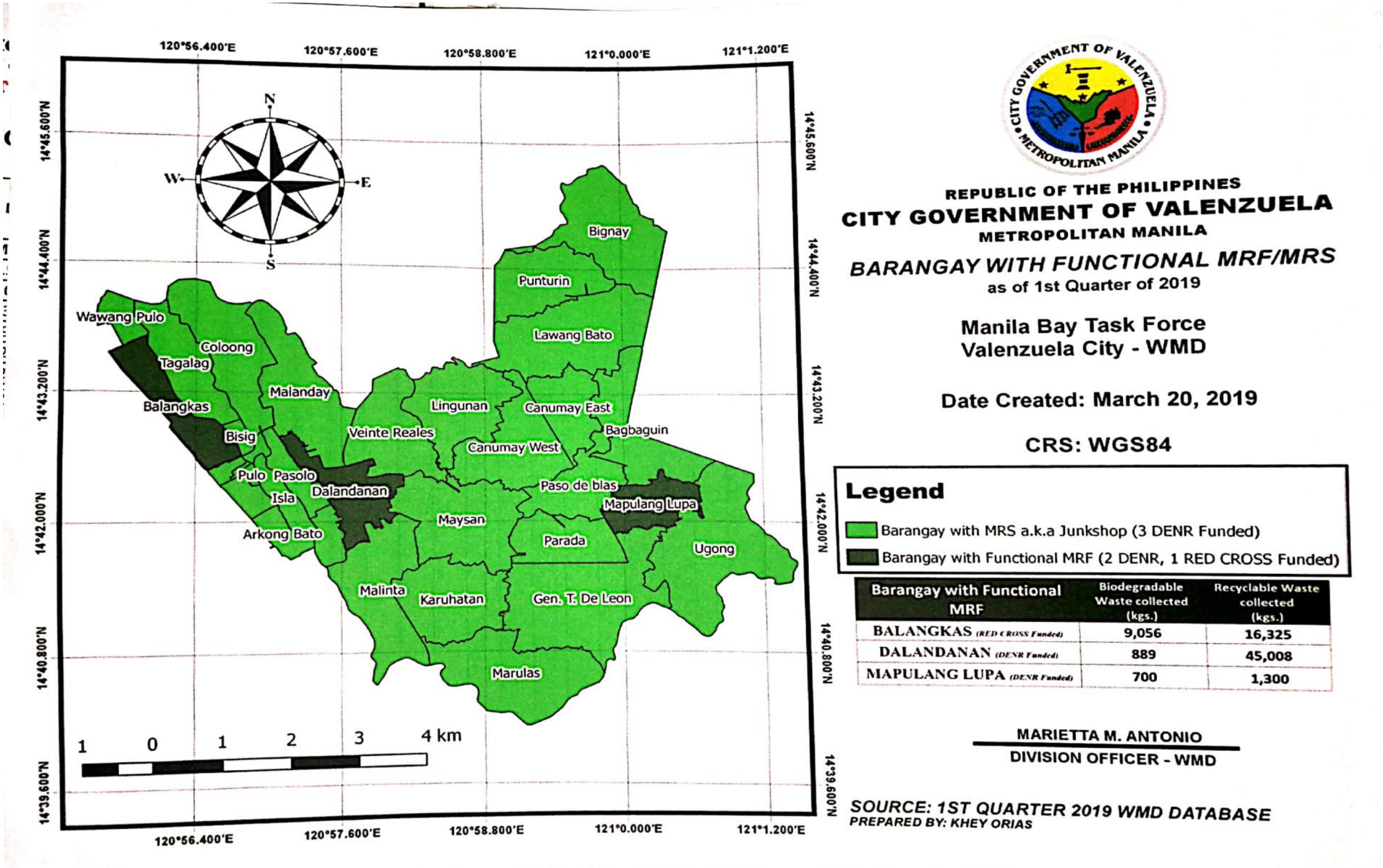


Figure 8. Map of Recreational Facilities in Valenzuela City; Taken from: Acurentes *(2009)*



Barangay with Functional MRF	Biodegradable Waste collected (kgs.)	Recyclable Waste collected (kgs.)
BALANGKAS (RED CROSS Funded)	9,056	16,325
DALANDANAN (DENR Funded)	889	45,008
MAPULANG LUPA (DENR Funded)	700	1,300

Figure 9. Existing MRF Locations in Valenzuela City; Taken from: Antonio *(2012)*

3. Methodology

3.1 Experimental Design

The study involved two parts, mainly data collection, from which components used in the model were obtained, and the model construction itself. Data collection was conducted for two categories: one for key ecosystem services and another for urbanization trends and development plans. The gathered data served as a guide to which components were to be used in the model as well as their respective means of quantification via indicator selection. Data gathering involved scoping of literature, key informant interviews, and meetings with the local government units (LGU) as seen in Figure 10. The UERI was built on the data from the LGUs to make it easier to integrate it in their city planning. Thus, most of the data sources were secondary data from the LGUs database. There were iterations for the models constructed in terms of their structures depending on the availability of data and information from the cities. Models structures were adjusted periodically upon consulting with the different offices. Structural validity was tested in Vensim particularly the stock flow diagrams to determine whether the models would run at the certain projections without having any inconsistencies with obtained values as compared to existing historical trends, if any, and possible unit errors. After finalizing the model, creation of a graphical user interface (GUI) was done for use of relevant stakeholders.

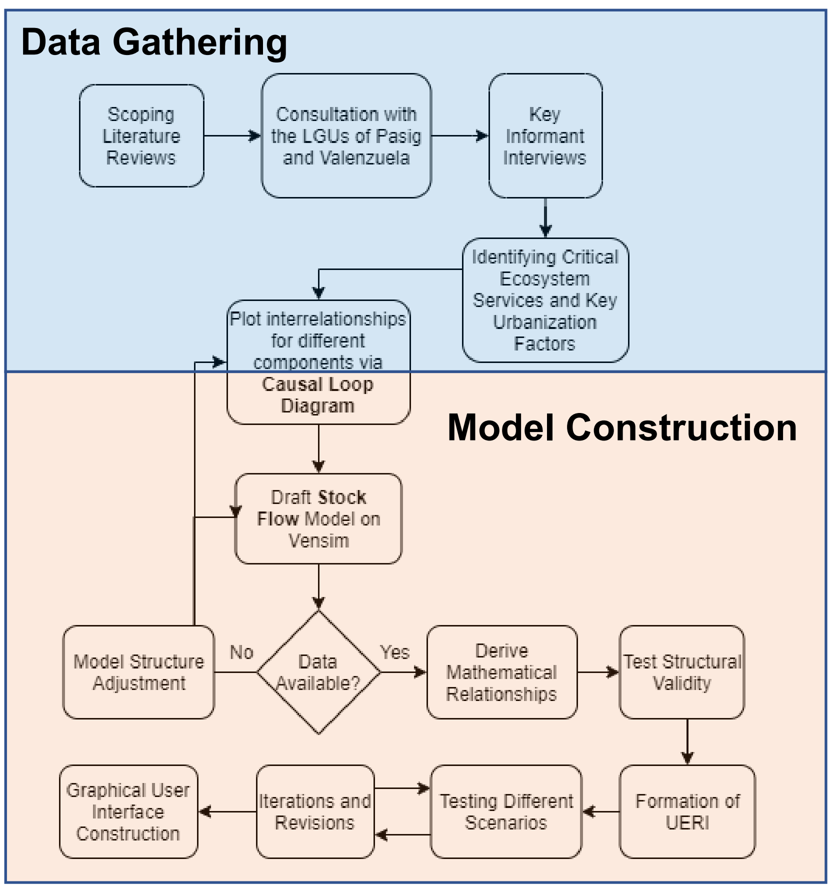


Figure 10. Methodological Framework

3.2 Data Gathering

3.2.1 National Government Agencies and Commercial Establishments

There are different National Government Agencies (NGAs) and LGU documents from which data sets were obtained for assessing the different ecosystem services in a city. Government offices provided specific data for the different provisioning services such as food, water, and energy. Data types included indicators to measure consumption as well as standards for consumption, service area coverage, and household expenditure. Offices from which data sets were collected from include the following: National Food Authority (NFA), Food and Nutrition Research Institute (FNRI), Environment Management Bureau (EMB), Department of Environment and Natural Resources (DENR), Metropolitan Waterworks and Sewage System (MWSS), and Metro Manila Development Authority (MMDA). Regulating service indicators which involve climate data such as air quality and local temperatures are obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration and Hydrological Services agency (PAG-ASA), Philippine Statistics Authority (PSA). Other regulating services such as river rainwater conveyance were consulted with the Department of Public Works and Highways (DWPH). Commercial establishments such as Maynilad and Manila Water were also contacted for additional data on allocation of services. Located in Appendix Table A1 are set of indicators that were requested per relevant office. From all these offices, acquisition of data was limited to requests without interviews.

3.2.2 Local Government Units and Key informant Interviews

Important to the study was the (KII) which involved repeated consultations with the LGU and stakeholders. The study considered different scenarios based on what stakeholders and LGUs envisioned for their city. Located in Appendix B**.** NGAs and LGUs Consulted are the list of offices from both the LGUs of Pasig and Valenzuela City and the NGAs that were consulted on for model iterations. Data provided by LGU were mostly from the required documents such as CLUP, CDP, AIP, and LCCAP and possible resilience plans if available, while the NGAs provided reports, maps and master plans of the Metro Manila. Also in Appendix B, questions asked that aided in the collection of data from the offices as well as structural adjustments were also mentioned.

3.2.3 Indicator Selection

Indicators were chosen for each of the Urban Ecosystem Services in the city. They were categorized into the different types of UES depending on their functions as seen in Appendix Table A1. Indicators of Ecosystem Services. Indicators chosen were obtained from different documents such as the comprehensive land use plans for land use change and other relevant documents from the different organizations such as national government agencies (NGAs) and LGUs in the given cities. Indicators used were based on how they can quantify the resilience scores of UES. An example of this would be the use of population density as a metric for population. Other components include how population changes over time such as population growth, death rate, birth rate.

3.3 Model Development and Simulation

3.3.1 Model and Index Design

The creation of the Urban Ecosystem Services Index followed the ecosystem services approach. This involved measuring the different urban ecosystem services in city to derive their resilience scores to form the UERI. In designing the index, the component factors of the UERI were normalized and combined such that the final index would have a value of 1 if demand is equal to supply or if quality is equal to set standard; less than 1 for sub-optimal conditions; greater than 1 for surplus or better conditions as seen in Table 1. Each stock-flow diagram contained an indicator (such as an auxiliary variable) to indicate the score. This was a ratio of either stock, auxiliary, or flows. The purpose of normalizing the data allowed all the ecosystem services to be subject to urbanization and how it was characterized in the model. Therefore, the value of the UERI would be a composite of the different scores representing the different urban ecosystem services, following the scheme of Table 1.

Aside from the index for resilience, another was made for self-sufficiency as seen in Table 2. The index had a value of either 1 or less than 1. Having a value of 1 meant services were provided within the city while less than one if services are derived from outside the city as well. The purpose of this was to determine whether the city was outsourcing services and to what extent. Equations were derived based on the relationships between components as well as based on different models found in related literature. The model construction would require constant revision based on new data gathered. All of the models were constructed using the Vensim® platform. They were then subject to iteration when consulted upon from the various LGU and NGA offices.

Table 1. *UER Index, Adapted from* (Josol, 2014)

SCORE	IMPLICATIONS
>1	Surplus Greater Conditions
=1	Supply = Demand Conditions = Set Standard
<1	Supply < Demand Conditions are lower than Set Standard

Table 2. Self-Sufficiency Index

SCORE	IMPLICATIONS
=1	**All internal**, **no external**; Services are provided in the city
<1	**Internal < External**; Services are provided inside and outside the city

3.3.2 Causal Loop Diagrams (CLD) and Stock-Flow Diagrams

The causal loop diagrams were created to identify key variables in the city system as well as indicating causal relationships between them. The tool was used to understand complex behavior within systems via a causal perspective. This is particularly useful when understanding how the different the feedback mechanisms between the ecosystem services produce certain behavior which could affect how other ecosystem services function in the long term. By identifying key variables, only crucial mechanisms were considered in the system while still being able to reflect how the system functions real life. Therefore, a consolidated CLD depicting the interrelations between the 4 UES seen in Figure 11 was constructed. This consolidated CLD was created to give an overview of all the processes relevant to UER to guide government agencies towards city planning. With that, the CLD also included loop labels and letter labels for easier tracking.

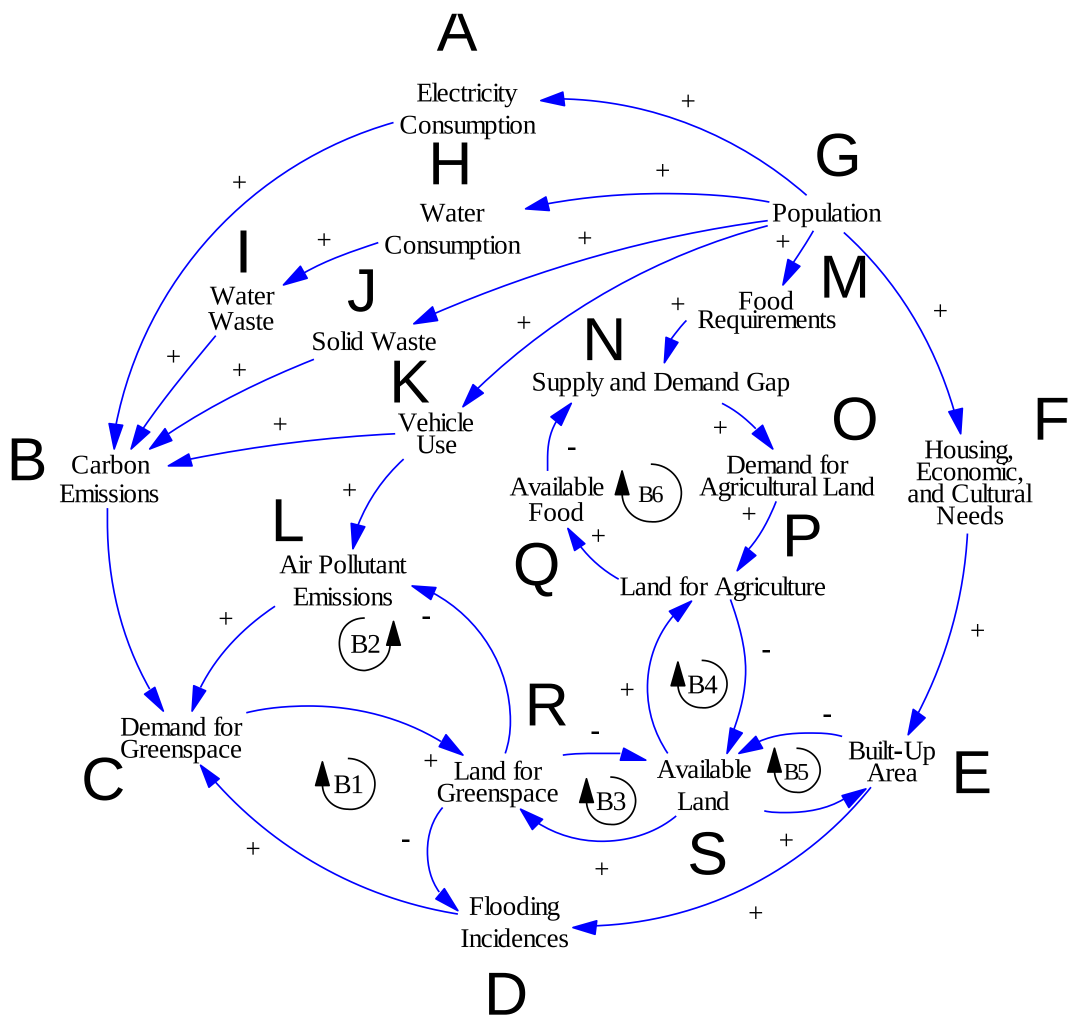


Figure 11. Consolidated Causal Loop Diagram of Different Ecosystem Services

There are six balancing loops in the model. B1 and B2 both deal with increasing regulating services via the benefits provided by greenspace. B1 (C-R-D-C) refers to the increasing the amount of land for greenspace decreases the flooding incidences B2 (C-R-L-C) refers to the contribution of greenspace to in reducing air emissions through pollutant removal. B3 (S-R-S), B4

(S-P-S), and B5 (S-E-S) refer to the limits conversion due to having limited available land in a city. Lastly, B6 (N-O-P-Q-N) refers to the mechanism of the factors affecting the supply and demand gap for food. A growing population increases the food requirements needed by the population while this same gap also increases the demand for agricultural land, which increases available food. This, overall, decreases the supply and demand gap. The consolidated CLD only shows the trade-off across all ecosystem services. Specific dynamics of each service was highlighted in their respective sections.

Discussing the consolidated CLD further, the main trade-off that was observed across all ecosystem services was land-use change. Different services required an appropriate amount of land for them to function properly. This dictated that the land use model was incorporated in the overall structure of the models. Another factor present in all services was population. As the population increases, so do the demand for different provisioning services such as food, water and electricity. An increase in consumption of resources resulted in an increase in emissions such as solid waste, wastewater, air, and carbon emissions. Additionally, an increase in population also lead to increased demand for different types of urban infrastructure. This results into more built-up area in the city which may contribute to more flooding incidences. As such, main drivers of change found in the city system involve land use and population.

The consolidated CLD was then translated and broken into the models for the two cities, Pasig City and Valenzuela City, then were further translated into sub-models per UES category. From the overall causal loop diagram, 11 sub-models were developed to represent the dynamics of the following ecosystem services as seen in Table 3: 3 for the Provisioning Services, 5 for the Regulating Services, 1 for the Supporting Services and 1 for the Cultural Services. Lastly, a population model was also created.

Each sub-model had a sub-CLD and a stock-flow diagram to quantify the resilience and self-sufficiency scores. However, A sub-CLD for the land use model was not created because it was framed as an input to the other sub-models. Each service per category had a resilience score in their stock-flow diagrams calculated using the logic indices found in Table 1. *UER Index, Adapted from* and Table 2 in the previous section. The resilience index per category linked to the UERI variable which calculated the overall score for the city.

Table 3. List of Sub-Models per UES

PROVISIONING	REGULATING
1. Electricity Provisioning 2. Water Provisioning 3. Food Provisioning	1. Solid Waste Management 2. Wastewater Regulation 3. Air Quality Regulation 4. Carbon Emission Regulation 5. Rainwater Conveyance
SUPPORTING	**CULTURAL**
1. Land Use Change	1. Cultural Services

The sub-models are discussed in the following sections, including modifications made for the specific contexts of Pasig and Valenzuela. The steps of model construction can be seen in Figure 10. The variables, equations, and sources for each sub-model can be found in Appendix C. Valenzuela City Sub-Model Variables for the Valenzuela Models and Appendix D. Pasig City Sub-Model Variables for the Pasig Models. It should also be noted that some variables had grey arrows connecting to the stocks, as marked by the software, given that any variable connected to a stock would have a grey arrow. This does not reflect any structural implications, and they were retained to show how the stock values were computed instead of enumerating a static initial value. One example is seen in the Land Use Model in Figure 41.

Variables that were also encased in brackets (or "<>") and are grey also denoted what are called shadow variables. These are variables were from another part in the same sub-model or from other sub-models. These are used when one diagram is too large or when the variable comes from another sub-model and one variable A would need to be integrated in another part of another sub-model. One example is seen in the Air Quality Regulation model in Figure 30.

3.3.2.1 Population Sub-Model

The section contains the population sub-model for both Pasig and Valenzuela City. No causal loop diagram was made as it was integrated in all the other services. The stock flow diagram found in Figure 12 refers to the structure used for both cities.

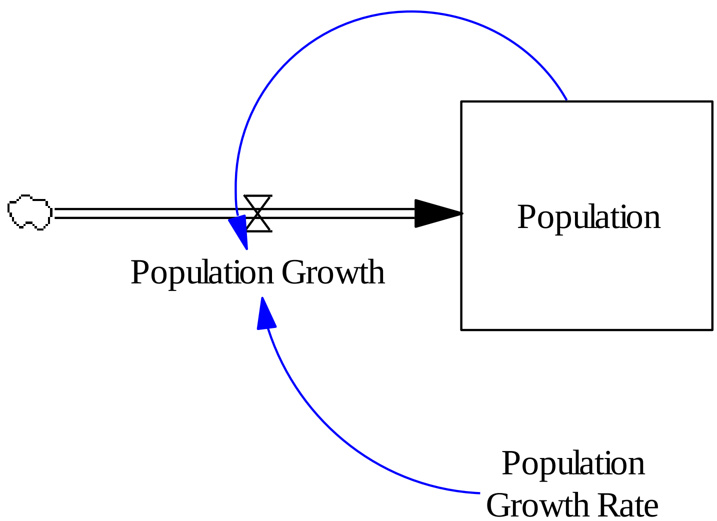


Figure 12. Stock-Flow Diagram for Population Model for Pasig and Valenzuela City

The datasets for population were obtained from the 2000 and 2015 census done by the Philippine Statistics Authority for Pasig and Valenzuela and was reported in their respective comprehensive land use plans (Palermo, 2009; Acurentes, 2009). The growth rate for the populations were already pre-computed to include the birth rate and death rate. These rates were projected till the last time step selected for the models. For Pasig, the earliest population value recorded from the census was 2000 (PSA, 2002) while for Valenzuela it was also 2000 (PSA, 2002). In determining the population for the respective starting years, data points were computed using data from the 2000 and 2015 population census. Equation *1* was used to determine the population growth rate in order to compute for the population for 2012 in Pasig and population for 2009 for Valenzuela given that these were the respective starting points for the models.

$$\mathrm{P} = \mathrm{Poe}^{\mathrm{rt}}$$

Where

P = Current Value

P_0 = Initial value

r = rate of change

t = time

Equation 1. Exponential Growth Formula

3.3.2.2 Provisioning Services Sub-Model

The section on provisioning ecosystem services was divided into three different modules mainly: electricity, water, and food. The provisioning model measures the ability of the city to provide for the different necessities to the people inhabiting it such as food, water, and electricity. The delivery of these services is affected by different factors such as natural hazards and urbanization drivers such as land use change and population growth. The base causal loop diagrams and stock flows considered only effects from urbanization drivers.

The model was made to show the dynamics of supply and demand of these services in the city amidst changes brought about by urbanization drivers. Therefore, provisioning resilience was measured as the cities' ability to satisfy the provisioning needs of the people over time given these changes. This was computed by getting the ratio between the total supply over overall demand per year. The idea for the scoring of physical services was adapted from the Physical Hazard Index Model (Josol, 2014) which was applied for the whole Metro Manila using a system dynamics approach. This idea of measuring services used in that model was contextualized and applied to the provisioning services model, specifically through the supply and demand mechanics of selected goods in a city. The use of the demand and supply approach was chosen to measure provisioning resilience. This is grounded on sustainability concepts mentioned previously which deals with ensuring that basic services will be enough for future generations, without compromising the needs of the present.

3.3.2.2.1 Sub-Model for Electricity Provisioning

The dynamics of the electricity service can be seen in Figure 13. The structure shows how supply and demand of electricity in cities drives different behavior and is influenced by different factors. There are five balancing loops and one reinforcing loop in the system.

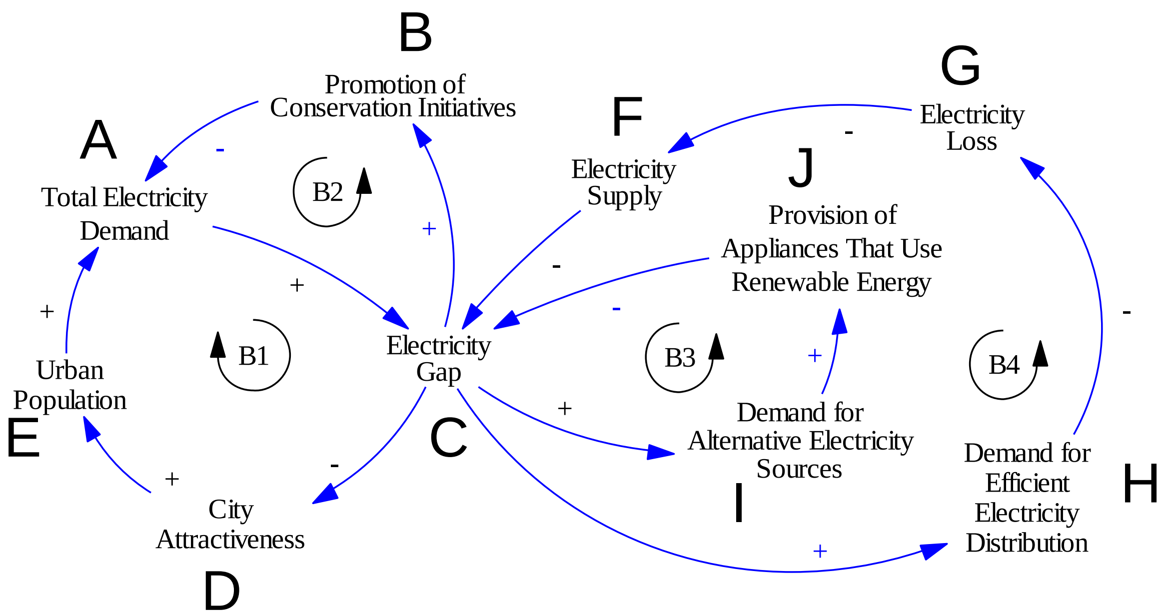


Figure 13. CLD for Electricity Provisioning Services

The structure shows how supply and demand of electricity in cities drives different behavior and is influenced by different factors. There are four balancing loops and one reinforcing loop in the system. B1 (A-C-D-E-A) refers to how urban population dictates total electricity demand. As the population grows, so do the demand for electricity which in turn, increases the gap between what is available and what is needed. The gap will determine the attractiveness of the city which feeds back into the population. B2 (A-C-B-A) refers to how the total electricity demand increases the gap between the supply and demand. However, this same game, is also the one that will entice policy makers to promote conservation initiatives which, in turn, lower the demand. B3 (C-I-J-C) refers to how the gap increases the demand for other forms of electricity provisioning. This demand would also be the one to convince the providers to produce and provide appliances that use renewable energy. Lastly, B4 (C-H-G-F-C) refers to the demand in a more efficient electricity distribution which lowers electricity transmission loss. This would overall decrease the electricity gap.

The stock flow diagram translated from the causal loop diagram, as seen in Figure 14 and Figure 15 is a simplified version of the CLD. The *Resilience Score for Recommended Electricity Supply* was the name of the variable that measured the resilience score of the electricity service. This was computed from the ratio between the total maximum electricity supply of the city and the total recommended electricity supply of the city as seen in *Equation 2*. This scoring was used to determine how much more electricity is needed in the city given the current maximum supply of city as compared to the growing recommended supply. This scoring criteria was applied to both cities.

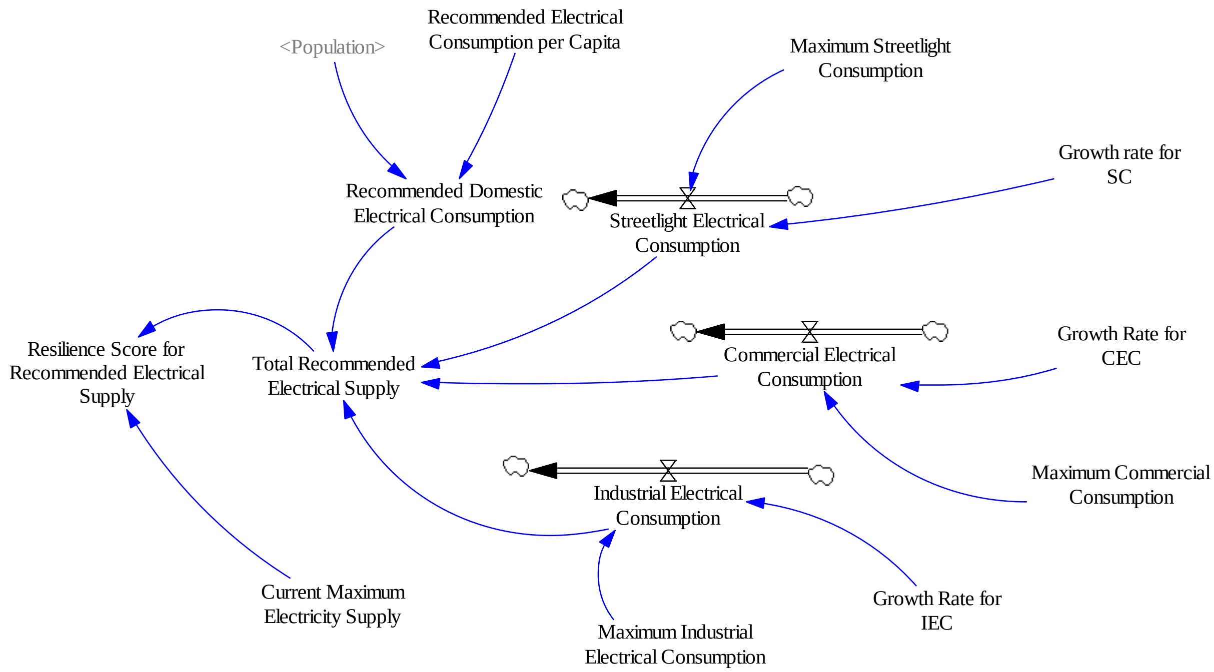


Figure 14. Stock-Flow Diagram for Electricity (Valenzuela City)

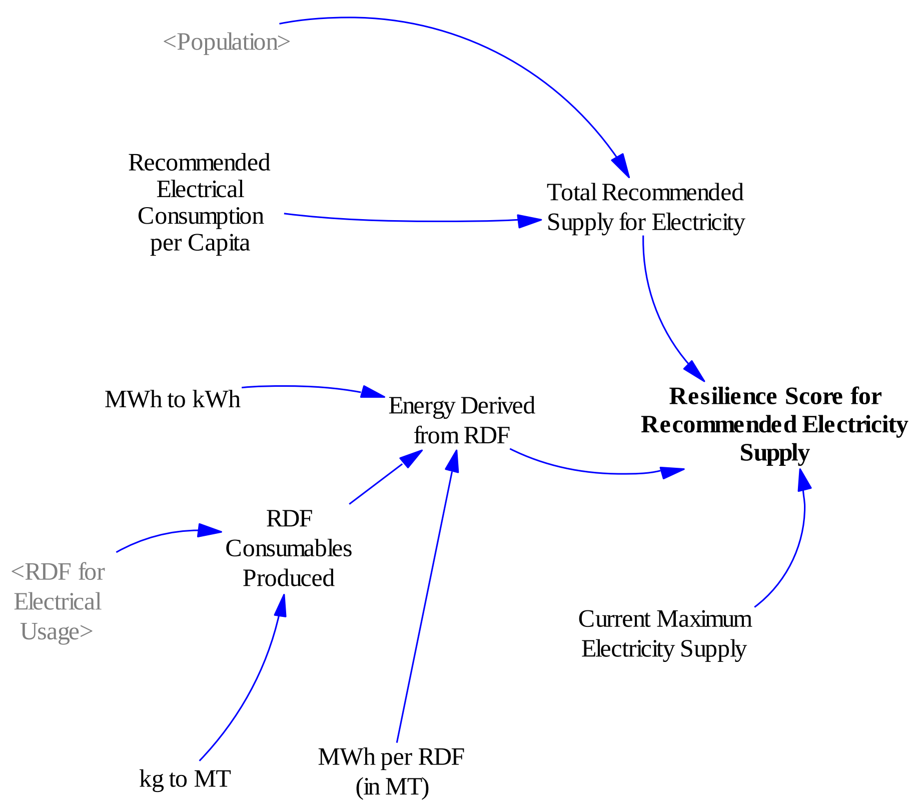


Figure 15. Stock-Flow Diagram for Electricity (Pasig City)

The data sets for Valenzuela city electricity provisioning service model were obtained from the yearly socio-ecological profiles of the city (Sison, 2017). These data sets contained disaggregated values for commercial, residential, industrial, and streetlight. The data set used for the Pasig city electricity provisioning service model was obtained from the Greenhouse Gas inventory (Pasig City Government, GHG Inventory Report for the Municipality/Pasig City, 2012). This data set only contained one aggregate electricity consumption data for the year 2012. The model structures differed between both cities with the Valenzuela accounting for growth rates for non-domestic components given observed trends from the historical data as compared to Pasig city. Both data sets did not contain any values of supply and only for consumption. Given this, total recommended supply of the city was framed using the values of consumption following how electricity provisioning works between MERALCO and the city. Distributors do not allocate certain levels of electricity to cities but only distribute based on the demand. This would mean that the supply would be equal to consumption in this context. Therefore, the sum of the maximum consumption per component using electricity in the city would be the value of total recommended electricity supply. In terms of framing the current maximum supply, the highest year of aggregate consumption from the historical data sets, if any, would serve as the value.

There was a difference in computing for the domestic consumption as compared to the other components which used readily available data. Domestic consumption was computed by multiplying population with the recommended electrical consumption per capita as obtained from (Kojima, et al., 2016). The difference between the variables used for comparison for both cities would depend on the resolution of the data provided. Valenzuela accounted for disaggregation in between components, therefore was able to consider the contribution of industrial, commercial, and streetlights to the total recommended energy supply. As for Pasig, only the domestic consumption was considered given that the data set obtained was not disaggregated and the contribution of the other components could not be accounted for.

$$\text{Resilience Score for Recommended Electrical Supply} = \frac{\text{Current Maximum Electricity Supply}}{\text{Total Recommended Electrical Supply}}$$

Equation 2. Resilience Score for Electricity

3.3.2.2.2 Model for Water Provisioning

The dynamics of the water service found in Figure 16 was framed similarly to the causal loop diagram of electricity. The loops follow the same behavior as that of the electricity with slight changes in the variable name to reflect the resource of interest.

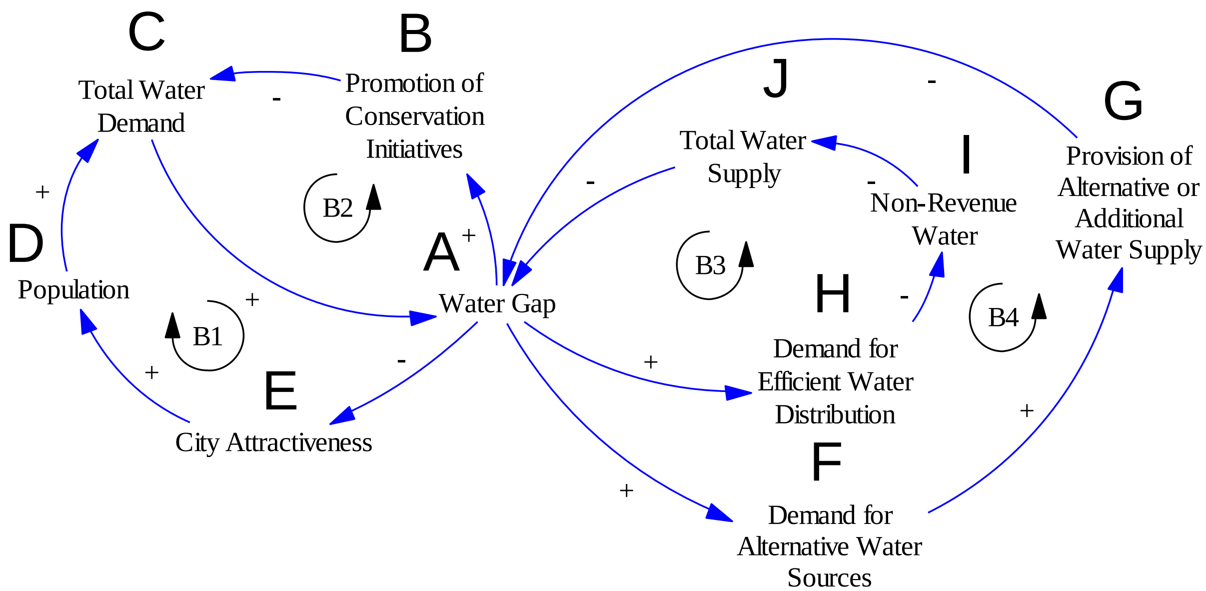


Figure 16. CLD for Water Provisioning Services

There were four balancing loops in this CLD that are affected by the water gap. The population still drives the increasing demand for water resources as seen in B1 (D-C-A-E-D). A higher water demand also increases the water gap, which lowers the city attractiveness, balancing the increasing population. This is addressed by decreasing the total water demand of available water by increasing the conservation initiative B2 (C-A-B-C). B3 (A-H-I-J) refers to the demand for efficient water distribution caused by an increasing water gap. The increasing water gap referred to in this CLD is caused by how non-revenue water (NRW) decreases the total water supply, which decreases the gap. B4 (A-F-G-A) refers to mechanisms that increase water availability either by improving efficiency or adding another water source to increase available water.

The stock-flow diagrams for water provisioning as seen in Figure 17 and Figure 18 and were also framed similarly to the electricity model (Figure 14 and Figure 15). The variables included in the diagram were used to show total available water consumption and total water supplied in order to derive the resilience score.

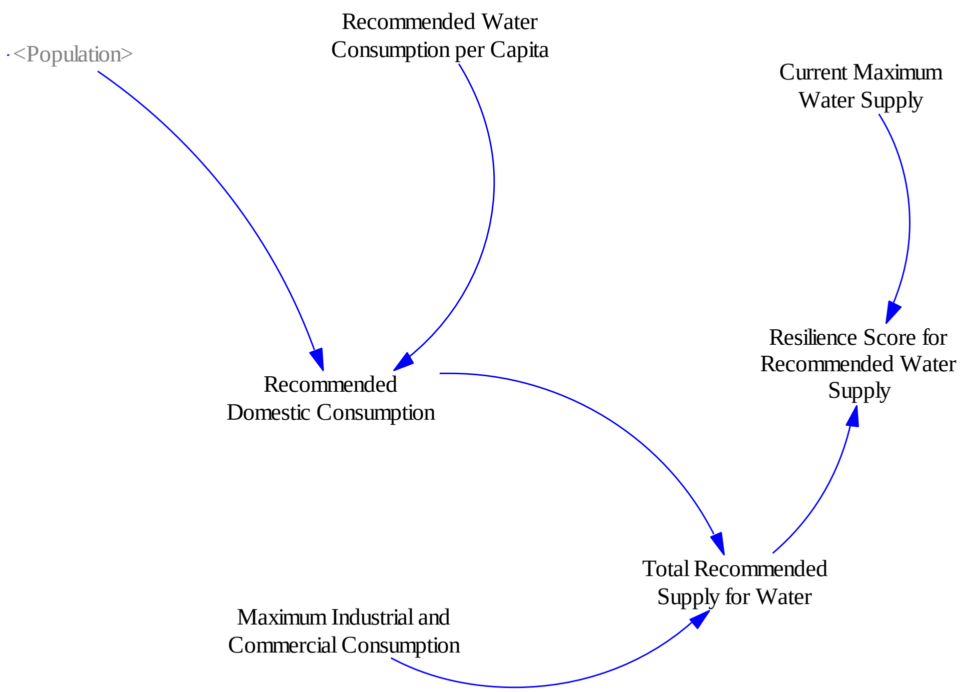


Figure 17. Stock-Flow Diagram for Water Provisioning (Valenzuela City)

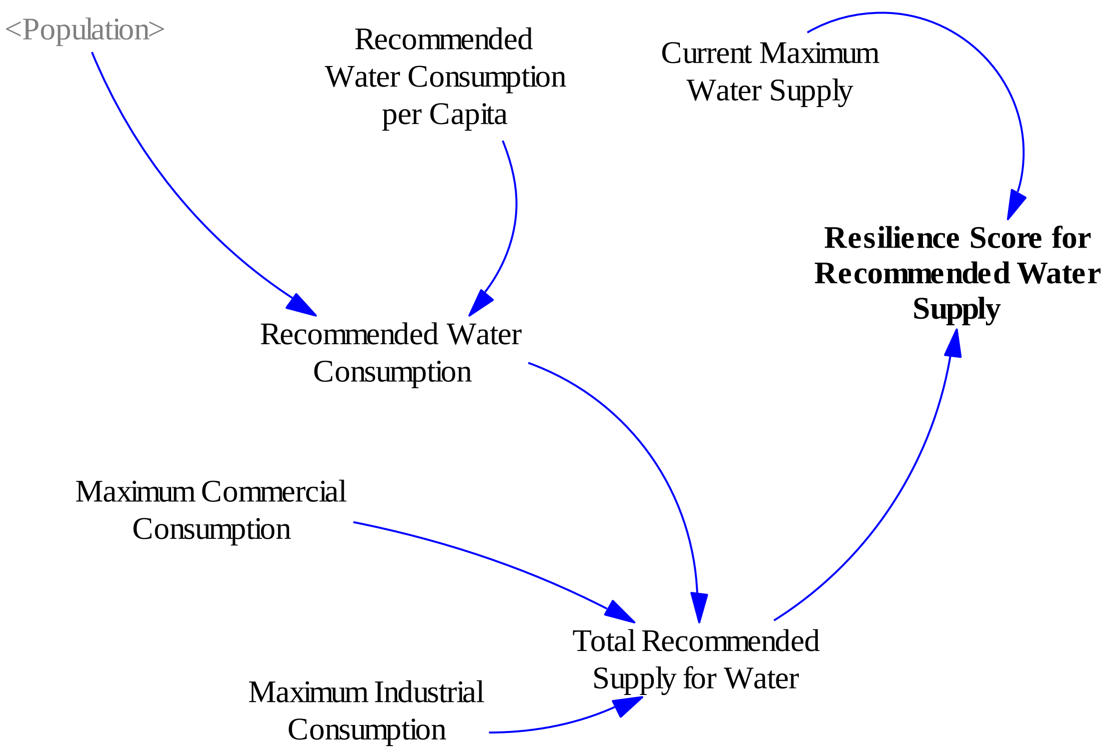


Figure 18. Stock-Flow Diagram for Water Provisioning (Pasig City)

The values used for the commercial and industrial water consumption were the ones reported by Batalla (2020) and Co (2020) and were not affected by a growth rate. The domestic consumption was also the only sector influenced by population as the recommended consumption was on a per capita basis based on a study by Philippine Institute for Development Studies (Inocencio, Padilla, & Javier, 1999) pegged at 100 lpd or 36.5 m^3 per year. The difference in the models of Pasig and Valenzuela were that the values for the commercial and industrial consumption for Valenzuela were aggregated. The maximum supply variable was a value obtained from the highest water supply recorded from a certain timespan. The total recommended consumption for water was based on the same list given by Batalla and Co. The maximum values per sector were assumed to be the recommended values used in the model. These were compared to the total recommended supply to test is the *Current Maximum Water Supply* could meet the recommended consumption.

Concessionaires do not allocate a set maximum volume of water per city, and instead only distribute what is demanded based on the number of connections. This would mean that the supply would be equal to the consumption much like in the electricity provisioning model. From this, the resilience score was computed using Equation 3 as the comparison of the recommended consumption versus the maximum supply which depicted resilience for water availability.

$$\textit{Resilience Score Based on Recommended Water Supply} = \frac{\textit{Current Maximum Water Supply}}{\textit{Total Recommended Water Consumption}}$$

Equation 3. Resilience Score Based on Recommended Water Supply

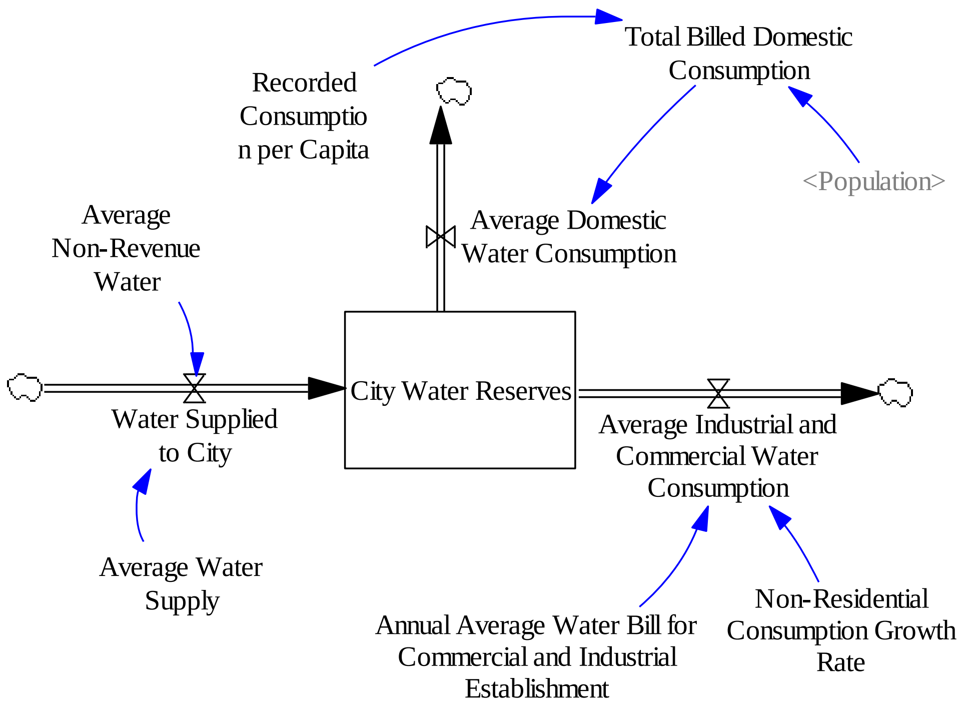


Figure 19. Stock-Flow Diagram From Water Model Correction

Figure 19 was retained so that the LGU could check for any discrepancies in data collection with regard to their supply and consumption. However, as seen in Figure 17 and Figure 18, this was not used in computing for the resilience score.

3.3.2.2.3 Sub-Model for Food Provisioning

The dynamics of the food service model is seen in Figure 20. The structure of the model was based on the demand and supply of food for consumption.

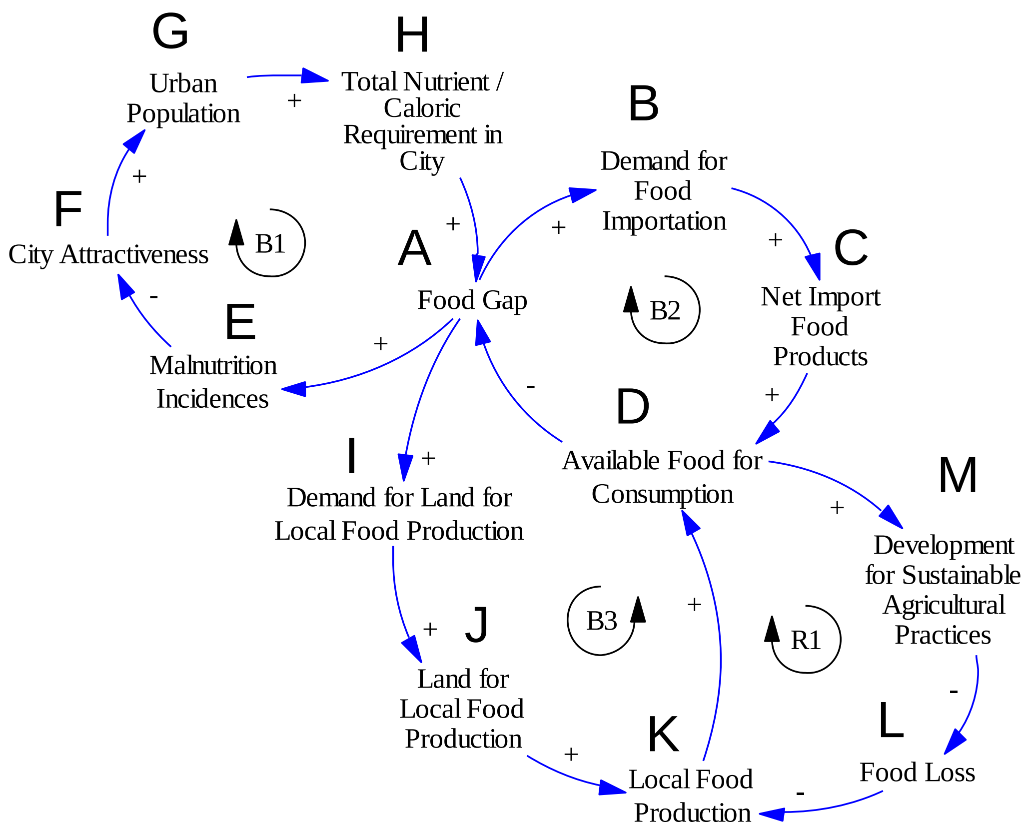


Figure 20. CLD for Food Provisioning Services

There are four balancing loops found in the system. B1 (A-E-F-G-H-A) reflects the food demand situation wherein increasing urban population results in higher total nutrient and caloric requirement in the city. This in turn leads to increased food gap given more food required. Having a higher food gap would result in more incidences of malnutrition which makes cities less attractive, eventually affecting population growths. Food gap drives two sets of balancing actions: either food importation or local food production. B2 (A-B-C-D-A) refers to the influence of food gap to the demand for food importation which results to more imported food products. Having more imported food products leads to more available food for consumption therefore, lessening the food gap. B3 (D-A-I-J-K-D) is also driven by food gap which involves increasing the demand for more land for local food production. Having more land for local food production increases overall production resulting to more food available for consumption. R1 (K-D-M-L-K) refers to the development of sustainable agricultural practices which overall increases available food for consumption. An increase in food loss results in less food produced, which is why sustainable practices counteract that.

There are two stock-flow diagrams for Valenzuela. The one for Valenzuela includes the resilience food model in Figure 21 and the self sufficiency food model in Figure 22.

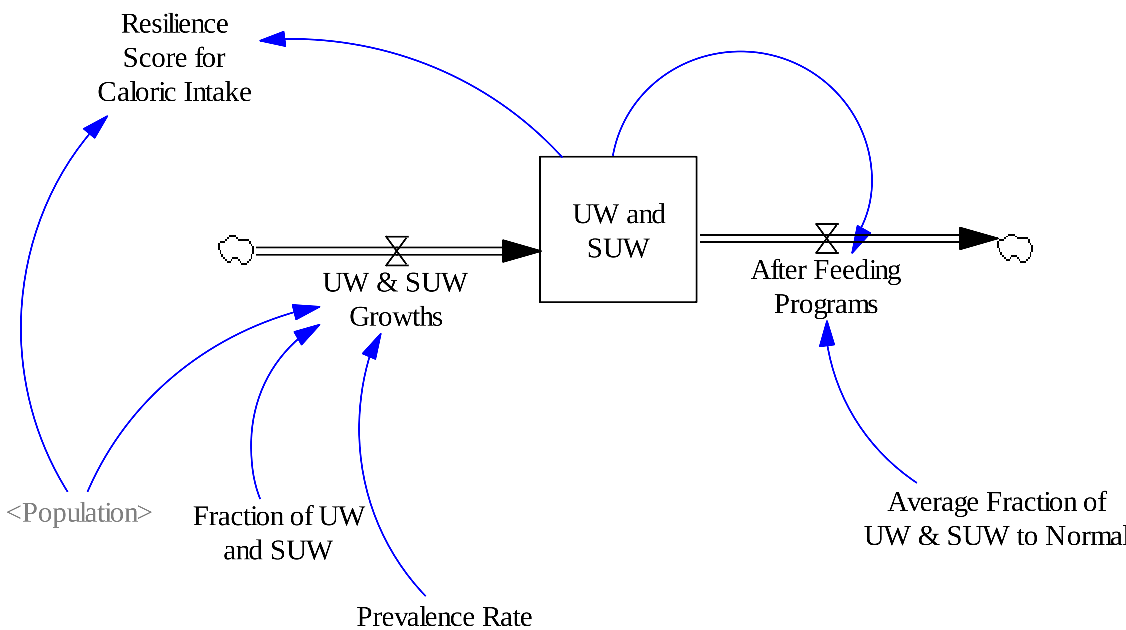


Figure 21. Stock-Flow Diagram for Food Provisioning Resilience (Valenzuela City)

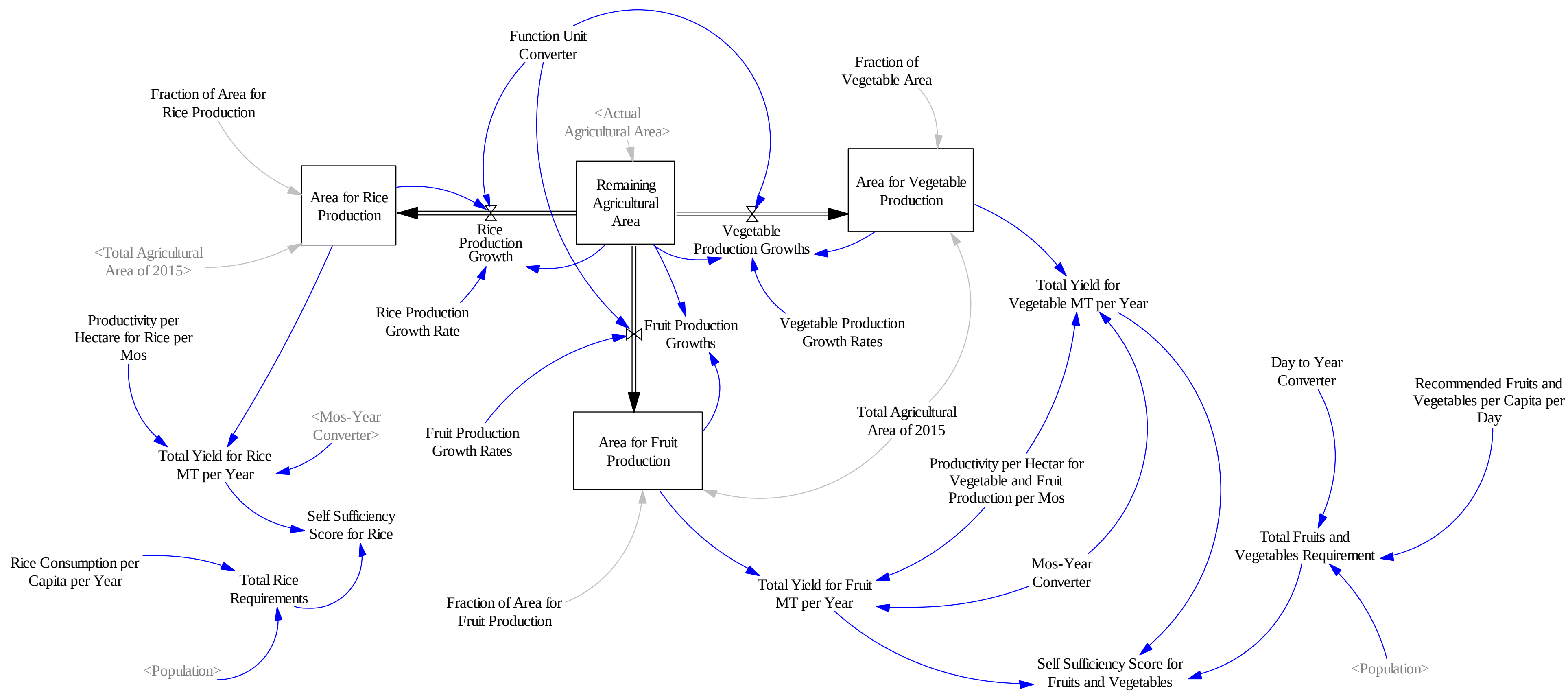


Figure 22. Stock-Flow Diagram for Food Provisioning Self-Sufficiency (Valenzuela City)

The food resiliency model dealt with determining the percentage of the population that did not meet the caloric standards per year. This was obtained from getting the ratio between the fraction of the population classified under normal versus the total population. The resiliency score can be seen in the auxiliary variable *Resilience Score for Caloric Intake*. Determining the percentage of the population that were classified as normal was computed by subtracting the underweight (UW) plus severely underweight (SUW), as reflected in the stock "UW and SUW", from the total population. The fraction for UW and SUW was obtained by getting the average of the cases of people under that category given that there were no observed trends. The earliest year wherein cases were recorded were in 2015. The fraction was assumed to be constant and was applied to each year, even those before 2015, to make the model run more effectively and with no errors. This framing was done given that there were no records from both cities on the actual food weight for supply and consumption. It was then assumed that those who were not classified as normal were deficient in caloric intake. The variable *After Feeding Programs* was also used based on the Timbang Project the City Health Office of both cities used (Galutera, 2015; 2016; 2017; 2018). This was the outcome implied after the feeding program, which reduced the stock. This variable is a rate pertaining to the amount of people categorized under UW and SUW that have normalized weight after the feeding program.

The resilience score was computed Equation 4. Values used for determining percentage of the population that are UW and SUW as well as by how many are reduced from the feeding programs is obtained from the Daycare Supplementary Feeding Program provided by the Valenzuela Health Office (VCHO, 2020).

$$\text{Resilience Score for Food} = \frac{\text{Population} - (\text{UW and SUW})}{\text{Population}}$$

Equation 4. Equation for Food Provisioning Resilience Score

The production values were assumed to have incorporated production loss in the specific stages of harvesting. In the model, the production of rice, fruits and vegetables were compared respectively with the consumption requirements. This was used to calculate the self - sufficiency score per respective crop using Equation 5. Equation for Food Provisioning Self-Sufficiency Score.

$$\text{Self} - \text{Sufficiency Score for Food} = \frac{\text{Total Yield of Food}}{(\text{Total Food Requirement})}$$

Equation 5. Equation for Food Provisioning Self-Sufficiency Score

The food self-sufficiency model as seen in Figure 22. Stock-Flow Diagram for Food Provisioning Self-Sufficiency (Valenzuela City) showed how much food was produced locally and was the framing used for the three scores of food model: *Self-Sufficiency Score for Rice* and *Self-Sufficiency Score for Fruits & Vegetables*. The value used for actual agricultural area were obtained from the Comprehensive Land Use Plan of Valenzuela City of 2009 – 2018 (Acurentes, 2009). From the total agricultural area, there were certain fractions for each type of product grown in that land area. The fractions of land were categorized into three main products mainly vegetables, rice, and fruits as reported from the Ecological Profile of the City (Sison, 2017).

In terms of determining productivity, computations involved multiplying land area for a certain type of food crop with the productivity of that crop per hectare per year times the number of days in a year. Productivity per hectare was obtained from different sources to be used in the model. Productivity per hectare for rice crop was reported to be 5.68MT (Tallada, 2019). This value was chosen given that it was the closest value to the recorded average for productivity yields per hectare. This implied that harvest was done during the dry period as productivity of rice is less during wet season (Tallada, 2019). As for fruits and vegetables, the value used for the model was derived from the Ecological Profile (Sison, 2017) and was computed to be an average 2 Metric Tons (MT) per hectare per year. Production would depend on the available agricultural land that grows the specific product. Over the years, these lands were either converted or expanded based on the land development scenarios (refer to land use model for the dynamics). The amount of production was assumed to remain constant for the successive years when projected and its value would be based on the final land area recorded. The units were also retained as MT to keep it consistent with the available data

In terms of the standard Equation 6 was used for the computation of total food requirements for fruit and vegetables. Consumption per capita of rice was reported to be 110kg (Tallada, 2019). The recommended total fruit and vegetable consumption was reported to be 400g according to the World Health Organization (WHO, 2003).

$$\begin{aligned}&\text{Total Food Requirement}\\&= \text{Recommended or Consumption per Capita}\\&* \text{Population}\end{aligned}$$

Equation 6. Equation for Total Food Requirement

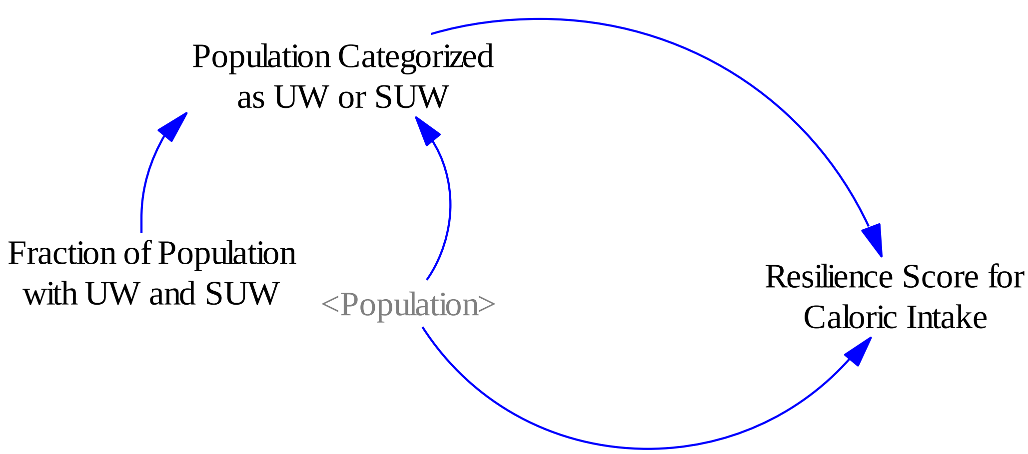


Figure 23. Stock-Flow Diagram for Food Provisioning Resilience (Pasig City)

The food resiliency model structure of Pasig was made different from the Valenzuela food resiliency model in order to adjust to the data sets given by the city. The UW and SUW fraction data for Pasig was obtained from the City Health Office Summary Report for Operation Timbang (Galutera, 2015; 2016; 2017; 2018). The earliest data available was 2015. Given that there were no trends observed as well for the number of UW and SUW per year in Pasig city, an average value was used as well similar to the Valenzuela model. There were no reported programs for reducing the number of UW and SUW as of now. Equation 4 was also used for computing the resiliency score for food.

3.3.2.3 Regulating Services Model

The section on regulating services model was divided into five different modules mainly: solid waste management, wastewater management, air emission regulation, carbon emission regulation, and river conveyance capacity. The regulating model measures the performance of the city to maintain natural conditions that allow for human life to thrive and flourish. These involve the services provided by the city to ensure that natural conditions are preserved by dealing with the anthropogenic changes brought about by the people inhabiting the city such as land use change and release of emissions. Therefore, regulating resilience is measured by comparing the standard conditions versus the actual conditions and deriving the performance capabilities of the city from there. This was computed by getting the ratio of the standard conditions set by an organization or the city versus the actual environmental conditions per year.

3.3.2.3.1 Model for Solid Waste Management (SWM)

The causal loop diagram as seen in Figure 24 for the solid waste management model followed the path of a target diversion gap which is balance out by the amount unmanaged waste and the amount of waste that is managed through recycling and composting. With that, there are two balancing loops

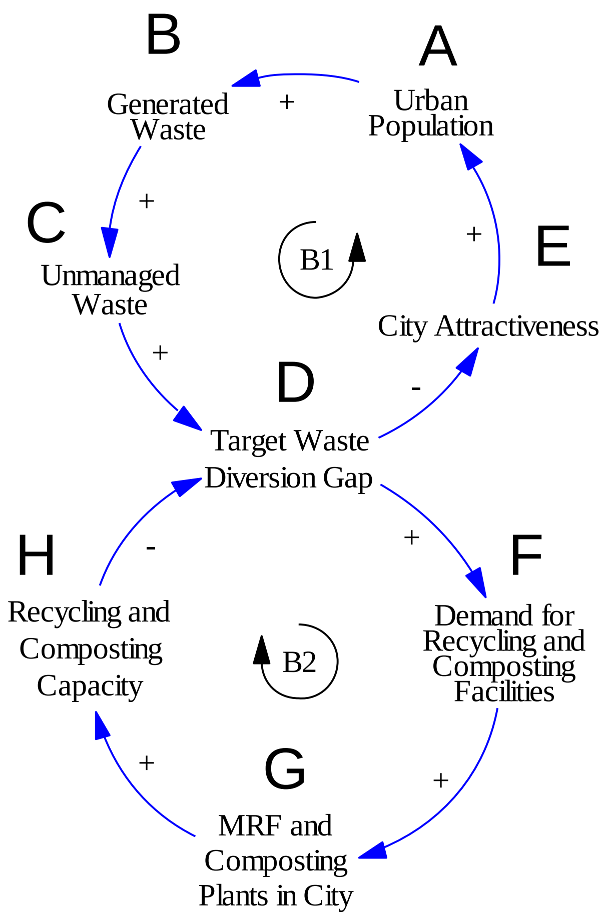


Figure 24. CLD for Solid Waste Management

Balancing loop B1 (A-B-C-D-E-A) followed how an increasing population also causes an increasing amount of waste and therefore the unmanaged waste. This increases the target diversion gap because this would increase the amount of unmanaged waste versus those that are treated or managed. When framed using a supply-and-demand logic, this would be the demand. This gap decreases city attractiveness due to the amount of unmanaged waste.

Balancing loop B2 (D-F-G-H-D) depicts that the same gap would then increase the demand for managing the waste through recycling and composting. The construction of facilities such as the MRFs and MRSs would help in achieving such, decreasing the gap.

The model in Figure 25 followed the flow from the estimated waste generated which was computed as the population of city multiplied by the waste generation rate per capita in the city.

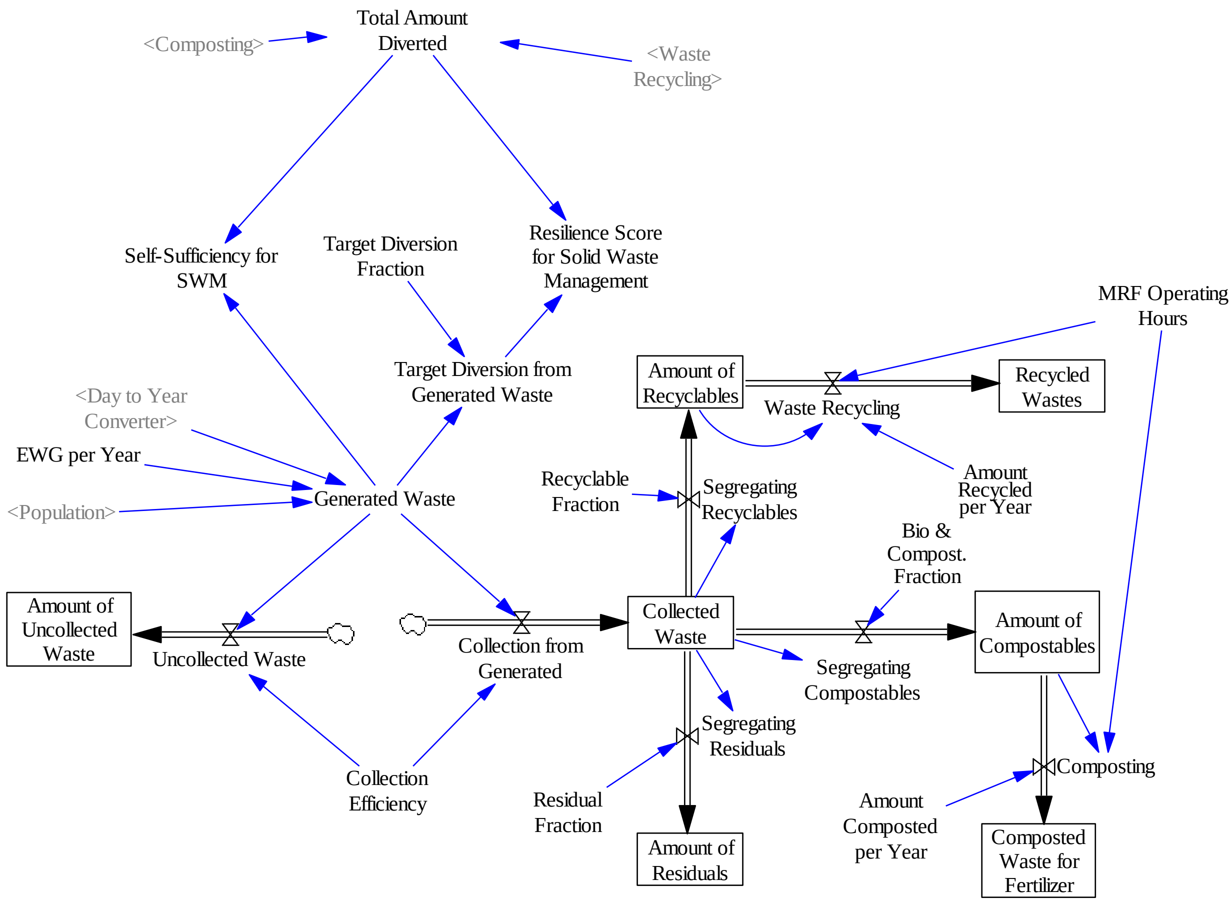


Figure 25. Stock-Flow Diagram for Solid Waste Management (Valenzuela City)

In this stock-flow diagram, a new variable called *Collection Efficiency* was introduced. It was assumed that the reported collection efficiency multiplied to the estimated waste generation yielded the amount of waste collected instead of calculating it from the number of trucks and their trips. This same collection efficiency also dictated which waste was uncollected and which waste was collected for segregation. The segregation was based on the amount of the stock that was the amount of collected waste multiplied to their fractions as reported in the cities' solid waste management plans. This fraction was assumed to be constant as the average of all the fractions for a time range was the one that was reported in the plan. The amount of residuals was also aggregated to mean both the amount of residual waste and the other special waste because of how they were managed outside of the city (Antonio M. , 2012); (Angeles, 10-Year Solid Waste Management Plan , 2012).

From the segregated compostables and recyclables, the amount that was used for the composting and recycling, respectively, were both from the reported Environment Compliance Audit or ECA which gave a value for how much waste was recycled and composted per quarter (Angeles, 2020). When consulting the Solid Waste Management section of both cities, they stated that it was safe to assume that the value reported was on average. In calculating for the amount of waste recycled and composted, two things were assumed. First, this amount would either be the reported amount recycled or composted. Second, it could since the capacities MRF is per year and when they operate were not enumerated, it was assumed that the amount the was segregated from recyclables or compostables were also the same amount that was to be recycled and composted. From this, a *MIN* function was set in place to calculate the amount of waste was recycled under the Business-As-Usual scenario.

Lastly, the resilience score was derived from the equation of from the ECA for waste diversion with a standard diversion goal of 55% as reported by the MMDA for Metro Manila (Jarmin, 2020). It was framed such that if the LGU was able to meet the target diversion, then they would be considered resilient. The amount of residuals was also considered but not explicitly added in the computations as it reduced the stock anyway. The difference for the two cities is that in the case of Pasig City, the pathway for the residuals also passed through the potential RDF scenario. The equation was as follows:

$$Resilience\ Score\ for\ Solid\ Waste\ Management = \frac{Total\ Treated\ Waste}{Target\ Diversion\ from\ Generated\ Waste}$$

Equation 7. Resilience Score for Solid Waste Management

The self-sufficiency score was framed in a similar way, except that the target diversion was not factored in. The amount of residuals was also explicitly not considered for both cities this time. This is because residuals are brought outside the city and are therefore not counted as part of the score.

$$Self-Sufficiency\ Score\ for\ Solid\ Waste\ Management = \frac{Total\ Treated\ Waste\ within\ the\ City}{Generated\ Waste\ by\ the\ City}$$

Equation 8. Self-Sufficiency Score for Solid Waste Management

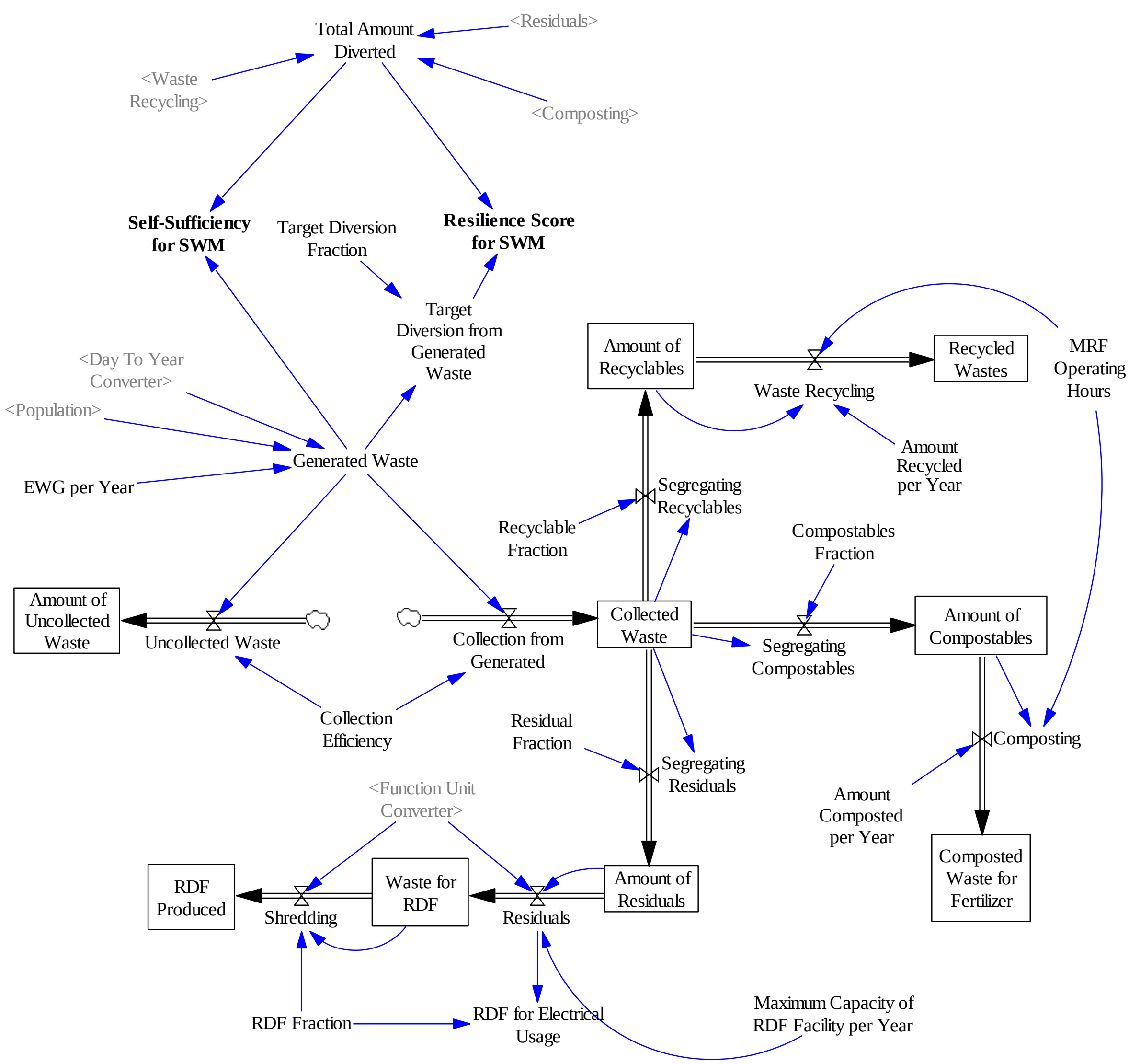


Figure 26. Stock-Flow Diagram for Solid Waste Management (Pasig City)

The stock-flow diagram for Pasig as seen in Figure 26 also had a similar structure as that of Valenzuela City's solid waste management model. This was because both cities reported a similar flow of waste and where each category ends up based on their 10-Year Solid Waste Management Plan (Angeles, 2015). The difference with Pasig City's model is that it factored in the scenario for refuse-derived fuel or RDF as seen in Table 7. This added an outflow for residual waste to be treated within the city (Angeles, 2020). Currently, the value remained at 0 as there has been installation of an RDF facility. This would mean that the resilience and self-sufficiency scores were computed similarly to that of Equation 7 and Equation 8.

3.3.2.3.2 Sub-Model for Wastewater Regulation

The wastewater regulation service as seen in Figure 27 depicted the pathway of wastewater treatment handled by private concessionaires Manila Water for Pasig and Maynilad for Valenzuela. The causal loop diagram found in Figure 27 refers to the dynamics between wastewater generation and treatment framed as a gap. This CLD has two balancing loops.

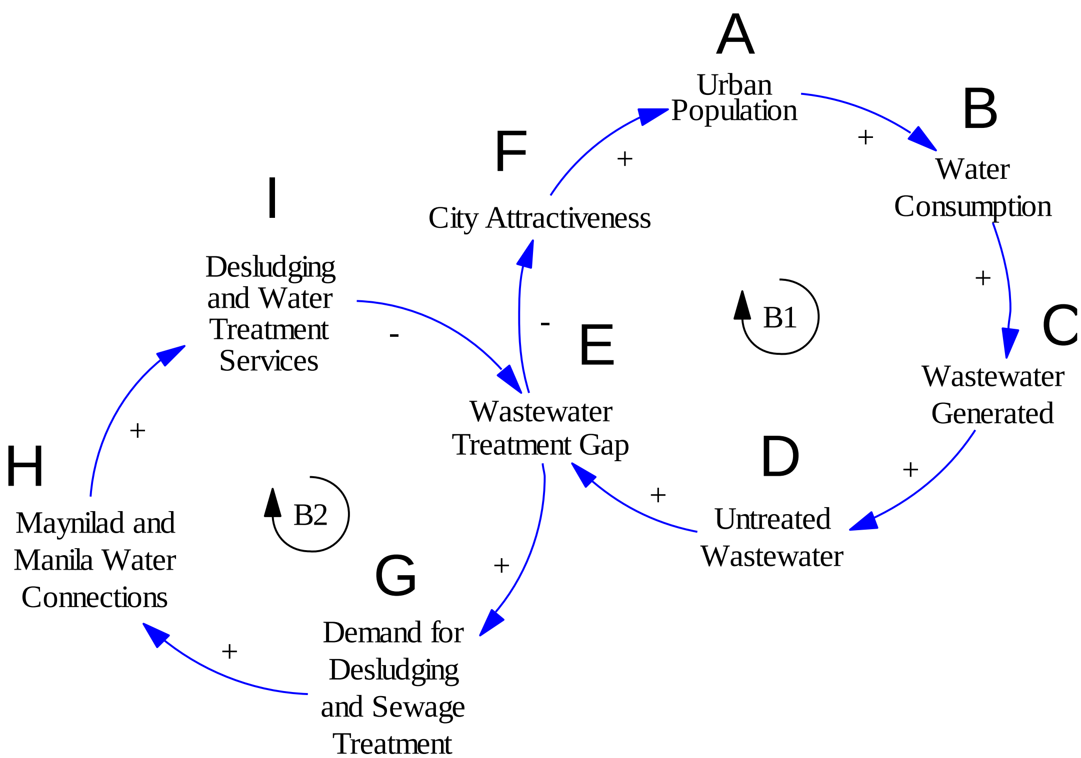


Figure 27. CLD for Wastewater Regulation

Balancing loop B1 (A-B-C-E-F-A) followed how an increasing population also causes an increase in amount of wastewater generated and therefore the amount of untreated wastewater. This increases the wastewater treatment gap because it increases the gap between the supply of wastewater treatment. When framed using a supply-and-demand logic, this would be the demand. This gap decreases city attractiveness due to the amount of unmanaged waste.

Balancing loop B2 depicts the same wastewater treatment gap that increases the demand to treat the wastewater generated. Increasing the connections to Maynilad and Manila Water would then mean increasing the amount of desludged and treated water, decreasing the gap.

The stock-flow diagram for wastewater as seen in Figure 28 was similar for both cities in terms of overall structuring of wastewater pathway. The main difference in the model were in the case of Valenzuela's sewage treatment, which as of present, does not have any connections to the sewer lines meaning they were assumed untreated. This model was also constructed with auxiliary variables because the capacities of the septic tanks and septage treatment facilities were not specified with the data sets collected and cannot be framed into flows.

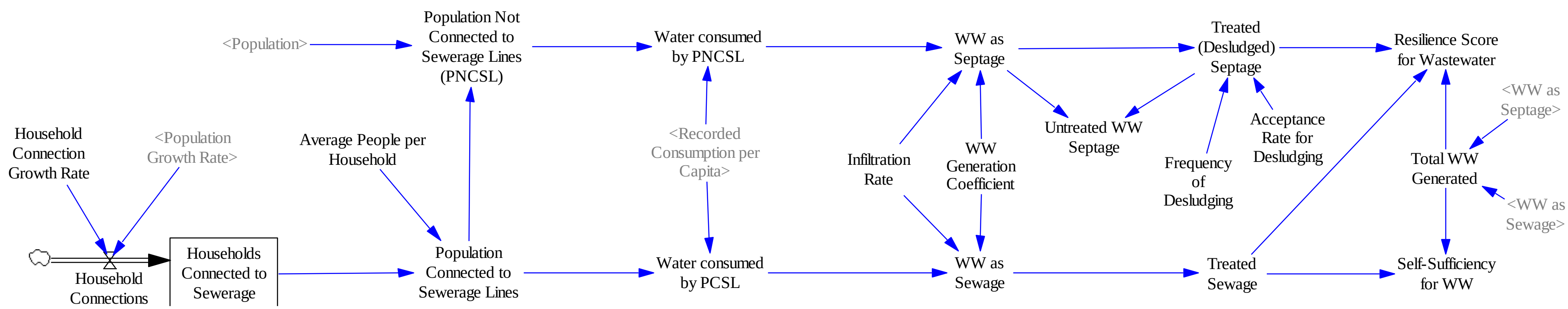


Figure 28. Stock-Flow Diagram for Wastewater Regulation (Valenzuela and Pasig City)

The stock-flow diagram for wastewater as seen in Figure 28 was similar for both cities in terms of overall structuring of wastewater pathway. The main difference in the model were in the case of Valenzuela's sewage treatment, which as of present, does not have any connections to the sewer lines meaning they were assumed untreated. This model was also constructed with auxiliary variables because the capacities (in terms of volume treated over time) of the septic tanks and septage treatment facilities were not specified with the data sets collected and cannot be framed into flows.

As reported by Manila Water, the amount of sewage treated was still below the capacity of the STP within Pasig City. One difference was that the amount of people who were connected to sewerage lines was 100% of the population according to Manila Water (Co, 2020). Both cities, given the same structure for wastewater, followed the same scoring criteria for resilience self-sufficiency as seen in Equation 10 and Equation 11.

In terms of treatment, the model differentiates between sewage and septage via the number of people who were connected to septic tanks and those who were connected to the sewerage lines. In order to determine the fraction of the population connected and not connected, households with connection lines, data set obtained from Manila Water (2020), was subtracted from total population, data set obtained for PSA (2002) to derive households not connected. The amount of people who were not connected to sewerage lines were assumed to be connected to septic because it was also reported that for Pasig, 100% of the population is connected to Manila Water (dela Cruz, 2020). Determining household connection would allow the model to differentiate between which of the population's wastewater is treated as septage and which as sewage. Additionally, the rate by which connections grew per year had an exponential trend. With that, the exponential growth formula in Equation 1 was used to compute for household connection rate.

To calculate the amount of water generated per capita, the equation used by Maynilad and Manila Water for Average Dry Water Flow (ADWF) was used:

$$Average\ Dry\ Water\ Flow = Billed\ Volume \text{ x } 0.8 \text{ x } Infiltration\ Rate$$
$$\text{Where Infiltration Rate} = Billed\ Volume \text{ x } 0.15$$

Equation 9. Equation for Calculating Wastewater Generated *(Garza, 2020)*

With that, Billed Volume was computed as the number of people connected to either sewerage lines or septic tanks multiplied to the average water consumption per capita per day. This was then converted to cubic meters per year for consistency.

Because treatment was separated, it was assumed that all households connected to the sewage lines had their wastewater completely treated. The difference in the treatment of septage was the frequency of treatment which happened every 5 years. This was represented by the frequency variable which was multiplied to the average acceptance rate in the city per year. This was done to determine the amount of treated septage per year. In terms of computing the untreated wastewater, the amount of wastewater generated was subtracted from the amount of wastewater that was treated, both as sewage and as septage, to determine how much was not treated. The value of this was used in determine emissions from untreated wastewater.

The wastewater model also contained a self-sufficiency score whose criteria was based on how much wastewater was treated in the city versus how much wastewater was generated overall. According the Manila Water, only sewage was treated within the city while septage was sent outside (Cruz, 2020).

The resilience and self-sufficiency scores were calculated as:

$$Resilience\ Score\ for\ WW = \frac{Treated\ Sewage + Treated\ Septage}{Total\ Wastewater\ Generated}$$

Equation 10. Equation for Resilience Score for Wastewater

$$Self - Sufficiency\ Score\ for\ WW = \frac{Treated\ Sewage\ in\ the\ City}{Total\ Wastewater\ Generated\ by\ the\ City}$$

Equation 11. Equation for Self-Sufficiency Score for Wastewater

3.3.2.3.3 Sub-Model for Air Quality Regulation

Seen in Figure 29 is the causal loop diagram for air regulation service. The causal loop diagram highlighs the dynamics of what influences amount air emissions and how it drives demand for regulation. In this CLD then are 2 balancing loops, and one linking variable.

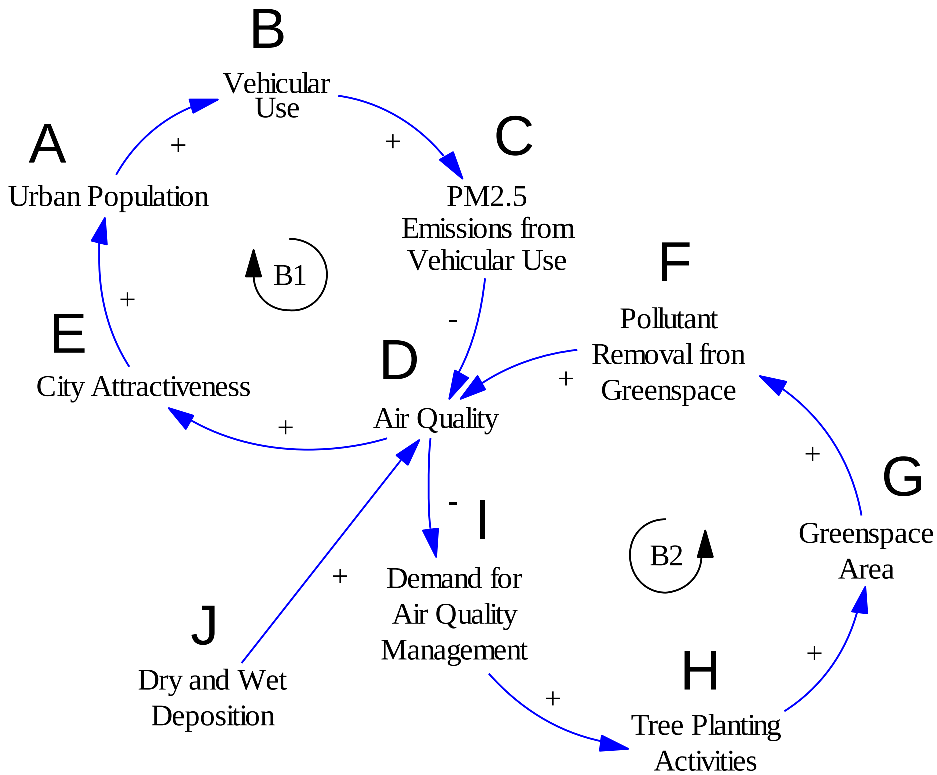


Figure 29. CLD for Air Regulation Service

Balancing loop B1 (A-B-C-D-E-A) followed how an increasing population also causes an increase in the number of vehicles on the road. This would affect air quality negatively due to the increase in $PM_{2.5}$ emissions from the number of vehicles on the road.

The same air quality also drives the demand for better air quality regulation. If the air quality is worse, there would also be an increase in air-quality-related illnesses. That would mean that there is a higher demand for air quality regulation activities such as tree planting. This would also increase the greenspace area which also removes pollutants from the air. Lastly, dry and wet deposition (J-D) also improves air quality as it is one natural way that air pollutants get removed as well.

The causal loop diagram was translated into a stock flow diagram, as seen in Figure 30, Figure 31, Figure 32 measure quantitatively the regulating capacity of the city for air emissions. Some variables from the CLD were also not included such as the incidence of respiratory illnesses. This was due to the data availability not being able to account for the incidences of such given model specificities but were included in the CLD anyway give a holistic view of the service.

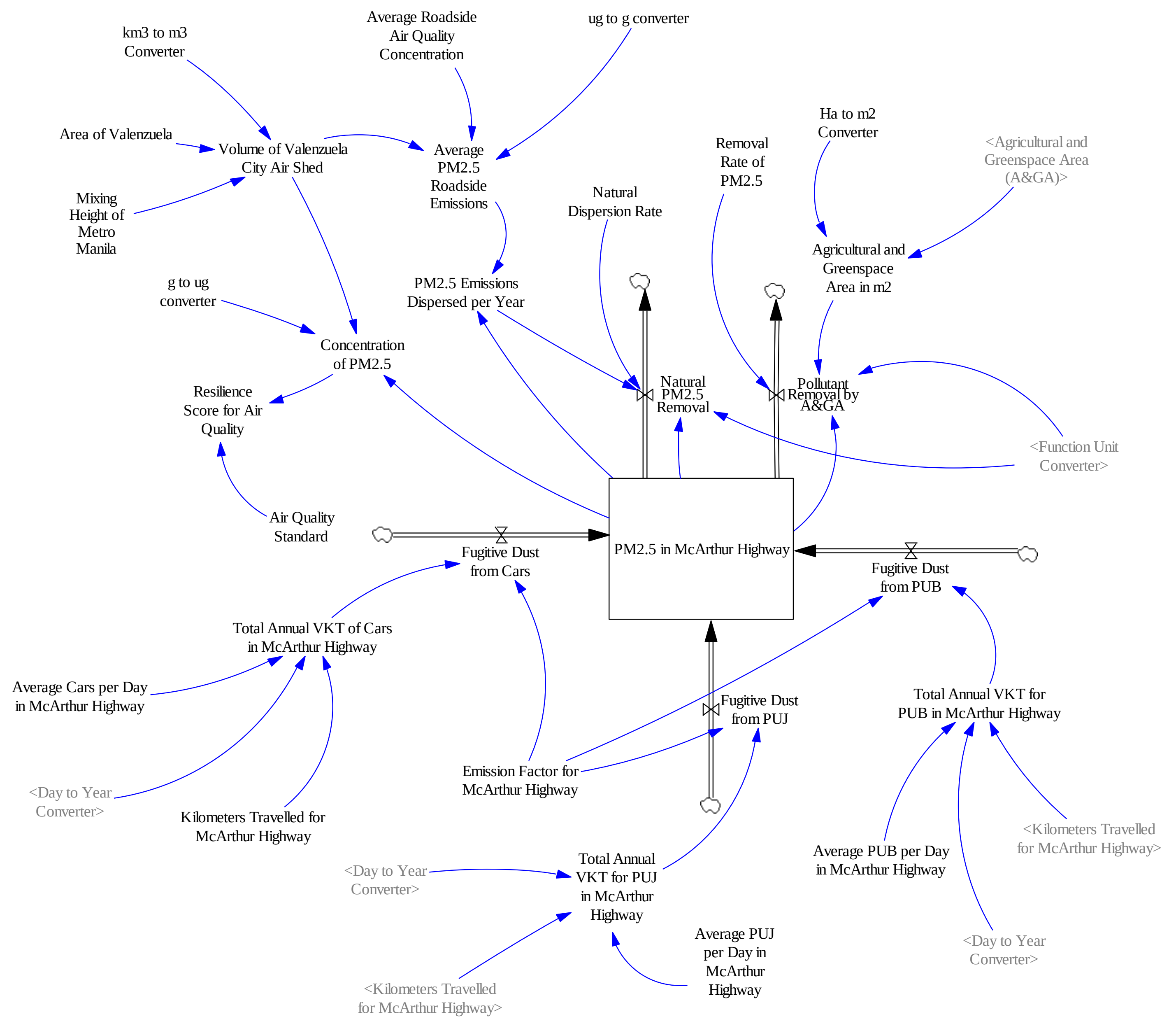


Figure 30. Stock-Flow Diagram for Air Quality Regulating (Valenzuela City)

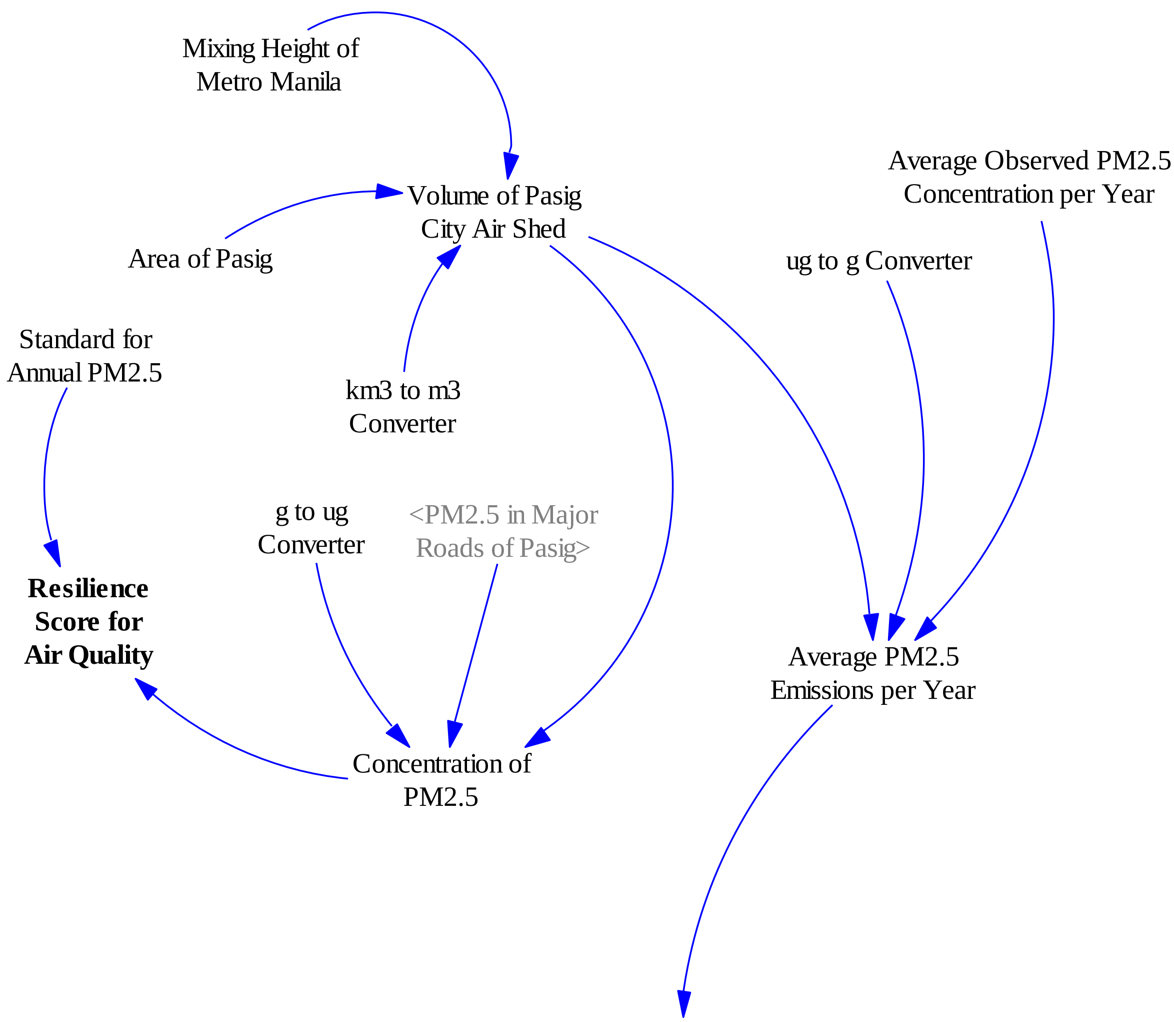


Figure 31. Portion of Air Quality Stock-Flow Diagram Representing the Resilience Score (Pasig City; Cut-off from the top part of Figure 32, from variable *$PM_{2.5}$ Emissions Removed per Year*)

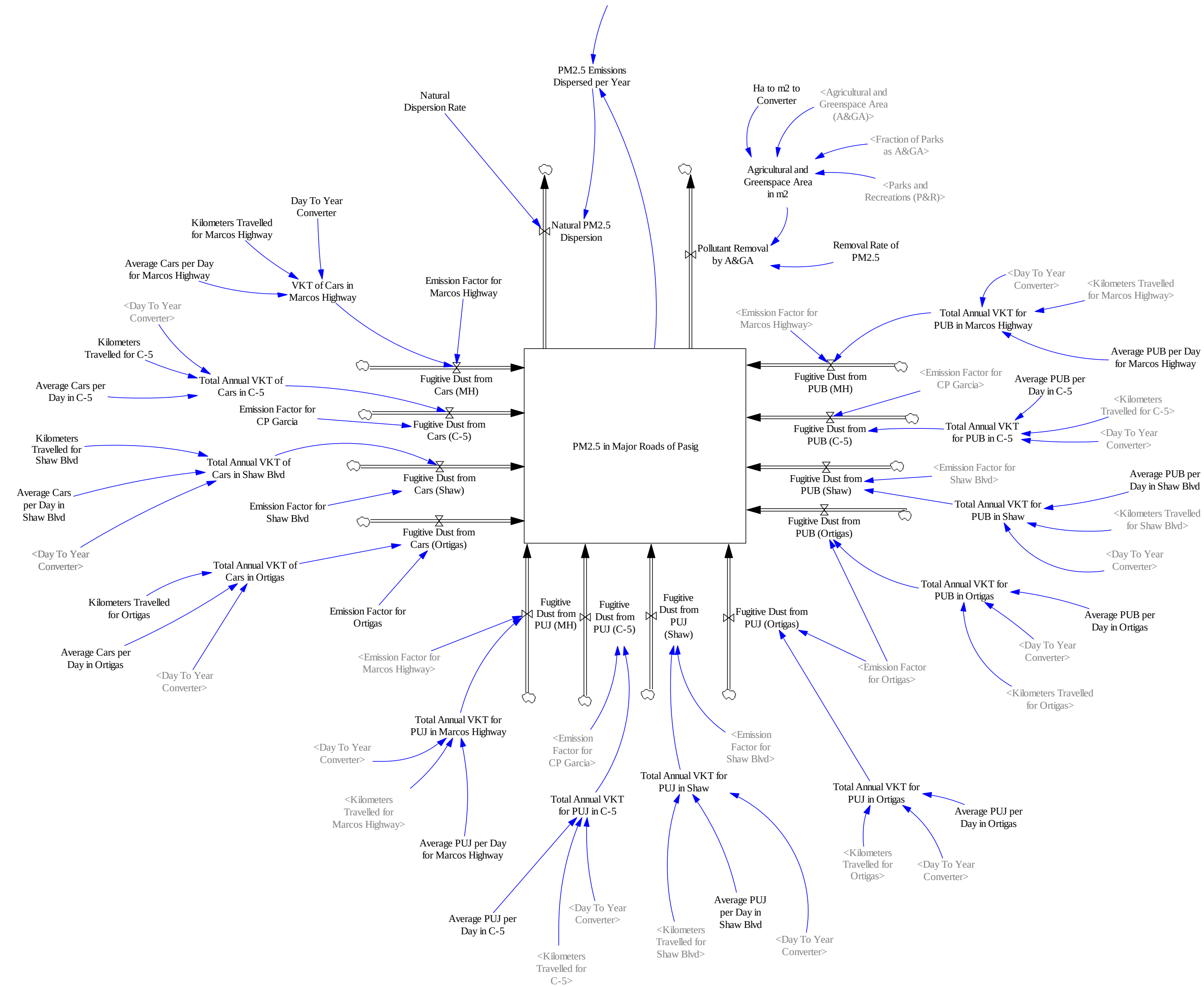


Figure 32. Stock-Flow Diagram for Air Quality Regulation (Pasig City; Connects to Figure 31 from variable *Average PM2.5 Emissions per Year*)

The sector of interest was the mobility sector to represent the partial air emissions in the city given that volume per road could be tracked by both the national government agencies and local government agencies. Additionally, the model was limited to tracking concentration of $PM_{2.5}$ produced and treated. Given this, the model was only a partial look at the overall air emissions as it did not include stationary sources such as industrial and household. The length for the portion of the national roads in the city was used as the kilometer travelled. Only three major vehicles were monitored in determining air emissions, mainly PUJ, PUB, and Private Cars. It should also be noted that while initially, a full mobility sub-model was planned, data limitations constrained the data collected as inflows to be inflows to these stock-flow diagrams based on the AADT collected from the MMDA (2018).

The stock flow diagram used two main equations to derive vehicular PM2.5 emissions. These equations were seen in *Equation 12* obtained from (US EPA, 2011). The empirical formula for solving paved roads first involved computing for the emission factor. The equation was used given the type of data sets monitored by the city. Values for base emission factor for particle size and road surface silt loading were obtained from the US EPA (2011). The particle size range used was that of PM2.5 which was 1.1 g/VKT while the silt loading value used was for a high ADT (for roads with at least 5,000 vehicles per day) and normal conditions which equated to 0.1. Given that the units for an empirical formula would not be resolved in the vensim model, the values were computed outside the model. Another important consideration was that the emission factor should be the same regardless of vehicle type. In order to resolve the difference, the average weight of all vehicles were obtained and used for the model.

$$E = VKT * EF$$

$$EF = k(\frac{sL}{2})^{0.65} * (\frac{W}{3})^{1.5}$$

Where
E = average annual mass emission rate (g/yr)
VKT = vehicle kilometers traveled (km/yr)
EF = emission factor (g/km)
k = base emission factor for particle size range of $PM_{2.5}$ (g/km)
sL = road surface silt loading (g/m^2)
W = average weight of the vehicles travelling the road (metric ton)

Equation 12. Equations for Computing Paved Road (Environmental Protection Agency, 2011)

Next, there were two outflows, one accounting for natural greenspace removal per hectarage and another for everything else such as diurnal changes, dry and wet deposition, and dispersion rate. The removal rate was based off a study by Selmi et al. (2016) and gave the values for the removal rates Given that the latter method required extensive data sets and real time sensors, the value for that outflow was derived by subtracting the average roadside emissions per year with the overall stock. This average roadside emissions, which were at 55 ug/m^3 were based from an EMB study (DENR-EMB, National Air Quality Status Report 2008-2015, 2015). The value obtained using the Paved road equation would be in terms of emissions. In order to convert this value into a volume to derive the concentration, a box model was applied for the two cities This required multiplying the area of the respective cities by the mixing height. The value obtained was the assumed value for which air emissions are dispersed or deposited. In terms of the mixing height (Tubal et al; 2002) configurations for which the value is in effect is usually during typical midday, without rain and often observed during summer time. Given the computed concentration, the value was then compared to standard imposed by the DENR DAO-2013-23 (2013) to derive the resiliency score of air as the standard over the actual. The score was seen in the variable *Resilience Score for Air Quality.* This was computed as:

$$Resilience\ Score\ for\ Air\ Quality = \frac{Concentration\ of\ PM_{2.5}}{Air\ Quality\ Standard}$$

Equation 13. Equation for Air Quality Resilience

The models for both Pasig City and Valenzuela City used the same assumptions and equations mentioned above. The difference between the models includes the number of roads per city. Only national roads were used given they were the only ones recorded by the city. This meant that for Pasig City, there were more roads factored in compared to Valenzuela City's one road, McArthur Highway. Regardless of the number of roads, the same equation (Equation 13) was used to calculate for the resilience score.

3.3.2.3.4 Sub-Model for Carbon Emission Regulation

The carbon causal loop diagram as seen in Figure 33 refers to all the sources of emissions and their possible sinks in terms of greenspace sequestration. For the causal loop diagram, the narrative follows the path of the relevant sources of emissions used in the model such as wastewater, electricity, solid waste management, and vehicular emissions.

Reinforcing loops R1 (A-B-C-D-E-F-G-H-Q-P-A), R2 (A-B-C-D-E-F-G-H-R-A), R3 (A-B-C-D-E-F-G-H-S-N-A) and R4 (A-B-C-D-E-F-G-H-I-M-A) refer to how an increasing population increased the amount of GHG emissions are produced through their specific sources such as in consumption and production of electricity, solid waste emissions, vehicle smoke, and generated compostable waste, respectively. This is driven by the increasing temperatures which drive people to demand for cooling. Balancing loops B2 (A-L-K-J-Q-P-A), B3 (A-L-K-J-R-O-A), B4 (A-L-K-J-S-N-A) and B5 (A-L-K-J-I-M-A) refer to how having carbon mitigation goals target the source and are aimed to reduce emissions while balancing loop B1 (E-A-B-C-D-E) referred how having a sink such as greenspace increases sequestration rates, therefore lowering cumulative carbon emission.

The stock-flow diagram for carbon emissions as seen in Figure 34, Figure 35, Figure 36, and Figure 37 tracked all the possible sources carbon emissions in the city as limited by data availability. Namely, these were the *Emissions from Transport*, *Emissions from Electricity*, and *Emissions from Waste*, which was a combination or the CH_4 emissions from WW and SWM converted to $CO2_e$.

Figures 34 and 35 for Valenzuela and Figures 36 and 37 for Pasig were split into two for readability. The cut-off point for the models for both cities started at the stock *CH_4 Emissions from SWM and WW* which connects to the variable *Emissions from Waste*, the same variable the second figure starts from.

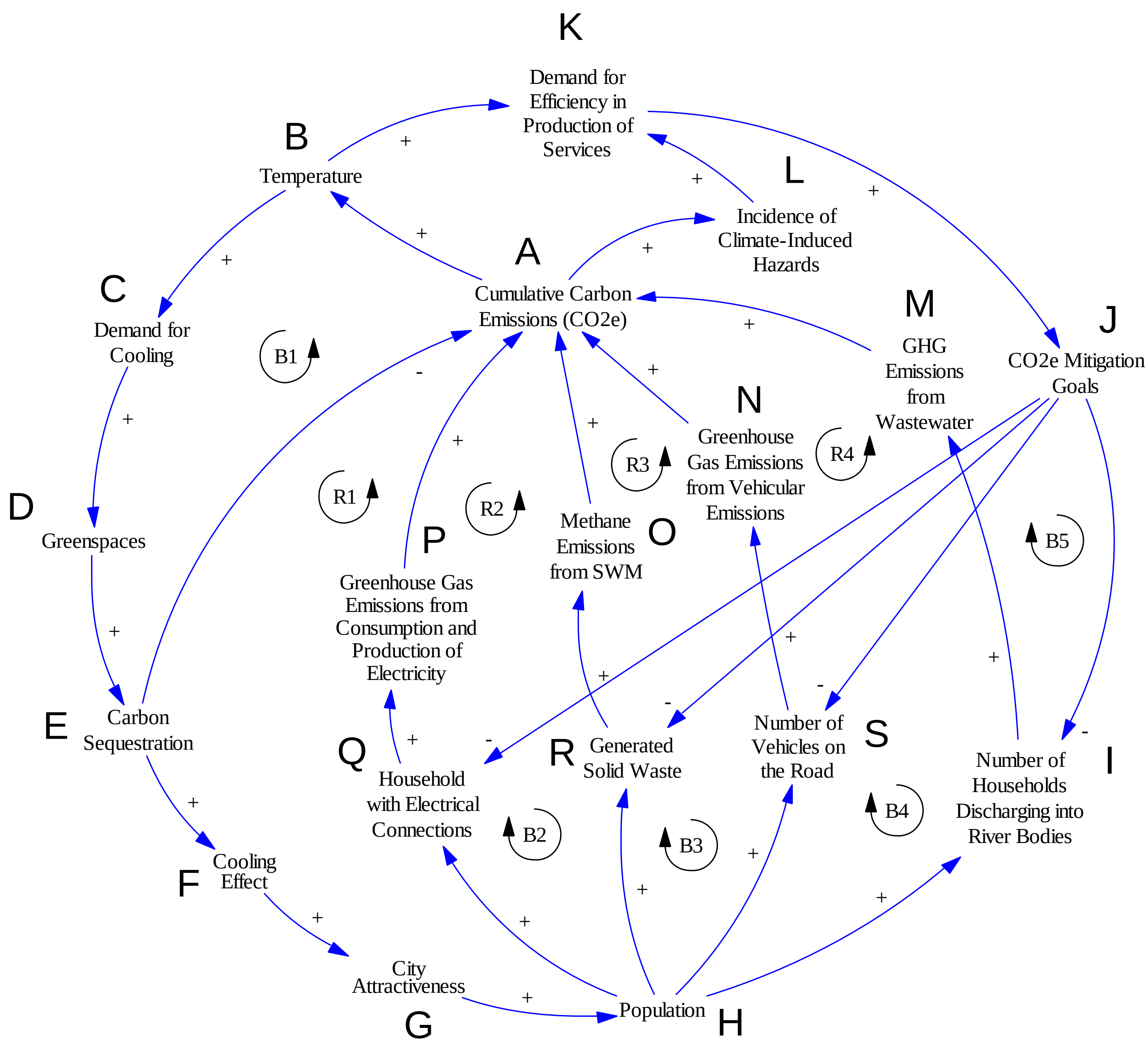


Figure 33. CLD for Carbon Emission Regulation

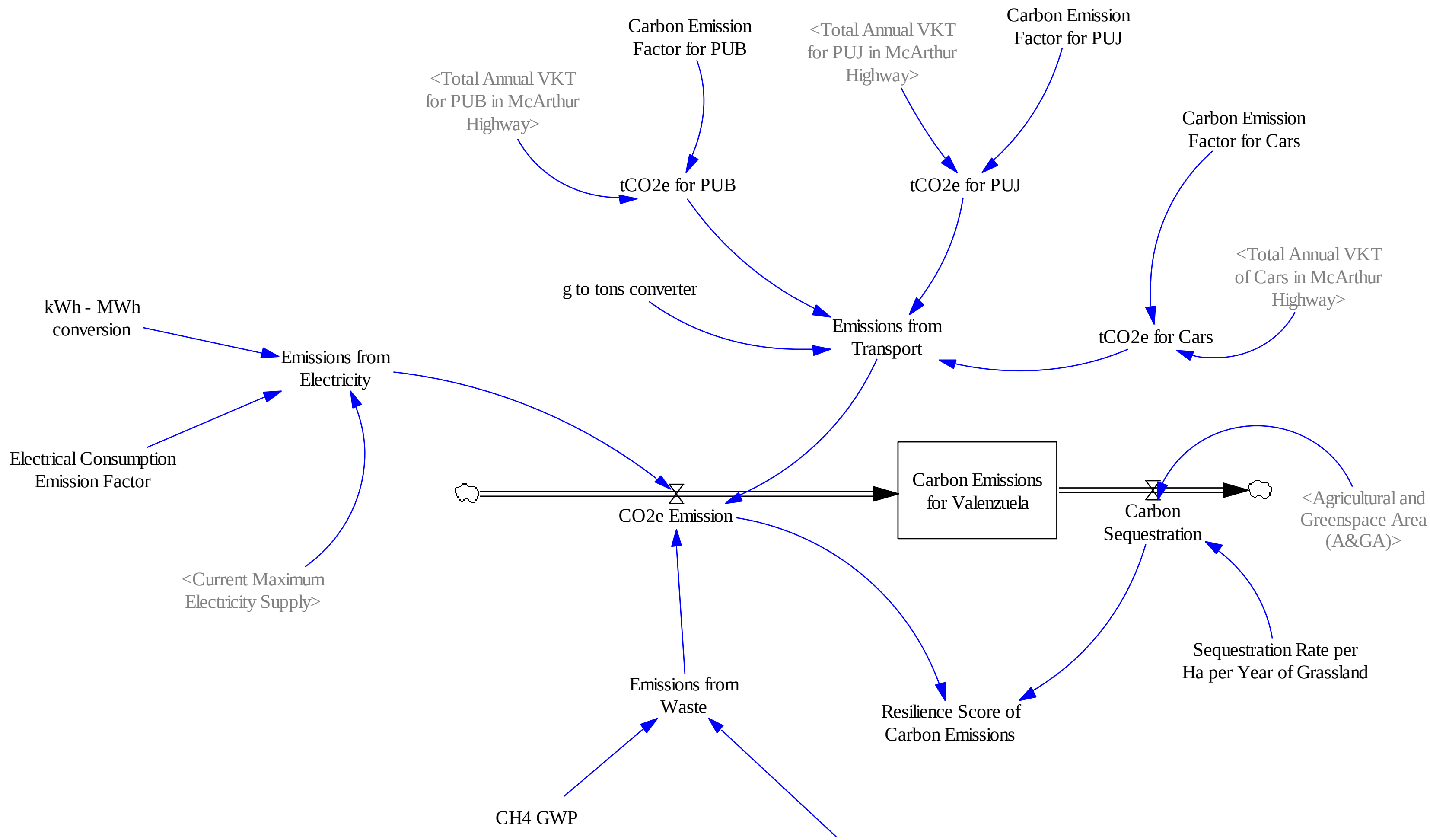


Figure 34. Stock-Flow Diagram for Carbon Emission Regulation (Valenzuela City; Electricity and Vehicular Carbon Emissions; Cut off from the variable *CH_4 Emissions from SWM & WW* connected to *Emissions from Waste*)

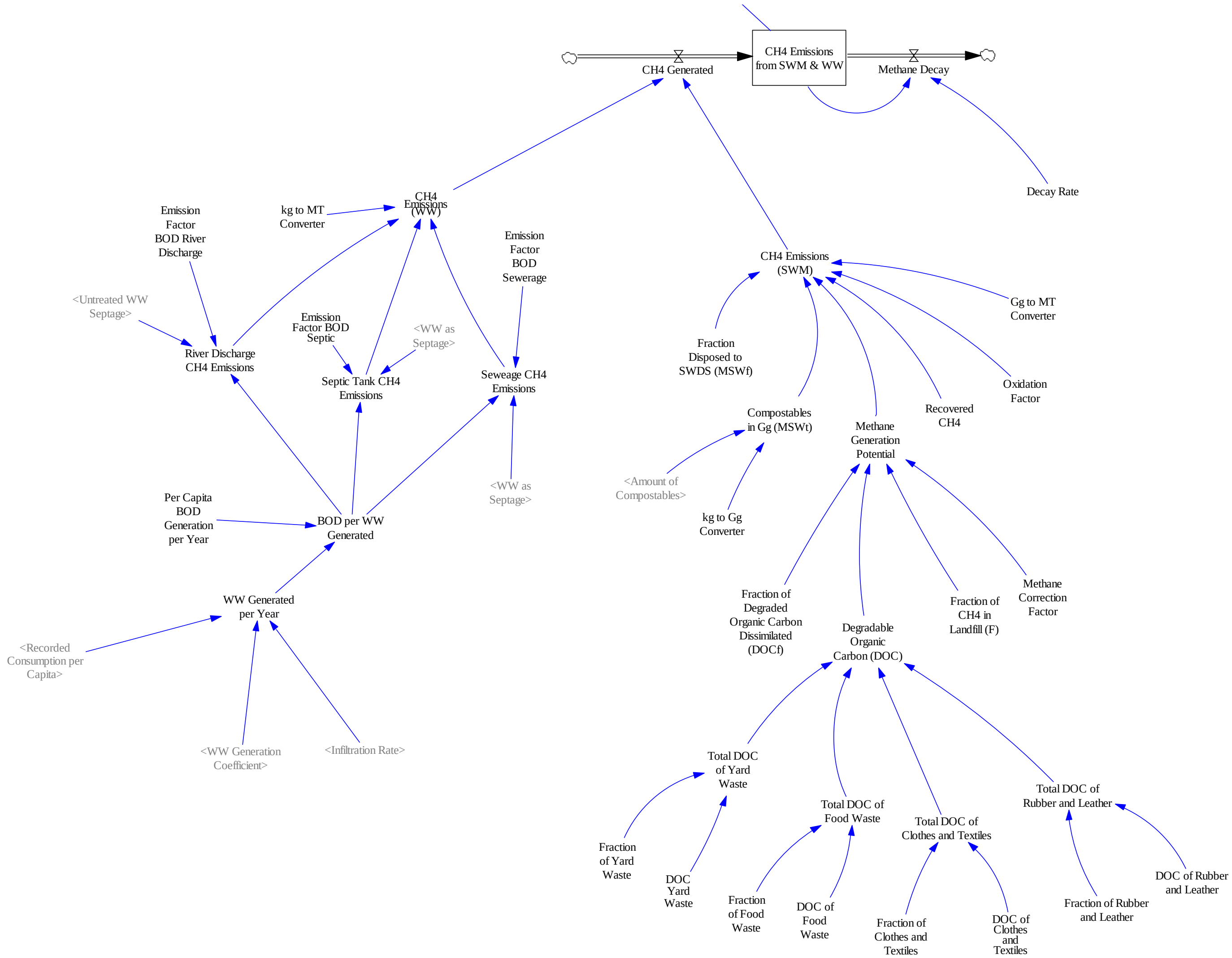


Figure 35. Stock-Flow Diagram for Carbon Emission Regulation (Valenzuela City; SWM & WW. Cut-off from Stock *CH4 Emissions from SWM & WW*)

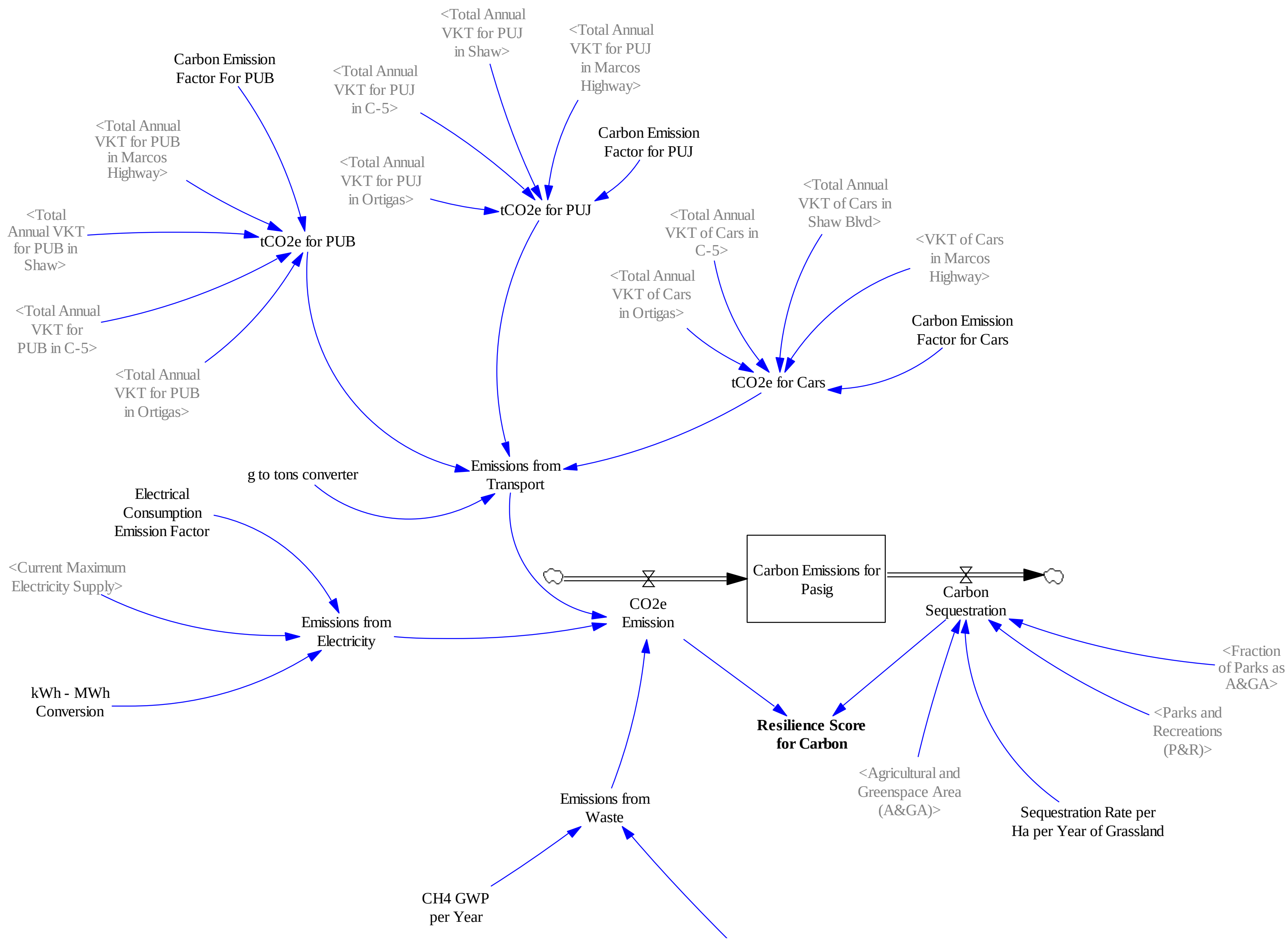


Figure 36. Stock-Flow Diagram for Carbon Emission Regulation (Pasig City; Electricity and Vehicular Carbon Emissions; Cut off from the variable *CH_4 Emissions from SWM & WW* connected to *Emissions from Waste*)

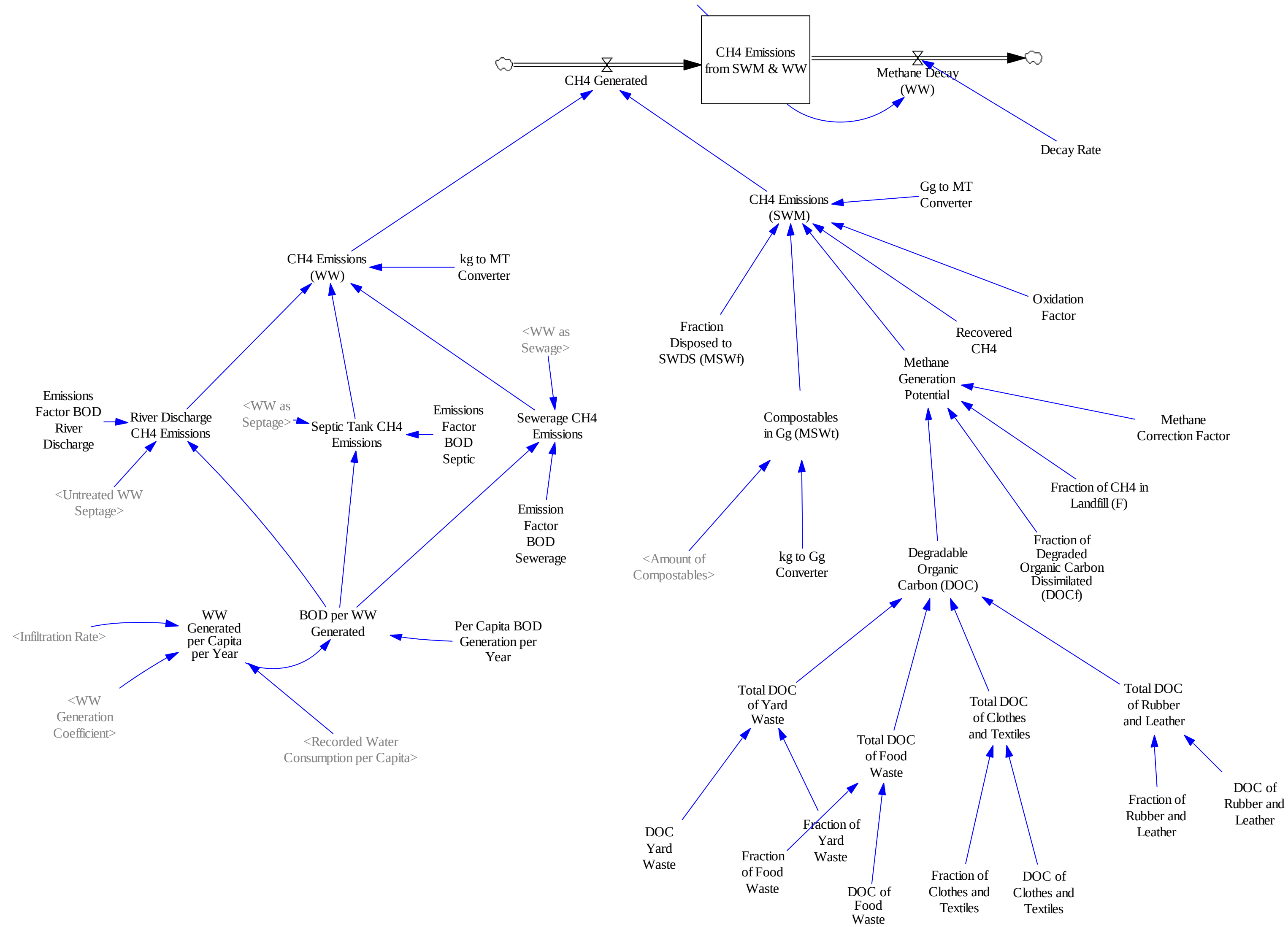


Figure 37. Stock-Flow Diagram for Carbon Emission Regulation (Pasig City; SWM & WW. Cut-off from Stock *CH4 Emissions from SWM & WW*)

For the solid waste part of the sub-model, it was assumed that all of the compostable processed by the city were the only that emitted carbon emissions in methane specifically. From the fraction given in the solid waste management plans of the cities, each had fractions for degradable organic carbon or DOC and emission factors per waste type. The same stock-flow diagram was also made for the Pasig model however, due to factoring in more roads, the model had to be adjusted accordingly. In this case, the resilience and self-sufficiency scores were calculated similarly. The values of the DOC and compostable fraction were used in setting up the equation for the emissions following the first-order decay method. The equation given by the IPCC is as follows:

$$\mathrm{CH_4\ emissions}\left(\frac{\mathrm{Gg}}{\mathrm{year}}\right) = [(\mathrm{MSW_T} + \mathrm{MSW_F} + \mathrm{L_0}) - \mathrm{R}] * (1 - \mathrm{OX})$$

Where

MSW_T = Total MSW generated (Gg/yr)

MSW_T = Fraction of MSW disposed at SWDS

L_0 = Methane Generation Potential (MCF * DOC * DOC_F * F * 16/12) ($GgCH_4/Gg_{waste}$)

DOC = Degradable Organic Carbon (fraction GgC/GgMSW)

DOC_F = Fraction DOC Dissimilated

F = Fraction by volume of CH_4 in landfill gas

R = Recovered methane (Gg/yr)

OX = Oxidation factor (fraction)

Equation 14. First Order Decay Method (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)

Based on the equation, it was assumed that oxidation factor was 0, methane recovery was also 0 and methane correction factor was at 0.4. The methane correction factor 0.4 because it was assumed that the type of solid waste disposal site was unmanaged, anaerobic and that there were instances for methane recovery.

For wastewater, the equation was derived from the GHG Inventory performed on the city in 2012. The equation was as follows:

$$\begin{aligned}\text{Total Emissions} = {} & \text{BOD per WW Generated} \\ & * [(\mathrm{EF_{Septic\ Tanks}} * \text{Septage Generated}) \\ & + (\mathrm{EF_{Septic\ Tanks}} * \text{Untreated WW Generated}) \\ & + (\mathrm{EF_{Septic\ Tanks}} * \text{Sewage Generated})]\end{aligned}$$

Equation 15. CH_4 Emission Calculator (Derived from GHG Inventory (2012))

Where

BOD per WW Generated =

BOD Generated per Capita per Year **x** WW Generated per Capita

The original equation from the GHG inventory used population. However, instead of using population, the volume of wastewater was used instead. This was done so that the emissions would be based on the volume of wastewater instead of the people specifically. This was computed as the wastewater generated per capita multiplied by average BOD generated. The amount used for that was a value dictated in same document as the average BOD generated per capita per day at 40 g. This was based of the GHG Inventory Report (2012) given by Pasig City. The vehicular and electrical carbon emission factor also followed the same values given in this report.

3.3.2.3.5 Sub-Model for River Rainwater Conveyance Resilience

The river conveyance causal loop diagram as seen in Figure 38 was framed to capture only the major rivers in Pasig and Valenzuela which contributed to flooding in the cities due to overflow. The causal loop diagram shows the factors affecting flooding incidences which was a result of excess surface water coming from run-off.

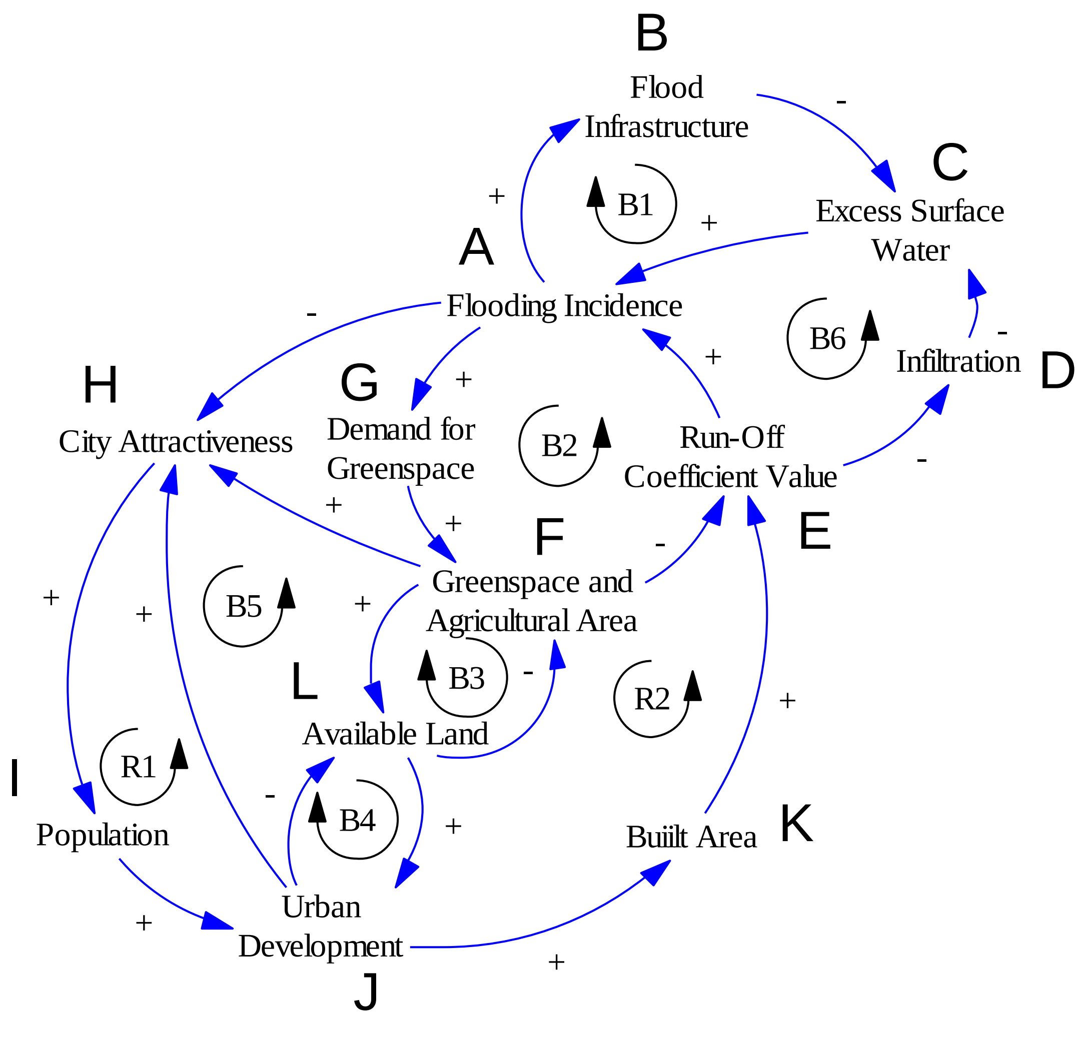


Figure 38. CLD for Rainwater Conveyance Regulation

There are 6 balancing loops and 2 reinforcing loops identified in the system. B1 (A-B-C-A) and B6 (A-C-D-E-A) deal with mechanisms which excess surface run-off could be mitigated or reduced. B1 refers to the additional of flood infrastructure, either natural or artificial, which serves to reduce excess surface run-off via services as buffer zones or improving infiltration. This in turn reduces incidences of flooding given a decrease in run-off coefficient value of the land as more greenspace have been built. What drives demand for greenspace would be the flooding incidences. Balancing loops B2 (A-G-F-E-A), B3 (F-L-F), B4 (L-J-L) and B5 (A-H-I-J-K-E-A) described the relation of flooding incidences to land use and urban development. The logic behind this focused on how increasing built up areas increased the run-off coefficient value (B5) and how greenspace and agricultural areas decreased run-off coefficient values. The demand for urban areas to provide for the different needs of the population has led to increased built infrastructure, increase the surface run-off coefficient of that land and making it more prone to flooding incidences.

Reinforcing loop R1 (H-I-J-H) referred to how that same urban development influenced the population to grow. Lastly, reinforcing loop R2 (A-G-F-H-I-J-K-E-A) refers to how more greenspace development increases the city attractiveness. This greenspace development is influenced by its demand from flooding incidences. With more population, there is more urban development, built-up areas and therefore a higher run-off coefficient value as well.

The stock flow diagram for flooding focused more on the cross section of the parts of the river that are within the boundary of the cities. The surface-run off coefficient used the totality of the area and derived its values from the CLUP. The model projects the ability of the river to convey surface run-off in the long run given different rainfall scenarios. It was assumed in the model that all surface run-off generated would be discharged, via the different drainage lines in the city, to the main channels. The model was only able to measure conveyance given the data sets collected and obtained from the city.

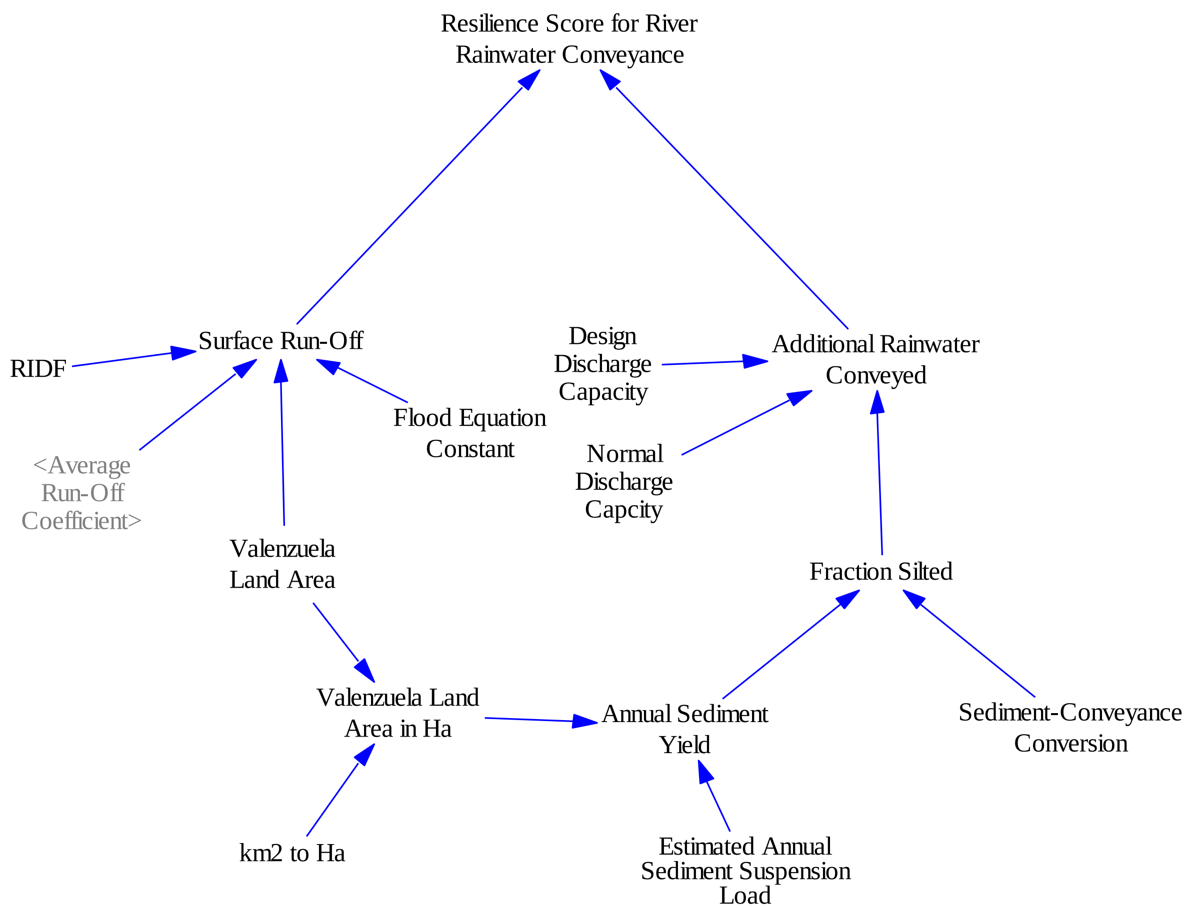


Figure 39. Stock-Flow Diagram for River Rainwater Conveyance (Valenzuela City)

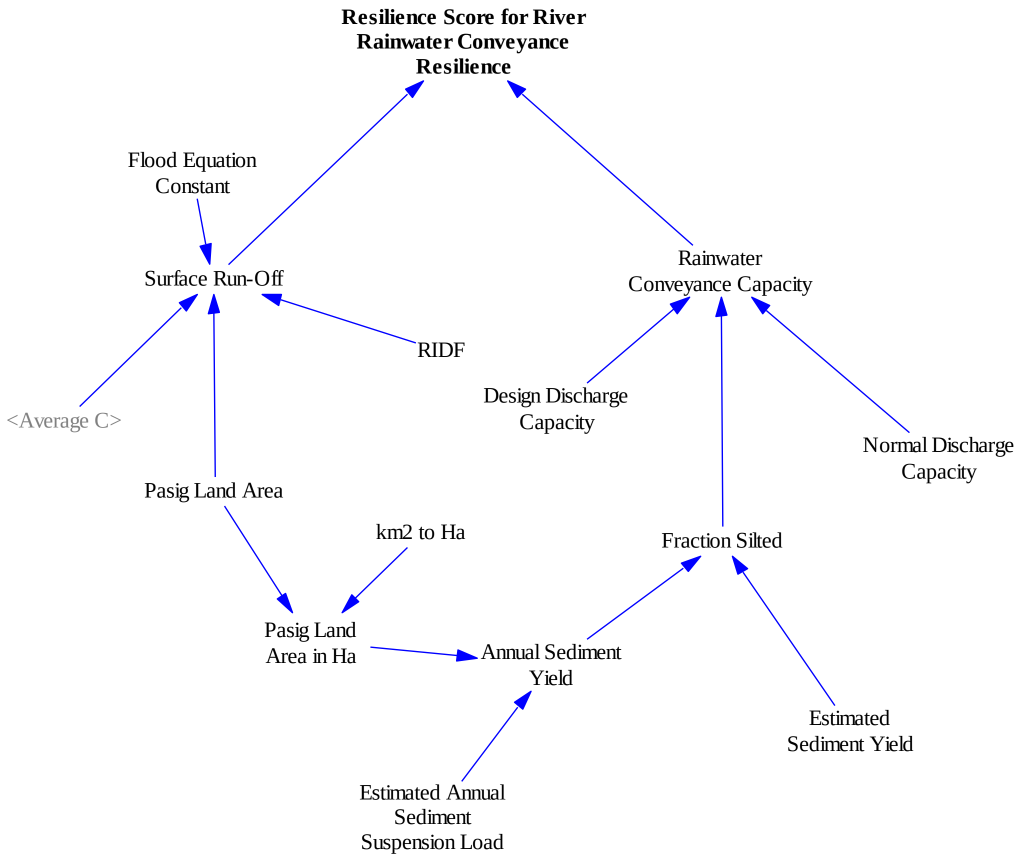


Figure 40. Stock-Flow Diagram for River Rainwater Conveyance (Pasig City)

The model did include artificial drainage performance (diverted by drainage or drainage overflow) or the contribution of tributaries in water diversion as it only focuses on the parts of the main river situated within city boundaries. The only assumption for the tributaries made was that if the flood occurred in the parts of the city where these tributaries were, then it would imply that the main river channel was not able to convey the incoming surface run-off. The scope was limited within city political boundaries and boundaries covered by Metro Manila. This was the case for Valenzuela as the Meycauayan River, which was not considered as part of Metro Manila also ran through a portion of the northern part of the city. The entire stretch for Tullahan River was also not considered as it runs along three other cities. Only the stretch within the city was taken account for in the computations. For Pasig, the river that was considered was the lower Marikina River given that the entire stretch ran through the side of Pasig. Therefore, in order to calculate the initial volume, the entire stretch was considered. However only the section at the confluence point between the lower Marikina River and the Pasig River was considered. This site was important because it was where the hydraulic radius and cross-section area were derived from. What was not considered was the natural flow coming from the upper basin. The consideration was limited to the surface run-off conveyed to the river from the city. Therefore, the model only measured the capacity of the river allotted only for the surface run-off as a result of both the rainfall data used and the land use of the city. It is also important note that while the siltation fraction was added in the model, the value remained at zero as it was not part of the scope of this stock-flow diagram nor the scenarios constructed from it.

Both models for Pasig and Valenzuela using the rational formula as well as the Continuity equation. The rational formula, which factored in the estimated amount of surface run-off was comprised of 3 variables which were the average rainfall intensity, the catchment area and the run-off coefficient. Run-off coefficient values were calculated in the land-use model. Average rainfall was calculated based on a JICA study (2003). This was tested and applied across the other Rainfall Intensity Duration Frequency (RIDF) values found in Table 4. These values were placed in the river rainwater conveyance models, and functioned as a slider value instead, signaling the user to input the values stated in the table only. Said values were computed outside of the model, which is why all the decimal points were retained anyway. The catchment area was also assumed to be that of the entire city as it was the part that was going to be affected by flooding. Equation 16 is as follows:

$$Q_{max} = \frac{CiA}{3.6}$$

Where $Q_{max} = \text{Maximum Discharge Capacity at cross} - \text{section} \left(\frac{\text{m}}{\text{s}}\right)$

$i = \text{Average rainfall intensity} \left(\frac{mm}{hr}\right)$

$A = \text{Catchment Area} \ (km^2)$

$C = \text{Run} - \text{off Coefficient Value}$

Equation 16. Rational Formula

Table 4. List of RIDFs Given Certain Return Periods

Variable	RIDF (mm/hr)
BAU 10 Year Return Period	85.245
BAU 25 Year Return Period	97.613
BAU 50 Year Return Period	107.233
BAU 100 Year Return Period	112.998

For the outflow, the Continuity Equation as seen in Equation 17. The equation used the Manning's Equation to calculate for the velocity seen in the Continuity Equation. Values for these equations were based off a DWPH study (2013) but were computed outside of the model. This was framed as the variable *Normal Discharge Capacity*. This was chosen given that flow of the river contained actual observed values rather than estimates. This would mean that if the actual flow could convey the estimated amount of run-off, the river would not overflow and flood the surrounding city. The *Rainwater Conveyance Capacity* (which, conceptually, was the outflow) was also framed as the comparison of the normal discharge capacity and the design discharge capacity. This design discharge was based off a JICA study (1990) for Valenzuela City and a UN study (1990) for Pasig City. This way, the amount of space left for any water flow based on their difference could be computed. The amount of siltation was also factored in here as seen in

Table ***5*** to be computed as *Fraction Silted* and was used for scenario testing. For Pasig, while it was not factored in, the variable was retained should users find it useful. The value for Pasig City was retained at 0. It should also be noted that the normal discharge capacity was computed outside of the model due to model and unit constraints. Instead, the values were retained as constants.

For the outflow, the continuity equation was as follows:

$$Q_{max} = VA$$

$$V = \frac{1}{n} * \left(\sqrt{S}\right) * \sqrt[3]{R^2}$$

$$\text{Where } V = \text{velocity at cross} - \text{section } \left(\frac{\text{m}}{\text{s}}\right)$$
$$A = \text{Area at cross section } (m^2)$$
$$n = \text{Manning's Roughness Coefficient}$$
$$S = \text{slope of the channel at cross} - \text{section } \left(\frac{\text{m}}{\text{m}}\right)$$
$$R = \text{Hydraulic Radius at cross} - \text{section (m);}$$

Equation 17. Continuity Equation and Manning's Equation for Actual Flow

With this, the resilience score was computed as the amount of the amount of additional water (beyond the normal discharge of the river) that can potentially be conveyed (based on design discharge values) versus the amount of estimated surface run-off generated in the area.

3.3.2.4 Supporting Services Sub-Model

The supporting services includes only one module which was the land use model. No resilience scoring was devised for land use service since the role of supporting services is to ensure that the other services are functioning well. This sub-model mainly provided input to the different models and was integrated in provisioning, regulating, and cultural services. Majority of the feedbacks that exist among services involve land use.

The stock flow diagrams as seen in Figure 41 for Valenzuela City and Pasig city, were based only on the reported values from the respective Comprehensive Land Use plan (Palermo, 2009; Acurentes, 2009) of the city. The overall land area in Valenzuela and Pasig were grouped into 5 main land use types in the model mainly: Parks and Recreation (P&RA), Roads (R), Built-up Area (BuA), Available Land (AL), and Agricultural and Greenspace (A&GA).

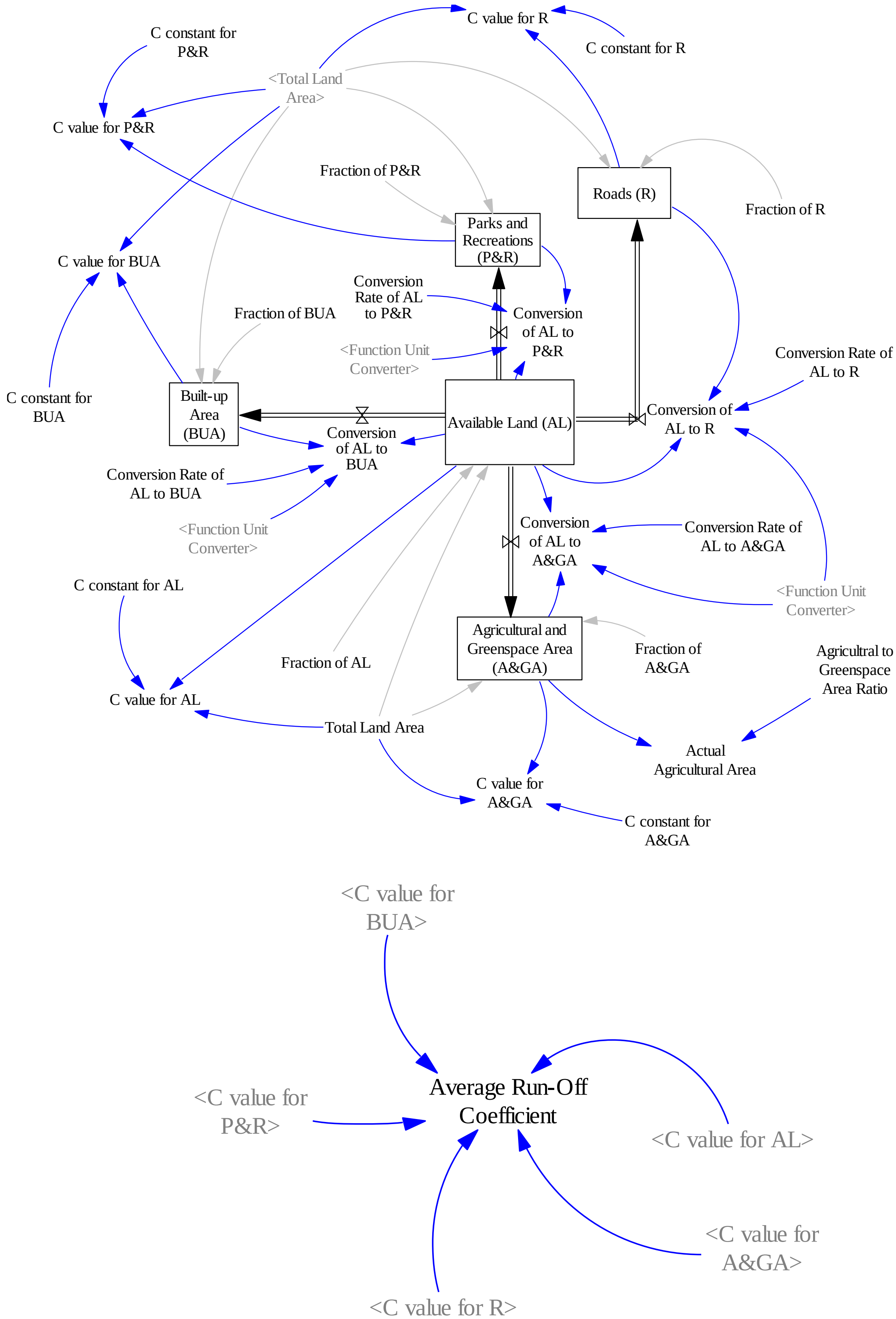


Figure 41. Stock-Flow Diagram for Land Use Change (Valenzuela and Pasig City – Top), Average Run-off Coefficient Stock-Flow Diagram (Bottom)

As for the case of Pasig, there was currently no category for agriculture and greenspace areas (A&GA), therefore its temporary value is set to 0. Both models follow the same structure for land use. When projected, values will remain the same as the last recorded value unless adjusted to consider future development scenarios.

The division was done to put land types of similar run-off coefficient values together to determine the overall runoff coefficient value of each land type area following the criteria used by JICA (2003). The values were used given they were contextualized for the case of Metro Manila. This would have a more accurate results as compared to using international values for surface run-off coefficients. Computing for the surface run-off coefficient was done by getting the average of the surface run-off per land type. The equation used to get the surface run-off coefficient of each land type was seen in Equation 18. The set of values for the surface run-off coefficient were obtained from the Manual of Flood Control Planning (JICA, Manual on Flood Controlling Plan, 2003).

$$\text{Surface Runoff per Land Type} = \frac{\text{Fraction of Land Area}}{\text{Total Land Area}} \times 100 \times \text{Surface Runoff Coefficient value for land type}$$

Equation 18. Surface Run-off Coefficient per Land Type

Aside from their contribution to surface run-off, categorization of land types was also based on their contribution to the different services. Land use types with similar uses were grouped together. This was the case for putting greenspace and agricultural land in one stock to be used for the cultural service. While agricultural spaces cannot substitute parks, they can be considered greenspace with their own cultural value as well (Contesse et, al; 2018). They were also grouped together in the model following the assumption that they both offer their own cultural value. This was also due to how they were framed in the Comprehensive Land Use plan. For the case of Valenzuela, the category of agriculture was removed in the later versions. To make the values more consistent in order to work in the model, they were assumed to belong to the same category as reported for both planning offices (Palermo, 2009; Acurentes, 2009).

As for the values used for the different land use changes in the model, they were obtained from the respective comprehensive land use plans made by the local government units (Palermo, 2009; Acurentes, 2009). Increase in a certain land type comes with the decrease of another. In the case of both cities, “Available Land” served as the main stock for convertible land. These consisted of mostly idle land, cemeteries, waterways, and easement of waterways. Given the assumption that the total land area of a city remains constant, what changes within the city are the percentages of each specific land use types based on the developmental plans of the local government units and limited by how much “Available Land” can still be converted. Conversion rates for each land use type were derived from the respective Comprehensive Land Use plans (Palermo, 2009; Acurentes, 2009) of each city and were computed based on the projected development using Equation 18 given that trends were observed in the amount of change over the years.

3.3.2.5 Cultural Services Sub-Model

The cultural model was divided into three subsections each containing their own scoring system for resilience over time. The cultural model measures the existing recreational space and compares it with the growing demand of recreational space per capita prescribed by different organizations. Given this, the scoring for this model was made to follow a supply and demand approach of the provisioning services but in terms of how much of the required recreational space per capita is achieved over time. This scoring was adapted from the Asian Green City Index (Economist Intelligence Unit, 2011) which created an index on 22 Asian countries using a greenspace per capita indicator as part of their land use component. While this index has been used for other cities, it has often been used to measure efficiency of building development or for regulatory purposes but not on measuring the cultural aspect of the city. Greenspace provides not just regulatory benefits but also human wellness benefits which is why it was chosen as an indicator for this model. In terms of computing for the resilience score, cultural resilience is measured as the ratio between the actual recreational area in the city and the recommended recreational space.

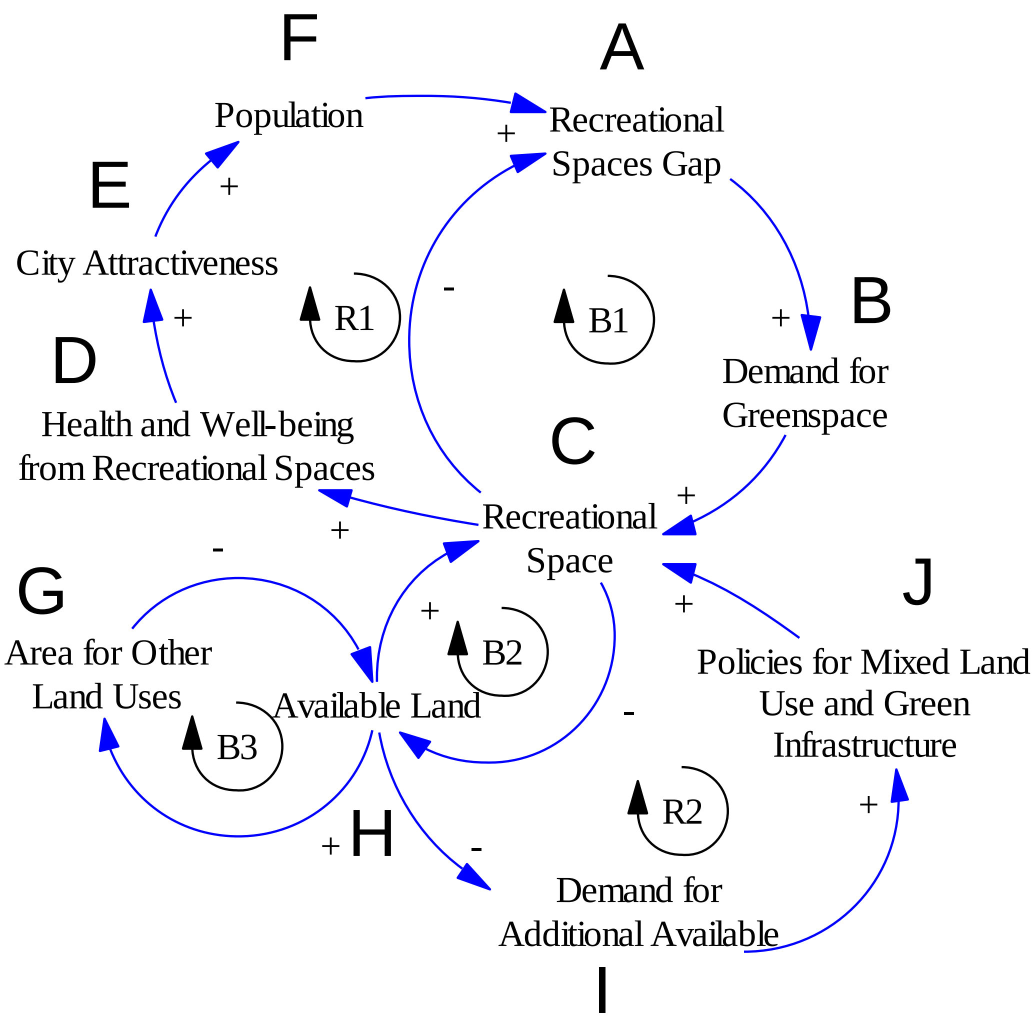


Figure 42. CLD for Cultural Services

The dynamics of the cultural system in the city is seen in Figure 42. There are three balancing loops and two reinforcing loops in the system R1 (E-F-A-B-C-D-E) refers to the continuous increase in recreational space driven by the demand to reduce the gap created by increasing population. As recreational spaces increase, so do the benefits derived from them therefore increase city attractiveness and promoting more population growth. B1 (C-A-B) tackles this continuous growth through the gap in which as the gap decreases, so does the demand for more recreational spaces. B2 (C-H-C) deals with the limits of continuous conversion given that a city has finite convertible land. B3 (G-H-G) refers to the other types of land which can be converted from the available land. Given this, not all land can be devoted to just recreational spaces. Lastly, R2 (H-I-J-C-H refers to the policies to address the problem of limited available land. This involves the use of mixed land use and integrated green infrastructure which does not require conversion of available land but simply to integrate recreational spaces in existing land.

When converted to a stock flow diagram, as seen in

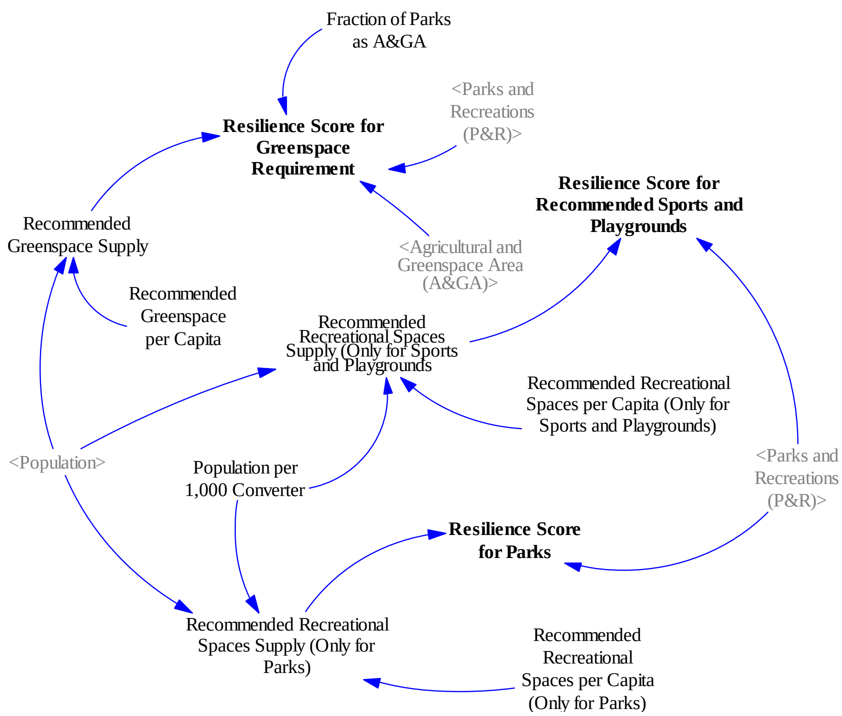
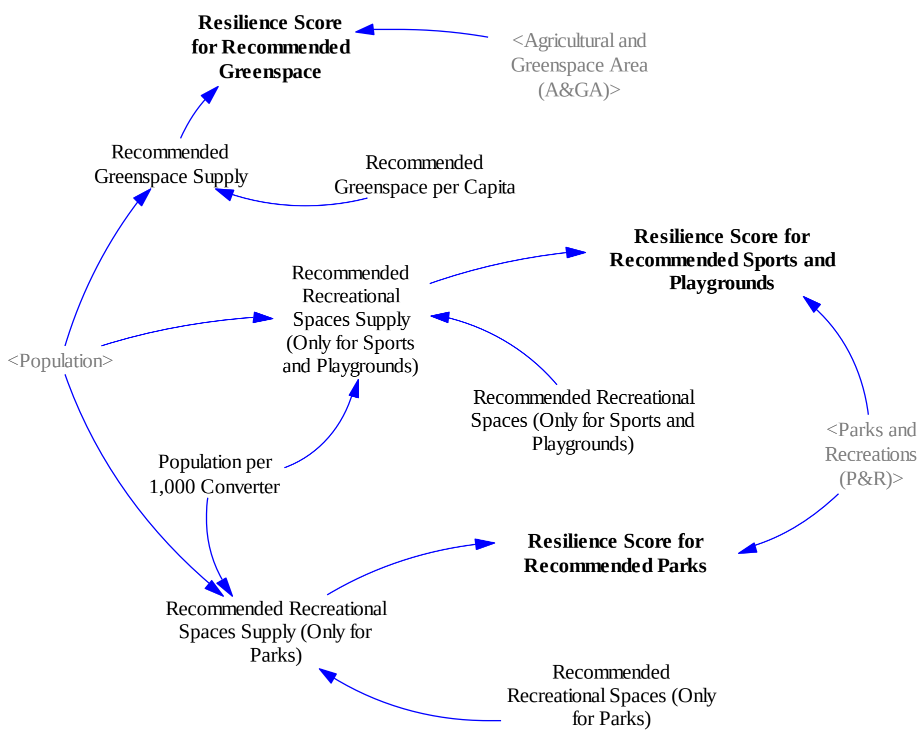


Figure **43**, both cities followed the same structure and only differ in one variable featured in Section 3.4.2.3 **Land Use Scenario**. The respective values for each city were derived from their respective land use models only variables of interest were included to be able to derive the score for resilience. The first subsection refers the *Resilience for Greenspace* whose scoring was based on getting the amount of greenspace required per capita. The values used for determining the percentage of greenspace were derived from the total land area from the land use model. Over time, as the population increases, so does the need for additional greenspace. The guideline set by the World Health Organization of the United Nations (WHO-UN, 2020) which prescribes 9.5 m^2 of greenspace per capita. This value was used to compute for the recommended greenspace needed following the concepts of Equation 19.

$$\text{Resilience Score for Recommended Greenspace} = \frac{\text{Actual Green Space}}{\text{Recommended Green Space}}$$

Equation 19. Cultural Resilience for Greenspace or Recreational Space

The scoring was based on the ratio between the changing percentage of greenspace versus the standard per capita. This can be seen in the auxiliary variable *Resilience Score for Recommended Greenspace*. This type of scoring system was also used for the other two subsections: *Resilience Score for Recommended Sports and Playgrounds* and *Resilience Score for Recommended Parks*. All these 3 scores for both cities follow Equation 19. The values used for the standards in these two subsections were derived from the guideline set by the HLURB in the CLUP Guidebook Volume 2 for Designing Resilience (2014) which states that there should be 500 m^2 or 0.05 hectares per 1,000 population for city parks and 0.5 hectares for 1,000 population for sports and recreational facilities. Following the framing of the food and land use models, the scoring when projected will depend on the final value recorded for all the three resilience scores. The difference in units were based off the CLUP Guidebook to follow their standards but were converted to hectares for unit consistency in the model.



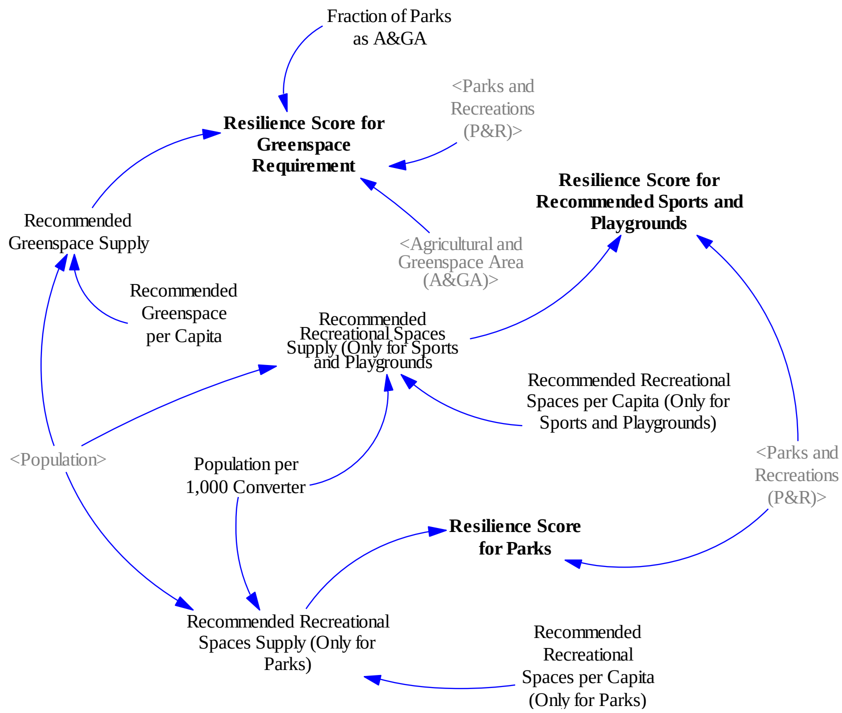


Figure 43. Stock-Flow Diagram for Cultural Services, (top) Valenzuela City and (bottom) Pasig City

3.3.2.6 UERI Calculation

In calculating for the UERI,the categories which had a resilience score were all linked together to form the *Urban Ecosystem Resilience Index*. This variable calculated the overall scores from each category by averaging the aggregate scores from each category:

$$Urban\ Ecosystem\ Resilience\ Index = \frac{Provisioning\ Resilience\ Score + Regulating\ Resilience\ Score + Cultural\ Resilience\ Score}{3}$$

Equation 20. Equation for Calculating the UERI

It should be noted that the there was no Supporting Resilience Score as, stated previously, it serves as an input the other categories only. Additionally, as this is a Vensim model, these scores are therefore integrated per year.

3.3.3 Graphical User Interface (GUI)

A graphical user interface created within the Vensim® model was generated for use of the respective LGUs of Pasig City and Valenzuela City. This featured sliders of the relevant variables from each of the 4 UES that would most affect the UERI performance. Featured also are the graphs for the UERI, the respective consolidated score per UES, which were color-coded, and the self-sufficiency interfaces and their respective graphs. Development of the interface was also thought to be useful for non-SD-modelers as the main focus would be on the sliders and the effect on the respective graphs. The purpose of the GUI was to enable stakeholders to assess the impacts of certain variables, representing development options or scenarios, on the index. The GUI allows the LGUs to run and use the model without the help of any expert. This would only work, however, if the models already are accurate and do not need any more structural revisions. It is recommended that variables that were observed to have large impacts to the respective services should be the focus for better data-gathering and more evidence-based decision-making.

Valenzuela City's GUI is shown in Figure 44 and Figure 45 while Pasig City's GUI was shown Figure 46 and Figure 47. Users should take note that for Valenzuela City's land use slider, the same amount subtracted from the AL should also be added to the fraction of A&GA, as stated in section 3.4.1.3 **Land Use Scenario**

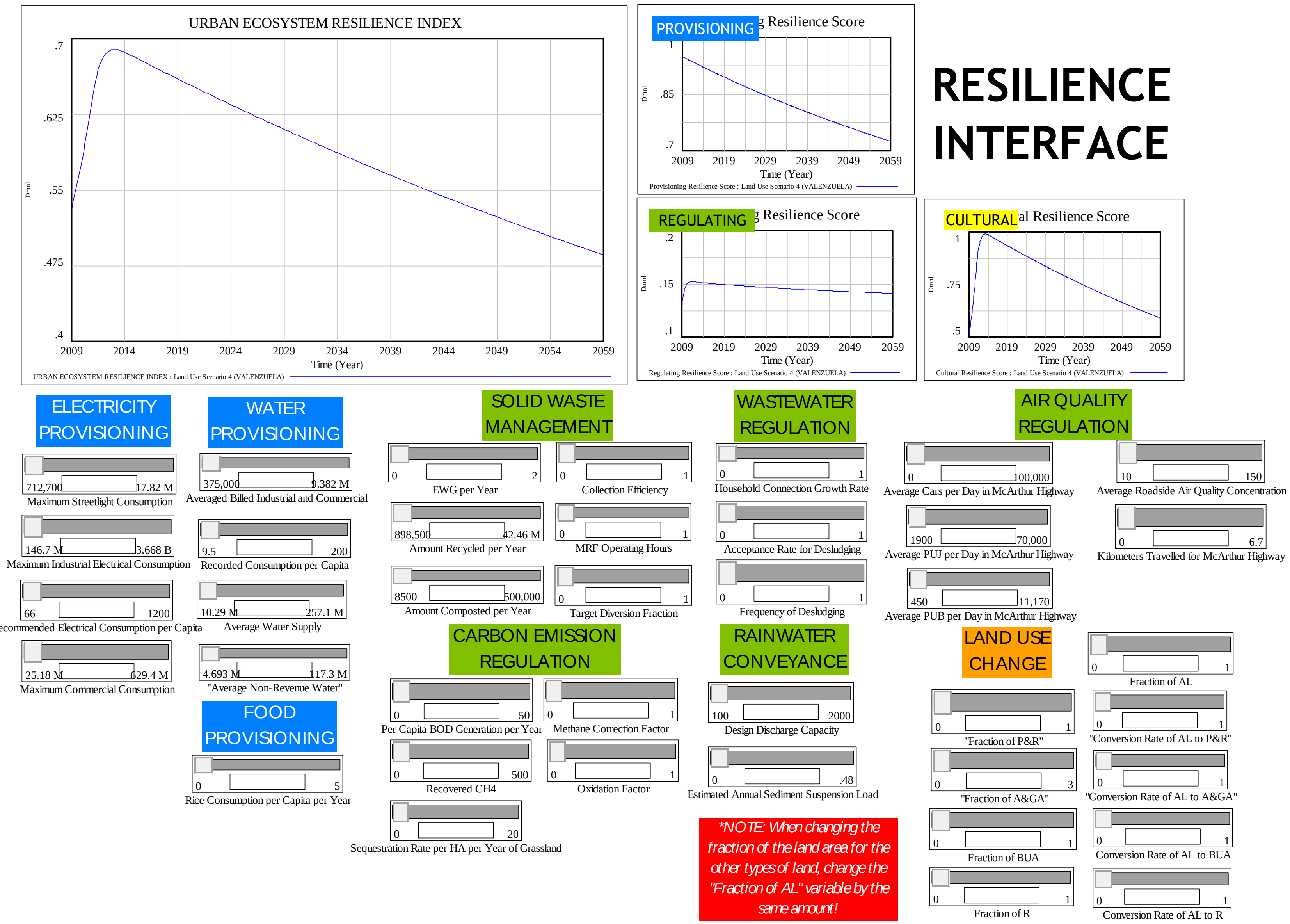


Figure 44. Resilience Interface (Valenzuela City)

SELF-SUFFICIENCY INTERFACE

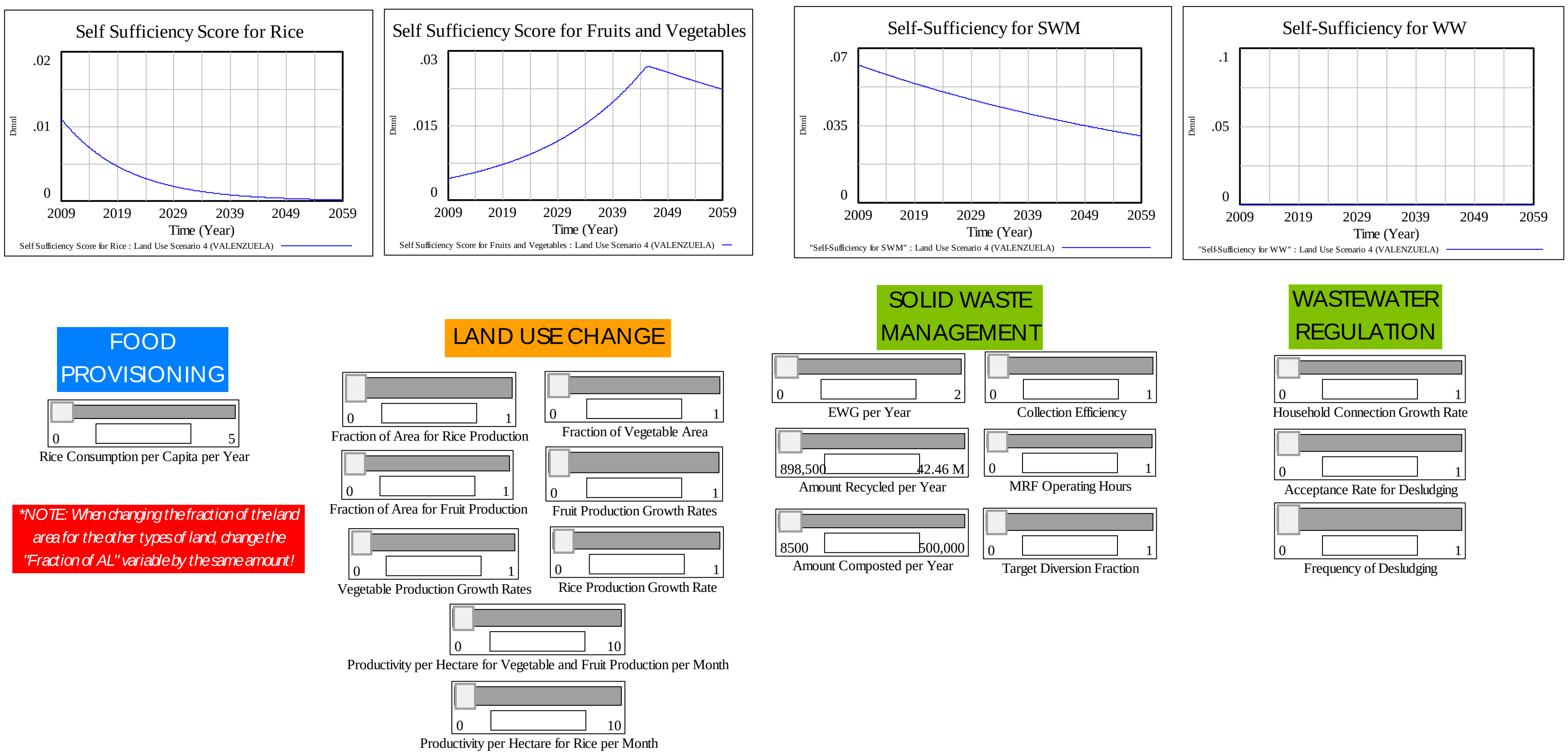


Figure 45. Self-Sufficiency Interface (Valenzuela City)

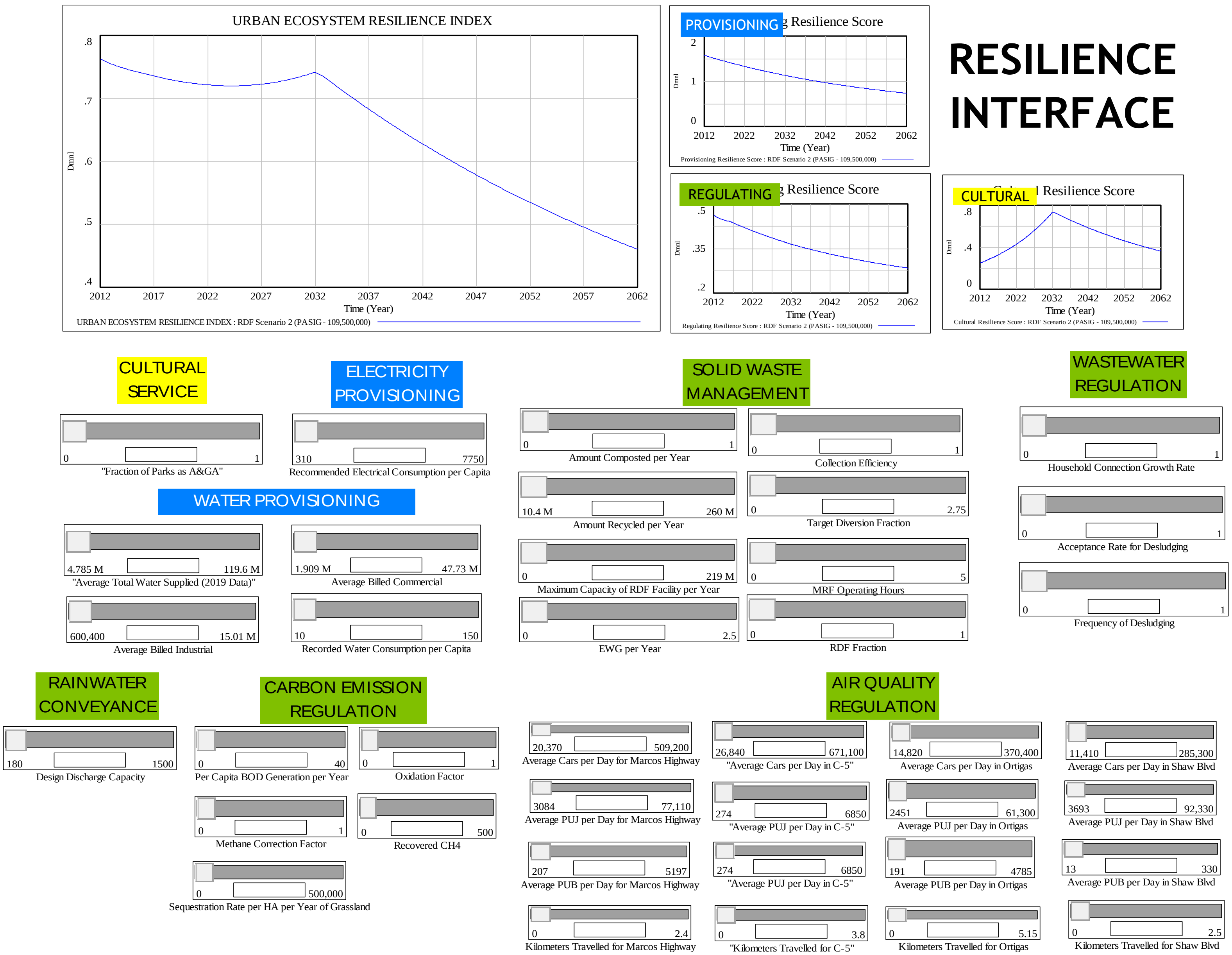


Figure 46. Resilience Interface (Pasig City)

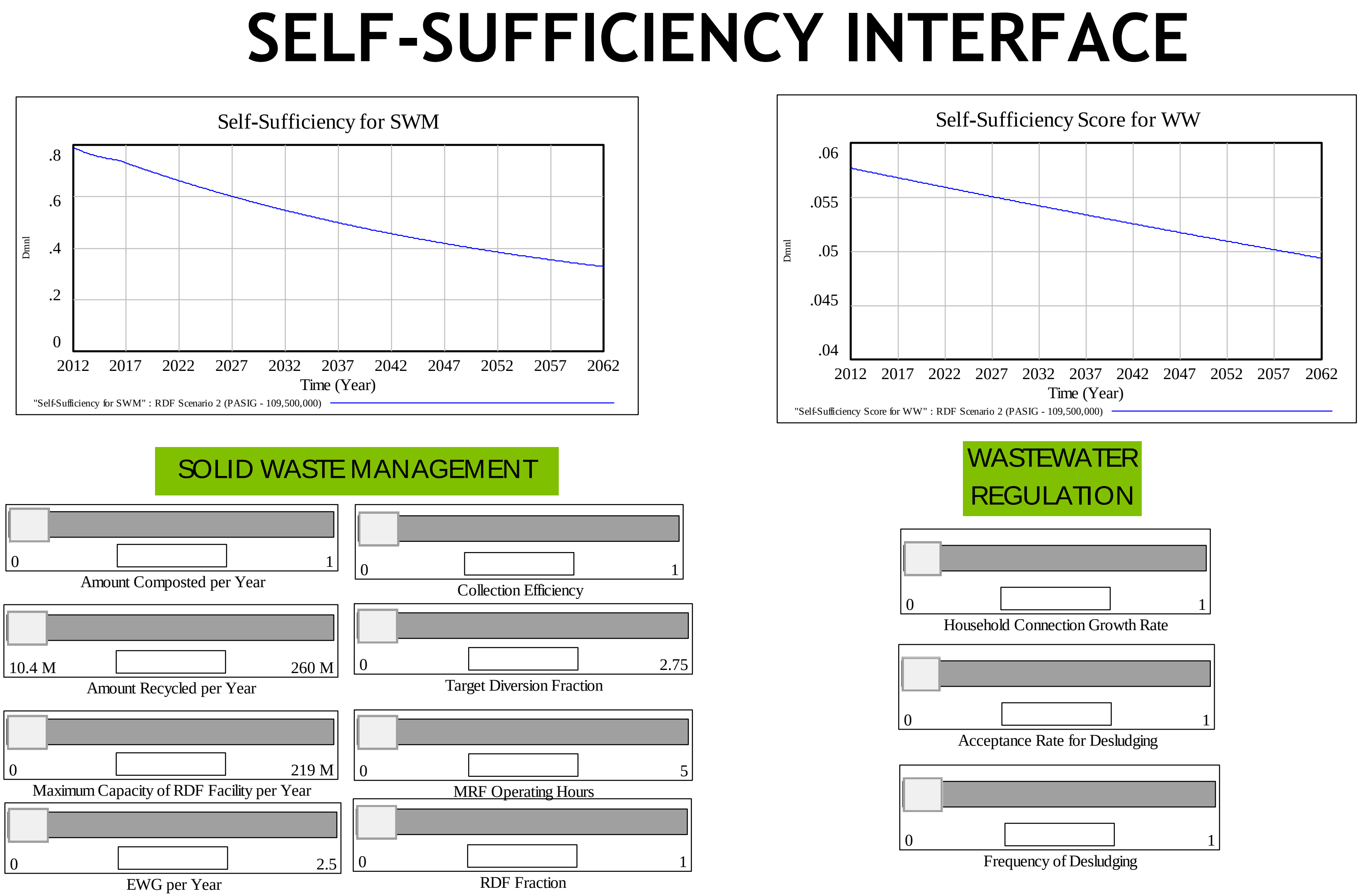


Figure 47. Self-Sufficiency Interface (Pasig City)

3.4 Scenario Development

Scenarios simulated were based on different development plans or interventions per city. Each scenario was derived from the main model described in the previous section. These scenarios used the same structure from existing models and only included changes in values per scenario. Scenarios were built around those services in each respective model based on their comprehensive development plans and input from relevant stakeholder consultations (Pasig City Government, 2014); (Valenzuela City Government, 2017).

3.4.1 Valenzuela Scenarios

In addition to the business-as-usual scenario, two simulations were designed to represent development goals involving the Land Use Sub-Model (Figure 41. Stock-Flow Diagram for Land Use Change (Valenzuela and Pasig City) and the Rainwater Conveyance Sub-Model (Figure 39).

3.4.1.1 Business-As-Usual Scenario

The Business-As-Usual scenario is a baseline model run with parameters as described in Section 3.3.2, and without any changes to the Land use and Rainwater Conveyance Sub -Models.

Table ***5*** and Table 6 depict the city’s conveyance capacity and drainage systems working at full capacity and land for A&GA fixed at that amount. The value for siltation was chosen this way because a scenario without any impediments was preferred, and therefore, by silting the rivers, would depict how much the resilience would be affected. For the land use model, the conversion rate and the fractions used were the ones mentioned in their CLUP.

3.4.1.2 Siltation Scenario

The Siltation Scenario was developed given Valenzuela City’s priority on flood management. It was observed from the data gathered that the city did not factor in the contribution of sediment yield to the conveyance and discharge capacity of the river. Therefore, the scenario was constructed as a response to the proposed dredging plan to improve flood control in the city. Considering the destructive nature of dredging, determining whether the benefits of dredging would outweigh the cost would depend the results of the scenario and whether siltation would have a significant contribution to reducing river rainwater conveyance resilience.

The siltation scenario involved the rainwater conveyance and how that was affected by introducing siltation. This focused on the factors that contributed to the decrease the outflow. The main factor affecting the inflow would be the RIDF given in Table 4 and the average run-off coefficient, and the main factor affecting outflow would be fraction silted. Based on the same table, the initial value of the *RIDF* variable was set and retained to the 50-Year Return Period scenario so as to test an intensity similar to Typhoon Ondoy. However, depending on LGU preference, they may change the value

For the framing of the *Fraction Silted* variable, the value of 0.48 MT/Ha/Year was calculated based on the estimated sediment load in Metro Manila given a certain land area, of which Valenzuela City's land area is similar (DPWH, 2013). This was to affect the *Fraction Silted* variable in Figure 39 by giving it percent silted. The way this calculated was by comparing a ratio and proportion which stated that if there was a certain weight (in metric tons) of riverway, then that meant that impeded conveyance by a certain amount. Specifically, in Tukur and Olofin's (2013) study, they reported that 8774.4 metric tons per hectare of silt meant impeding flow by 47%. This was computed as:

$$\text{Fraction Silted} = \frac{\text{Annual Sediment Yield}}{\text{Sediment} - \text{Conveyance Conversion}}$$

Equation 21. Equation for Amount Silted

Where Sediment-Conveyance Conversion = $\frac{0.47}{8774.4}$

Table 5. Amount of Sediment Load

Variable	Estimated Annual Sediment Suspension Load (MT/Ha/Year)
BAU (50-Year Return Period)	0
Siltation Scenario Testing	0.48

3.4.1.3 Land Use Scenario

The Land Use Scenario was implemented to reflect the development goal of increasing more area for agricultural and greenspace to allow for more urban farming. Given that the city still has available land, this scenario tested whether the LGU could convert more land into greenspace and agriculture and whether it would also have a significant contribution to the other services, given that land use is a supporting services. It should also be noted that other areas for agricultural land are found in the Disiplina Villages (Acurentes, 2009).

In changing the amount of land there was for fractions of agriculture and greenspace areas (A&GA), the fraction of the available stock was the one that was changed. This was the case for Valenzuela because it was cited in their CLUP and CDP that their priorities focused on having more greenspace in the city (Valenzuela City Government, 2017).

The values found in Table 6 refer to how much the values change per scenario. The fraction added to the A&GA was in increments of 0.03 hectares. This increment was derived from observations based on historical trends of land use conversion rates in the city. It was also realized that due to software limitations, the user had to subtract the same amount that was added to A&GA. This would mean that if the fraction of A&GA increased by 0.03, the fraction for available land (AL) had to decrease by the same amount.

Table 6. List of Values for Fraction Change for Land Use Scenario (Valenzuela City)

Variable	Fraction of Available Land (Ha)	Fraction of Agricultural Area and Green Space (Ha)
BAU	0.326	0.005
Land Use Scenario 1 (Valenzuela)	0.296	0.035
Land Use Scenario 2 (Valenzuela)	0.266	0.065
Land Use Scenario 3 (Valenzuela)	0.236	0.095
Land Use Scenario 4 (Valenzuela)	0.206	0.125

3.4.2 Pasig Scenarios

For the scenarios of Pasig City, the focus of the city's development goals that were chosen revolved around solid waste management and land use change. While the city has other priorities involving social welfare, these were beyond the scope of this ecosystem services-based model.

3.4.2.1 Business-As-Usual Scenario

The Business-As-Usual scenario focused on a baseline simulation, with the parameters as described in section 3.3.2, and without having any changes in the Solid Waste Management Sub-Model and the Land Use Sub-Model. Table 7 and Table 8 depict city running without an RDF and any land for greenspace were depicted in this scenario. These values were chosen because, at present, there is still no RDF facility in the city and there is no current report on the amount of greenspace there is.

3.4.2.2 RDF Scenario

The RDF scenario refers to the proposed RDF facility to be built in Pasig City to convert a portion of residual waste into RDF, a energy based on the fuel converted from shredding waste. The contractor proposed a maximum capacity of 600 tons and would cater to other cities outside of Pasig City. This was meant to reflect on the energy usage in the city as well and can be an example of a co-benefit in the model.

The RDF scenario in Pasig refers to the variables added to the *Amount of Residuals* stock which were featured in Figure 26 but not in Valenzuela City's SWM model and refers to the RDF process. This was framed to affect both the resilience scores of solid waste management, as well the resilience score for electricity provisioning. This is because the RDF facility that the city was planning to construct was planned to be in-city, meaning more waste could be treated within city boundaries. This meant that the self-sufficiency score and resilience score would also increase

The secondary effect would be the amount of waste converted into fuel. This was framed to influence electricity provisioning and its resilience score as well by providing an additional source of electricity for the city framed as MWH per metric tonne of RDF produced. This value was derived from (Thirugnanam & Pragasam, Refuse Derived Fuel To Electricity, 2013). Electricity is embedded within the electricity service and the values used for additional electricity would be from the RDF produced from the machine depending the capacity per year. This was framed as a subtraction from the estimated consumption per capita. Therefore, the new resilience score for electricity was reframed as:

$$\text{Resilience Score for Recommended Electrical Supply} = \frac{\text{Existing Maximum Electricity Supply}}{\text{Total Recommended Electrical Supply} - \text{Energy Derived from RDF}}$$

Equation 22. Reframed Equation for the Resilience Score for Electricity Provisioning Service for Pasig CIty

Table 7. List of Possible Waste Treated via RDF

Scenario	Maximum Capacity Per Year (kg)
Business-As-Usual (Pasig)	0
RDF Scenario 1 (Pasig)	54,750,000
RDF Scenario 2 (Pasig)	109,500,000
RDF Scenario 3 (Pasig)	154,250,000
RDF Scenario 4 (Pasig)	219,000,000

The values in Table 7 were based on the maximum capacity as reported by (Pasig City, 2015). Given RDF Scenario 4, the maximum reported amount of RDF to be treated for the entirety of Metro Manila was at 600 metric tons per day (219,000,000 kg per year). From this number, the values for the other RDF scenarios were derived in decreasing values of 150 metric tons converted to kilograms.

3.4.2.3 Land Use Scenario

Currently, there are no categories for greenspace and agriculture in the city. From interviews based on the CDP, the city wanted to expand their greenspace, but instead have focused on developing their BuA, leaving no room for expanding their A&GA. Therefore, this Land Use Scenario utilizes existing areas allocated for parks & recreation (P&RA) as potential greenspace areas as well. Instead of taking from available land, the areas for parks and recreation (P&RA) were converted to A&GA to varying extents (refer to Table 8). This was because there is little available land left in Pasig City to convert to greenspace.

Table 8. Fraction of P&RA Converted to A&GA

Scenario	Fraction of A&GA from P&RA	Initial Fraction converted to P&RA (Ha)
BAU	0	0
Land Use Scenario 1 (Pasig)	1/4	5.96
Land Use Scenario 2 (Pasig)	1/2	11.93
Land Use Scenario 3 (Pasig)	3/4	17.90
Land Use Scenario 4 (Pasig)	1	23.87

4. Results and Discussion

4.1 Valenzuela City Resilience Index

4.1.1 Business-As-Usual Scenario (Valenzuela)

4.1.1.1 Provisioning Services for Valenzuela City

The *Provisioning Resilience Score* of Valenzuela City under the Business-As-Usual scenario, as seen in the graph found in Figure 48, exhibited a decreasing trend. The decreasing value of provisioning resilience score over time was a result of the behavior of the graphs of services found under the provisioning category. Scores used for the *Provisioning Resilience Score* graph include the *Resilience Score for Recommended Water Supply*, the *Resilience Score for Recommended Electrical Supply,* and the *Resilience Score for Caloric Intak*e. The graphs of these different scores were presented as well, as seen in Figure 49, to show their overall contribution to provisioning resilience. Based on the resilience score value, the city was close to optimal in terms of their delivery of provisioning services earlier in the projections. The value was observed to have decreased over time due to the increasing demand for additional services brought about by population growth. This was the case for the decreasing resilience score of recommended water and electrical supply. The high value initially observed for the provisioning resilience score was also a result of the overall high values displayed by the three provisioning services in the initial part of the projection as well.

The units for the y-axis of the Resilience Score graphs were named *Dmnl*, short for dimensionless, given that this served as indicator variables in the model which was framed as ratios for either stocks, flows, or auxiliary variables. The x-axis referred to the time set in years.

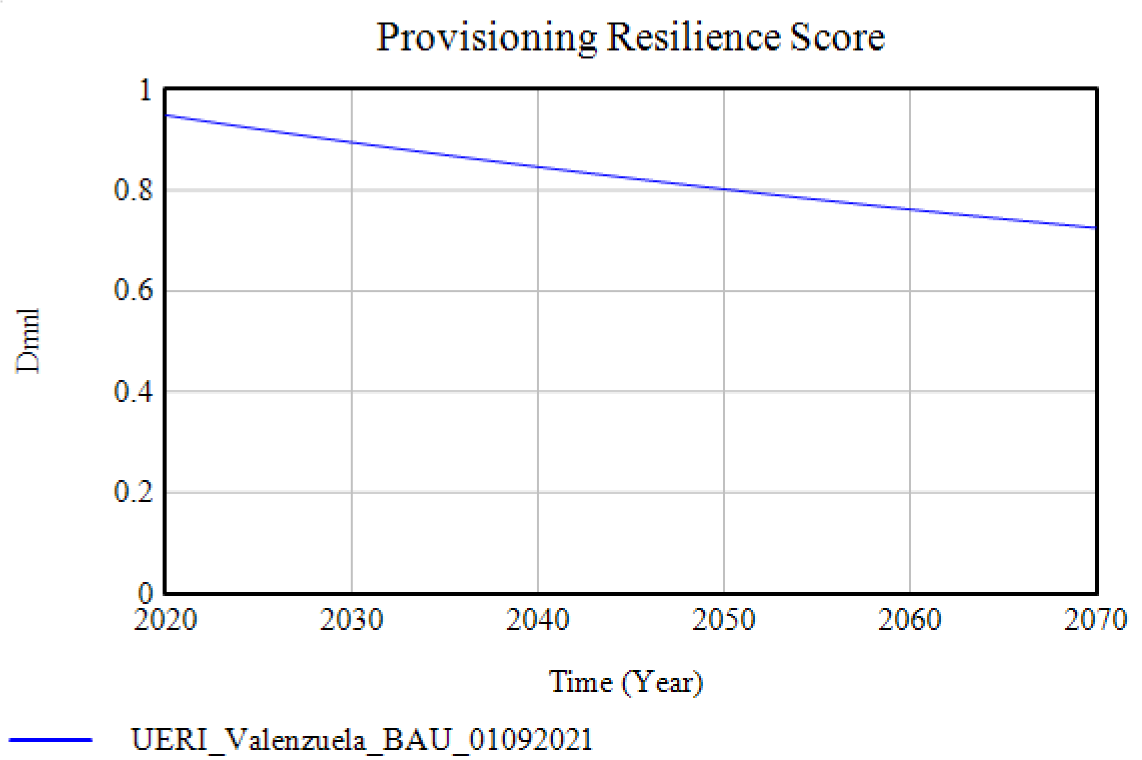


Figure 48. Provisioning Resilience Score Graph of Valenzuela City

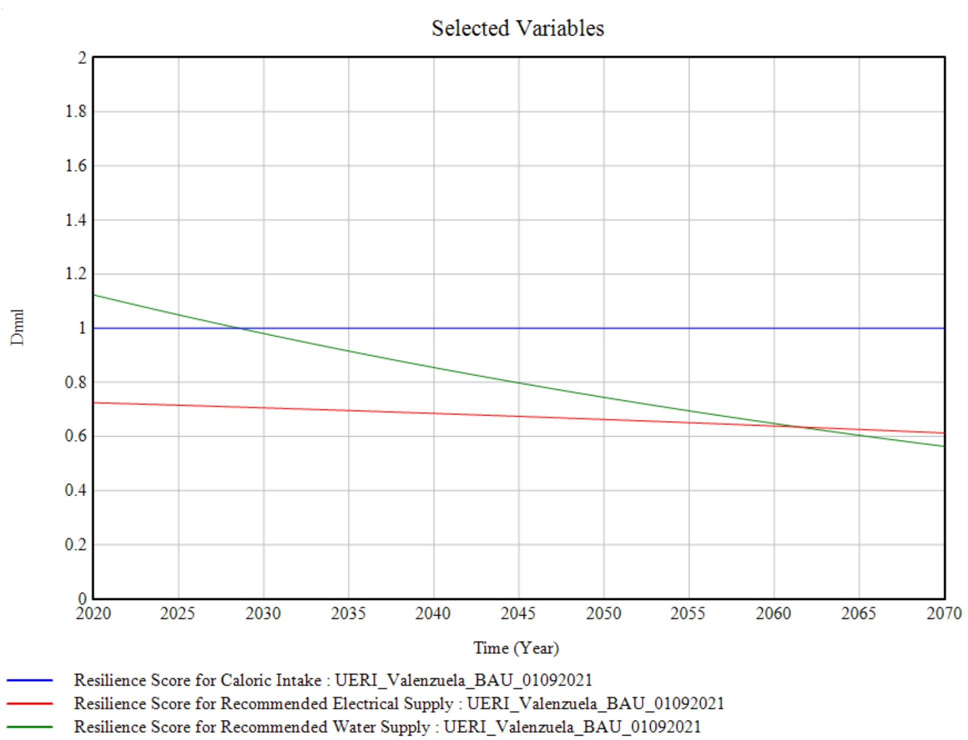


Figure 49. Components of Provisioning Resilience Score Graph of Valenzuela City

4.1.1.1.1 Water Provisioning Service

The value of the *Recommended Water Supply*, as seen in Figure 50, exhibited a decreasing trend implying that the resilience decreases over time.

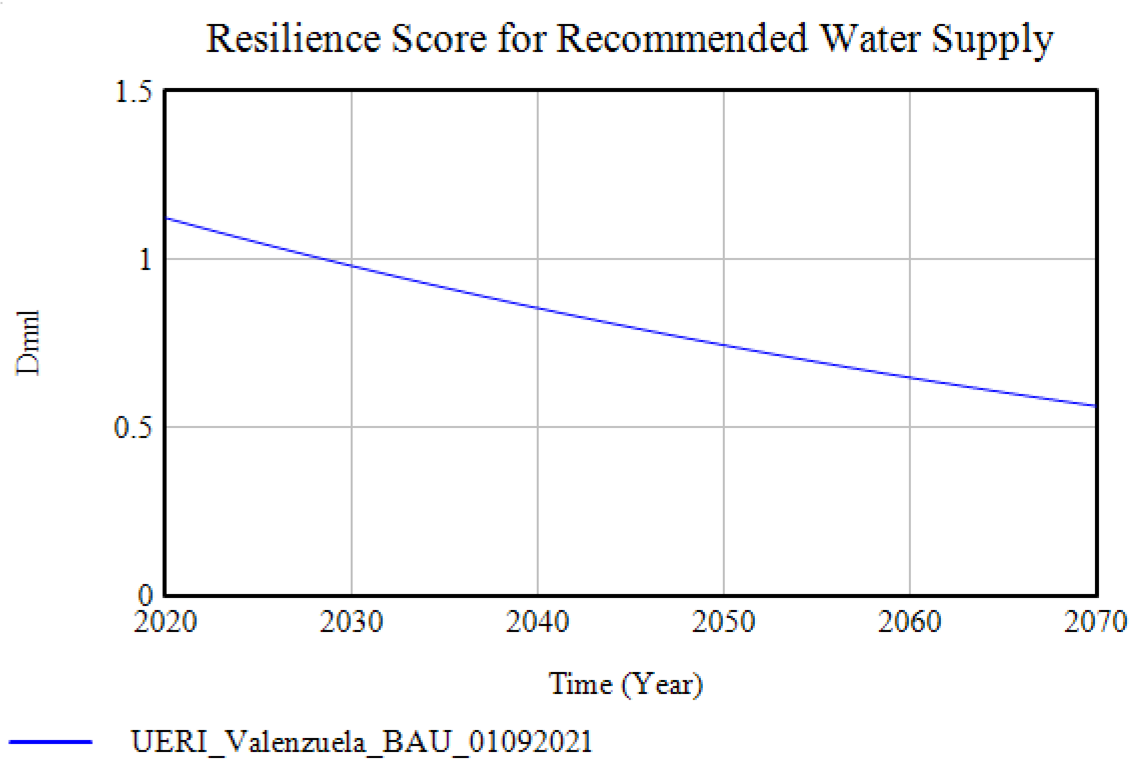


Figure 50. Graph of the Resilience Recommended Water Supply for Valenzuela City

The components of the *Resilience Score for Recommended Water Supply* seen in Figure 51, accounted for both *Total Recommended Supply for Water* and *Current Maximum Water Supply*. *Total Recommended Supply* was based on the total consumption values for *Recommended Domestic Consumption* and *Maximum Industrial and Commercial Consumption*. Among the two components used for the *Resilience Score for Recommended Water Supply*, only *Recommended Domestic Consumption* exhibited an increasing trend. Trends were not included for the industrial and commercial consumption as there were not enough data observed to assume any. While there may be existing trends observed from actual consumption in the city, these were not factored in the model. Thus, the projected demand is a conservative estimate since industrial and commercial consumption will likely grow in the future. *Current Maximum Water Supply* remained constant all throughout the projections which resulted in the *Resilience Score for Recommended Water Supply* to decrease over time as seen in Figure 50.

The decreasing value seen for the *Resilience Score of Recommended Water Supply* serves as an indicator for the increasing gap between the recommended water supply, based on the population demand, and the current maximum water supply for the city over the years. While the city was optimal till a certain point, the value was observed to become sub-optimal from the year 2028 onwards. This implies that with a score of less than one, not enough water can be supplied to meet the increasing consumption requirements of the due to its growing population. The capacity to supply more water must be increased to meet consumption needs for the future.

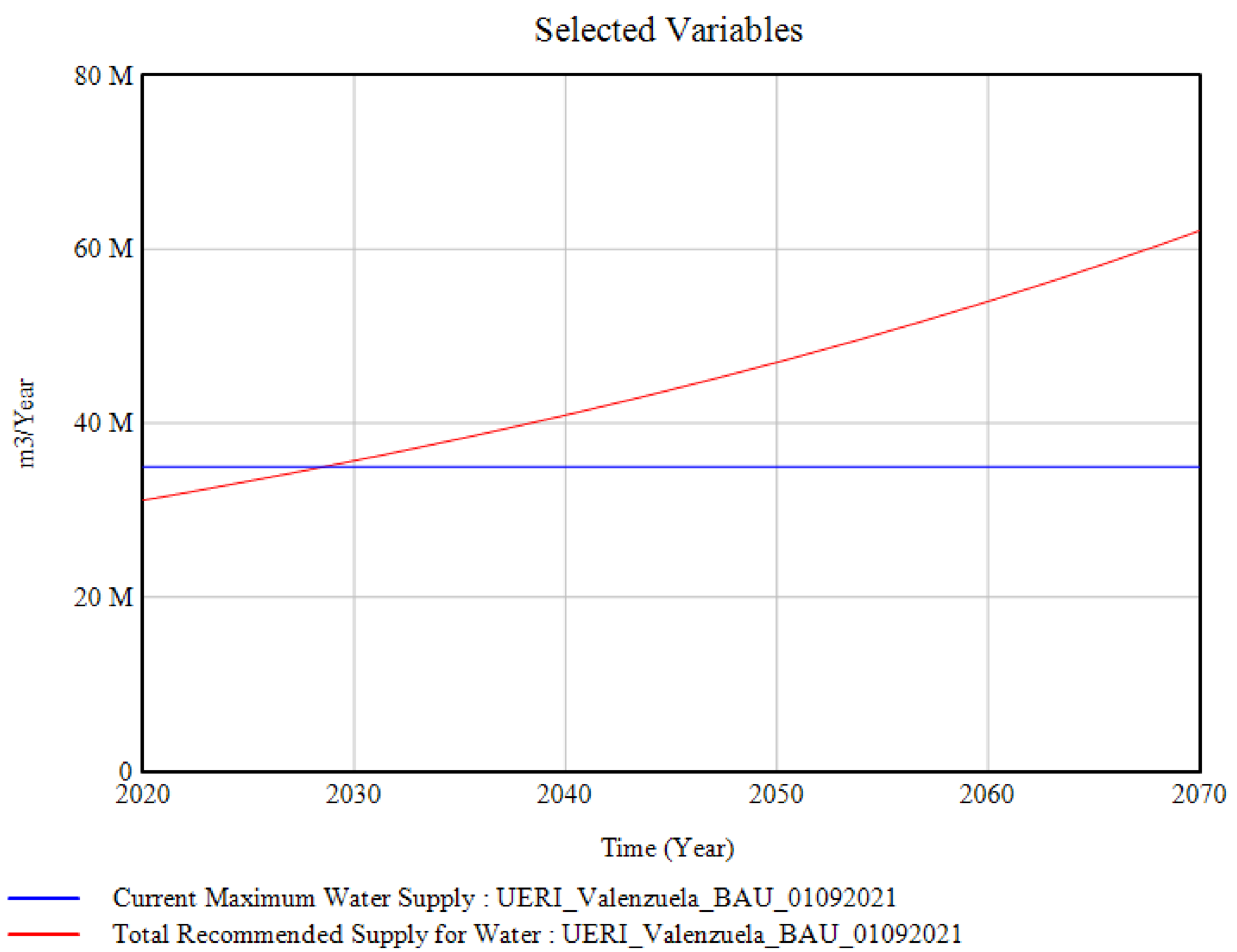


Figure 51. Components for Resilience Score for Recommend Water Consumption for Valenzuela City

4.1.1.1.2 Electricity Provisioning Service

The graph of the value of *Resilience Score for Recommended Electrical Supply* displayed decreasing trend as seen in Figure 52. This implies that the resilience score decreases over time. The observed value was a result of the of the different components in the electricity provisioning service model that were used in the computation of the value for the resilience indicator variable.

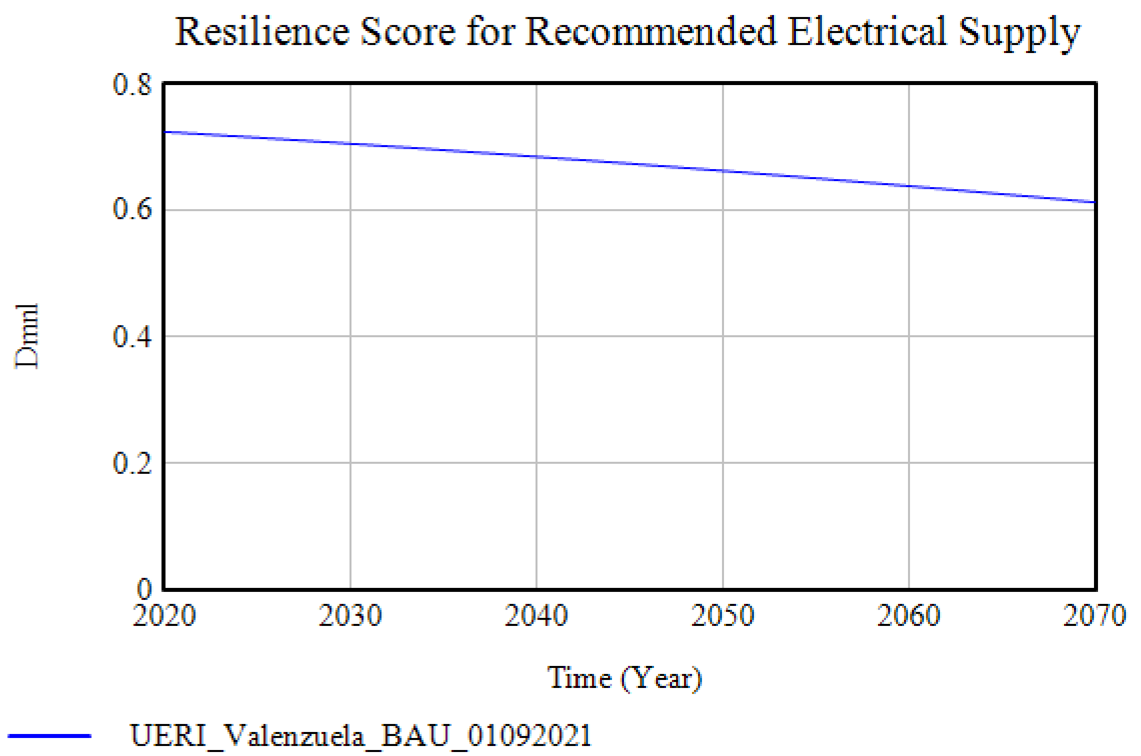


Figure 52. Graph of the Resilience Score for Recommended Electrical Supply for Valenzuela City

The graph of *Total Recommended Electricity Supply* exhibited an increasing trend, as seen in Figure 53, as the model was able to take into consideration the growth of consumption for all sectors in the city using electricity as they were disaggregated in the data set. In terms of the other component used for deriving the resilience score, *Current Maximum Electricity Supply* remained constant all throughout projection as there were not enough data to generate trends that can be assumed for the model. Among the four sectors, *Recommended Domestic Electrical Consumption* was the only component to have exhibited an increasing trend given that it was based on growing population demands for electricity. While there may be existing trends observed from actual consumption for the industrial, commercial, and streetlight in the city, these were not factored in given the lack of data points to create accurate trends similar to the case of water. This resulted in the increasing trend observed from *Total Recommended Electrical Supply* as observed in Figure 53. As for *Current Maximum Electricity Supply*, the same value was observed each year.

The value of resilience score for recommended electrical supply decreased over the years given the widening gap between its two components. The resilience score being sub-optimal all throughout projection indicates the insufficient capacity of electricity provisioning. This also implies that the city cannot accommodate all the necessary supply to match growing consumption. Over the years, the score decreases as electrical consumption increases without any changes made to increase capacity to supply electricity. Improving resilience would involve improving the maximum electricity that can be supplied to the city.

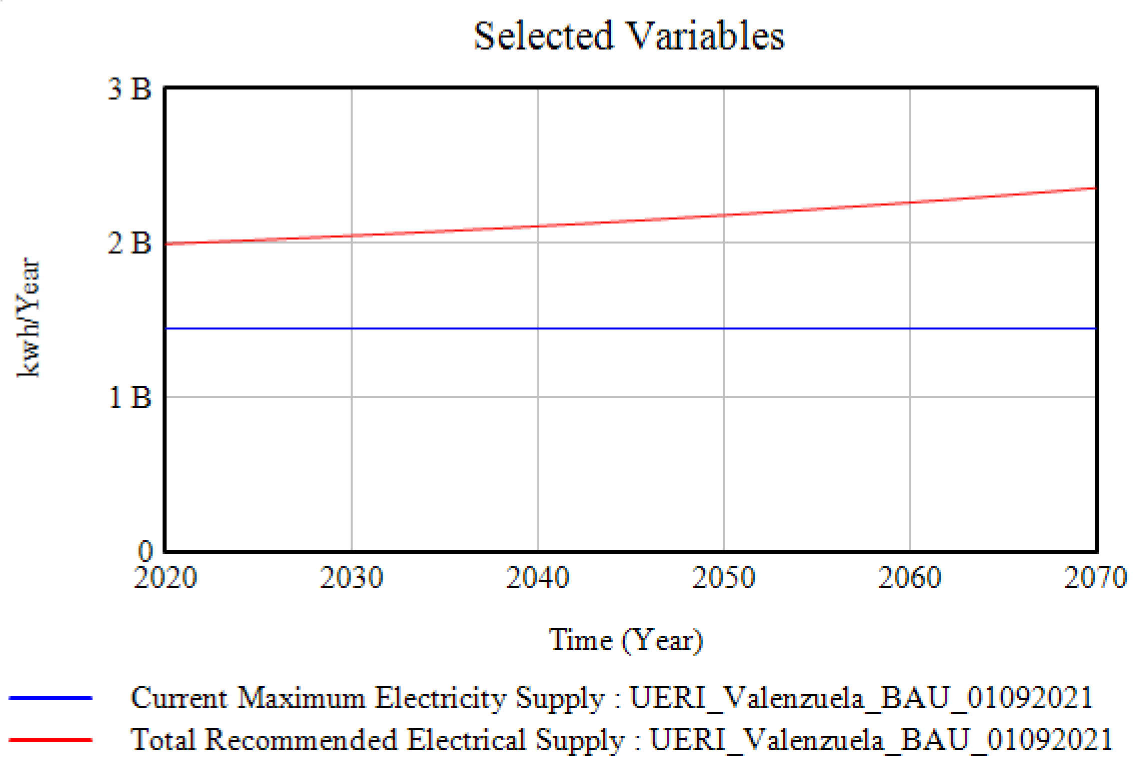
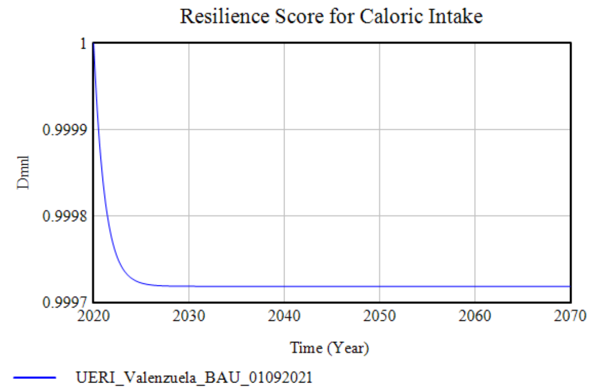


Figure 53. Components of Total Recommended Electrical Supply for Valenzuela City

4.1.1.1.3 Food Provisioning Service

Caloric intake was used as the measure for food provisioning resilience, represented as *Resilience Score for Caloric Intake*, given the lack of data to measure the inflow and outflow of food in the city. The graph of the resilience score, displayed a decreasing trend with minimal



change in value as seen in Figure ***54*** placed side by side with the adjusted y-axis to show the incremental change.

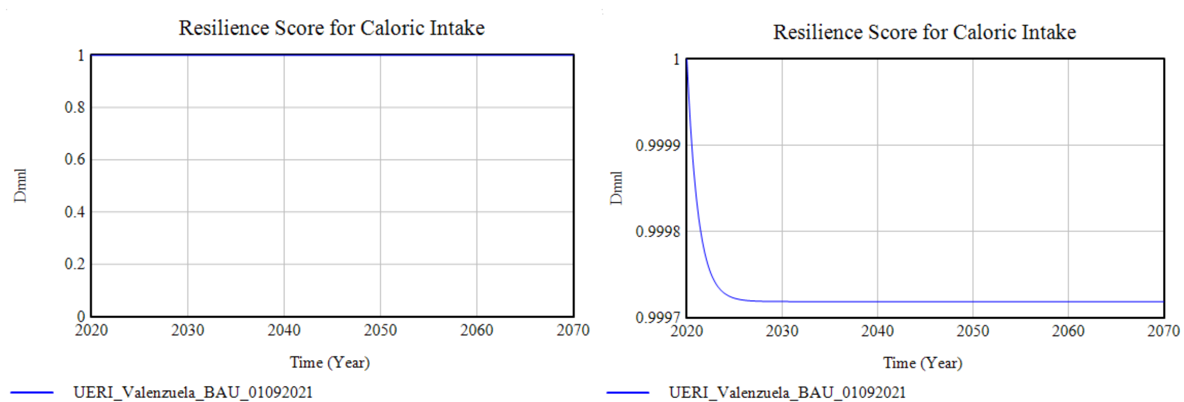


Figure 54. Resilience Score for Caloric Intake in Valenzuela City (Left) with Adjusted y-axis (Right)

The graph of the components that made up the behavior of the *Resilience Score for Caloric Intake* in Valenzuela City were seen in Figure 55. As observed from the graph, *UV & SUV Growths*, which represented the portion of the population classified as underweight and super underweight, was close to the value of those that were returned to normal status after interventions made by the city. The small value for resilience score implies that majority of the population falls under the normal status and that the feeding programs target only a small percentage classified as UV & SUV. The small gap between the two components implies that, given the already small portion of UV & SUV, only a small percentage of that was returned to normal after the feeding program. There was not much contribution observed from the effects of feeding program, given the small percentage of UV & SUV, as seen from the change in resilience score of caloric intakes.

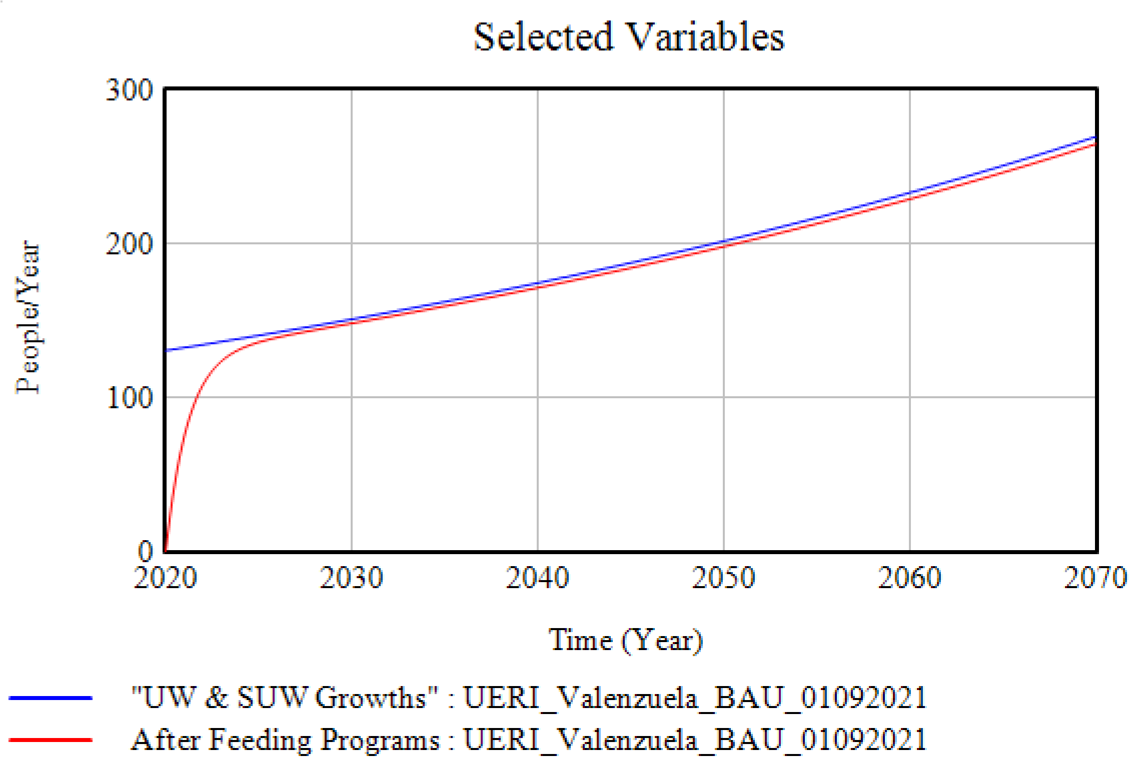


Figure 55. Components of the Resilience Score for Caloric Intake in Valenzuela City

4.1.1.2 Regulating Services for Valenzuela City

The overall trend of the *Regulating Resilience Score* for Valenzuela City, as seen in graph found Figure 56, initially displayed an increasing trend reaching a peak value of 0.15 on the year of 2020, after which was followed by a decreasing trend. The decrease was a result of the behaviors of different scores of regulating services, mainly: *Resilience Score for Air Quality*, *Resilience Score for River Rainwater Conveyance*, *Resilience Score for Solid Waste Management*, *Resilience Score for Wastewater*, and *Resilience Score for Carbon Emissions* as seen in Figure 57.

Based on the graph of the components, the *Resilience Score for Air Quality* followed by *Resilience Score for River Rainwater Conveyance* had the highest value for resilience over time. In terms of behavior, the *Regulating Resilience Score* graph was most similar the graph produced from the *Resilience Score for Air Quality*. While it does follow the trend of the *Resilience Score for Air Quality*, the value of the *Regulating Resilience Score* graph was from the influence of all components. What led to a lower overall value ranging from 0.12 to 0.15 was from the value of the *Resilience Score for Carbon Emissions*. The low value of resilience for regulating services implies that the overall performance of the different regulating services was greatly lacking in terms of meeting the standards set by different organizations to maintain natural conditions in the city.

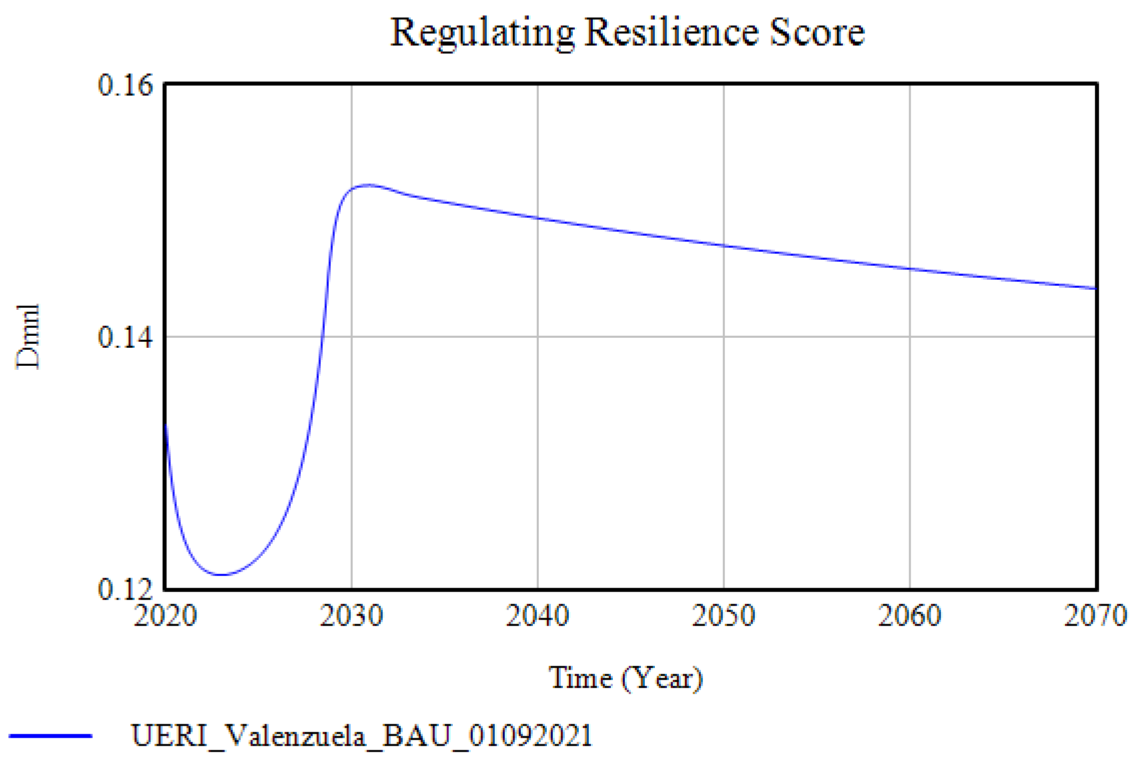


Figure 56. Regulating Resilience Score Graph for Valenzuela City

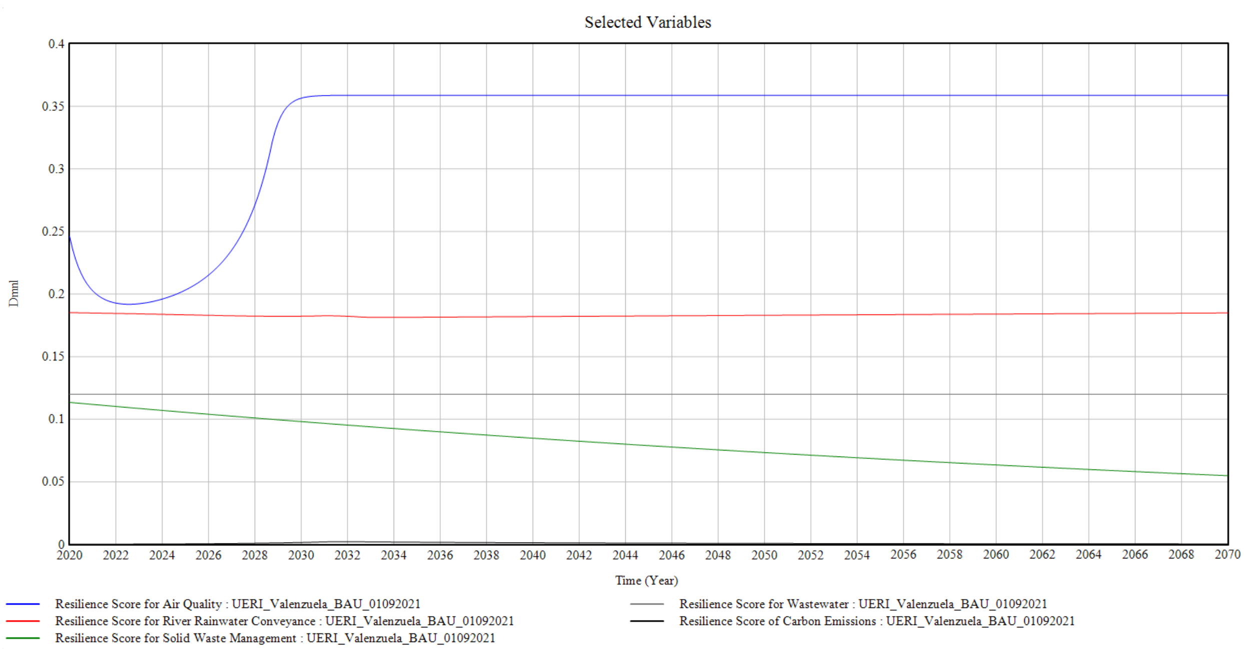


Figure 57. Components of Regulating Resilience Score for Valenzuela City

4.1.1.2.1 Solid Waste Management

The value of the *Resilience Score for Solid Waste Management*, as seen in Figure 58, decreased over time. This is indicative of the overall performance of the solid waste management service in the city which, as seen from the score, was sub-optimal in terms of being able to treat all the waste produced by the city itself. Measuring of performance was done by comparing the values of the three variables used to compute for the resilience score: *Composting and Waste Recycling* to represent the waste the city was able to treat, and *Target Diversion* which was set by the city and derived from *Generated Waste*. The values for these components were seen in Figure 59.

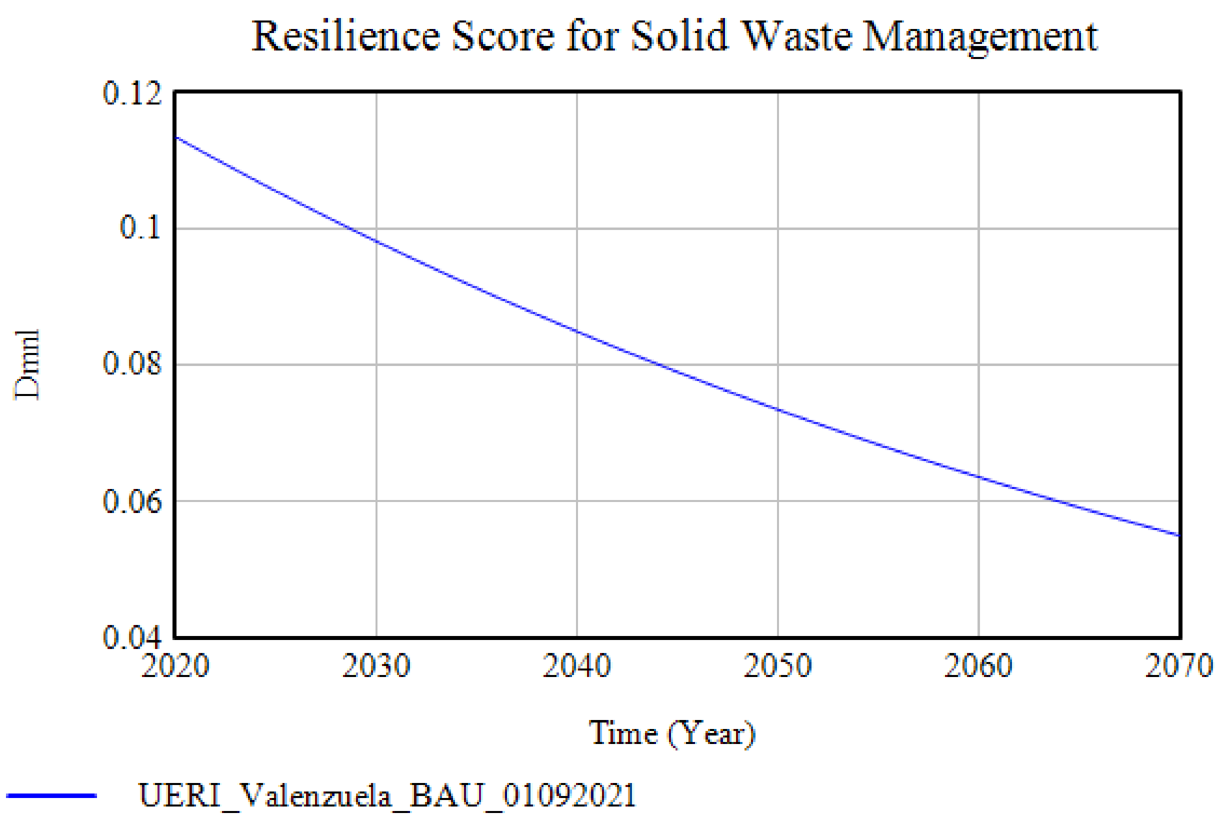


Figure 58. Resilience Score for Solid Waste Management Graph for Valenzuela City

Based on the graphs from Figure 59, the value of the *Resilience Score for Solid Waste Management* was observed to have decreased over time given that the capacity to divert and treat waste per year were less than the volume of generated waste per year. This was seen in the values for *Composting and Waste Recycling* which remained constant all throughout projections while the values for *Target Diversion* increased over time. This implies that over time, generated waste increases beyond the treatment capacity of the city therefore, decreasing resilience score over time. Increasing resilience for solid waste regulation would require either decreasing the generated waste or increasing the amount of waste diverted via increasing capacity of recovery facilities and composting sites.

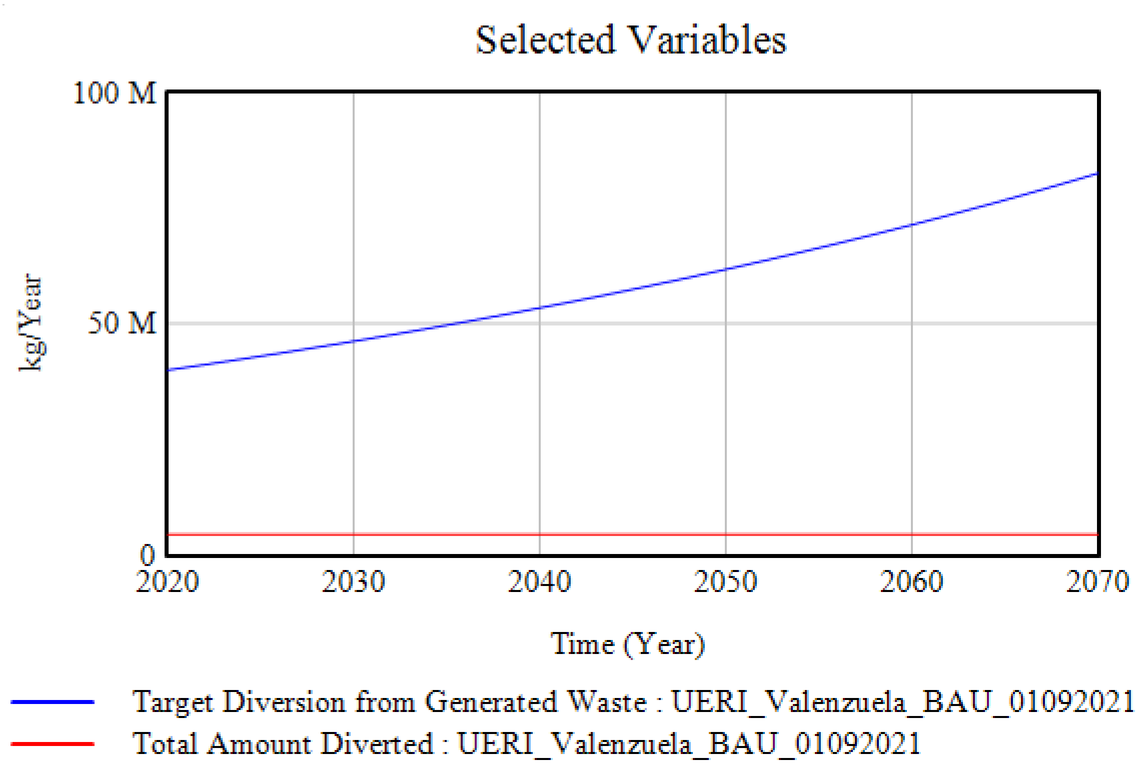


Figure 59. Total Diverted vs. Generated Waste Graph for Valenzuela City

4.1.1.2.2 Wastewater

The value for the *Resilience Score for Wastewater*, was observed to remain constant over time with a score of 0.12 as seen in Figure 60. The score was derived from the behavior of the variables used for scoring of the *Resilience Score for Wastewater*. These variables include *Treated (Desludged) Septage*, *Treated Sewage*, and *Total WW Generated* whose respective graphs can be seen in Figure 61. The fluctuations observed in Figure 60 was a result of the frequency at which desludging was done which was every 5 years. This implies that while the performance of the city to treat wastewater was constant, the amount of wastewater treated would vary depend on the time of desludging.

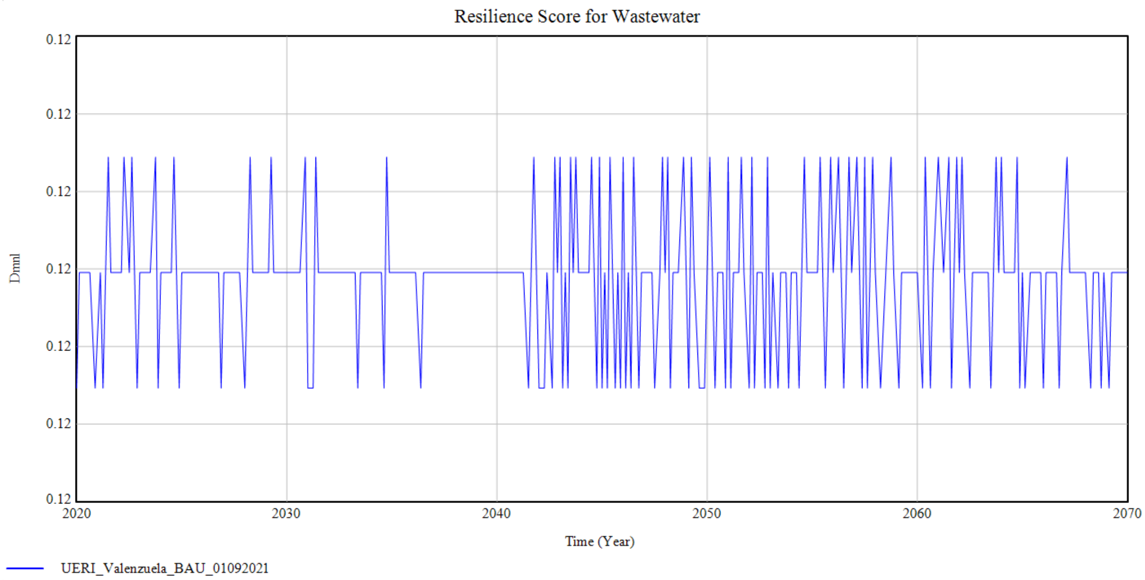


Figure 60. Graph of the Resilience Score for Wastewater for Valenzuela City

Based on the graph, *Total WW Generated* as well as *Treated (Desludged) Septage* were observed to have followed the same increasing trend, but *Total WW Generated* starts of at a higher value than *Treated (Desludged) Septage*. This implies that more wastewater was generated versus the volume treated in the city. The low amount of *Treated Septage* was due to the frequency at which desludging services are availed which happens once every five years. Additionally, the model also considered the acceptance rate in Valenzuela in which the last recorded value was 0.6 (Garza, 2020). These two variables used in the model limited the amount of wastewater treated in the city.

Given the lack of other treatment options, as well as the increasing values of generated WW due to population growth, the observed *Resilience Score for WW* was expected to remain constant as there were no new interventions introduce in this scenario. The rate of increase would be similar between *Total WW Generated* and *Treated (Desludged) Septage* given that both were derived from the same population data. Measuring performance was done in terms of determining the gap to derive the cities capacity of treatment over time. The low score for treated septage and the zero value for treated sewage was indicative of the low capacity for WW treatment in Valenzuela. Increasing the capacity would result in an increase in the *Resilience Score for WW*. This could be from the addition of sewer lines to decrease the load for septage. This would require building sewage treatment plants within the city to address the low resilience score. It was also observed that wastewater generated was dependent on the consumed water from the provisioning service model. Thus, without any adjustments made to treatment capacity, the wastewater resilience score would decrease given any improvements made to increase supply, and hence, consumption, of water. Therefore, wastewater treatment capacities must also be adjusted in accordance with improvements made to increase maximum water supply.

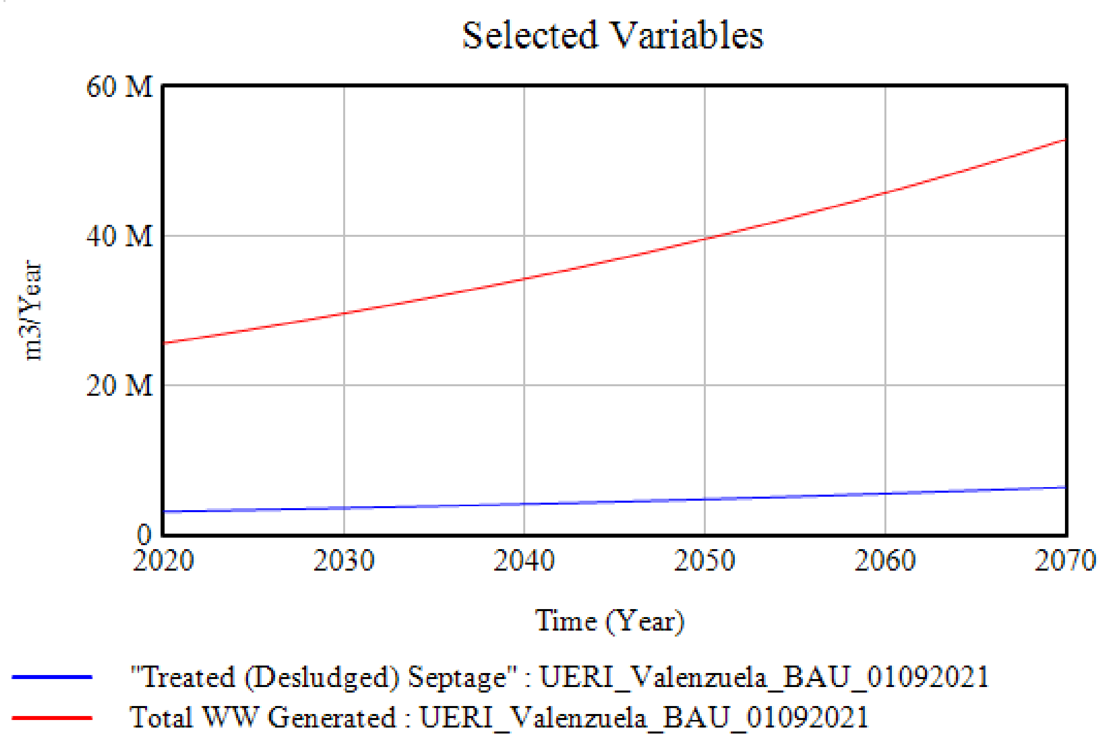


Figure 61. Graph of Treated Sewage and Septage versus Total Wastewater Generated for Valenzuela City

4.1.1.2.3 Air Quality Regulation

The model for measuring *Air Quality Regulation* provided only a rough estimation of the concentration of $PM_{2.5}$ in Valenzuela as it used only available activity data provided by the city for vehicle load in national roads. As observed in the graph seen in Figure *62*, the value of the *Resilience Score for Air Quality* reached a peak of 0.35 at year 2030. This was a result of the natural regulation $PM_{2.5}$ in the city which is consistent with observed average roadside emission values. There was an initial drop observed in the graph for the value of the resilience score which reached a minimum of 0.19 between 2020 to 2025. This is a result of the contributions of the regulating mechanisms of the greenspace and vegetation in the city. The Air Quality Regulation model could be enhanced further with additional data. What influenced the changing of values were the development plans of the city mainly in how land use change affected the mechanisms that deal with air regulation such as in the amount of allocated land where trees could grow. Trees possess natural regulating capabilities and were considered as one of the main regulators of air quality aside from the natural dispersion and deposition processes.

Initially, the city was focused on built infrastructure to address socio-economic needs. As for the succeeding years, the city shifted toward building more open space and agriculture. This resulted in an increase in performance for treating $PM_{2.5}$ given higher natural pollutant removal rates made possible from the addition of agriculture and greenspace. This indicates a synergy between the land use service with air regulation. The model assumed the natural dispersion (including effects of diurnal and deposition) to be constant with the only changing factor to be the natural pollutant removal.

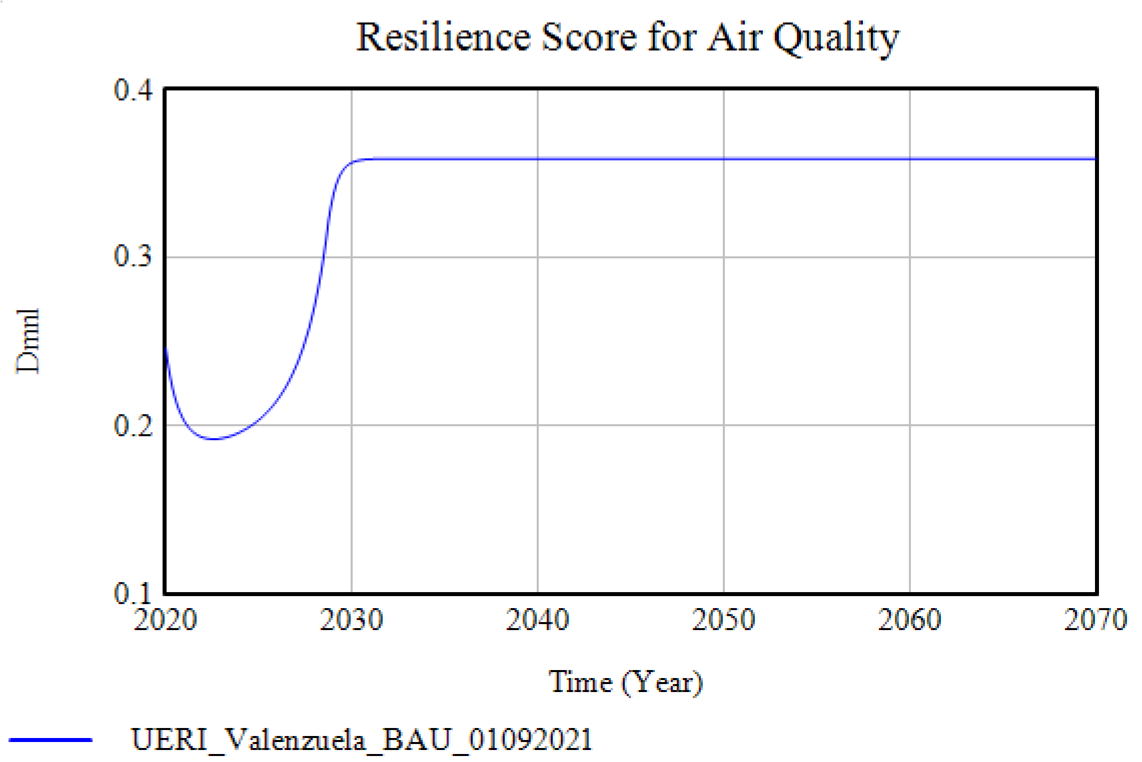


Figure 62. Graph of the Resilience Score for Air Quality Graph for Valenzuela City

4.1.1.2.4 Carbon Regulation

The value of the *Resilience Score of Carbon* graph, as seen in Figure 63, was observed to have increased reaching a peak value of 0.0022 for the year 2032 before resulting in a decreasing trend throughout the projection. What contributed to the behavior of the graph and the change in values were from land use change wherein the addition of greenspace would contribute to a higher carbon sequestration rate as reflected in the variable *Carbon Sequestration*. As observed in the figure, the graph showed an increasing trend for carbon sequestration but when compared to the total carbon dioxide emissions in the city seen in the variable *CO2e Emissions*, *Carbon Sequestration* appeared almost negligible as seen in Figure 64. This resulted in a very low score observed in the *Resilience Score of Carbon*. This serves as the measure of performance for regulating carbon emissions wherein the city was not able to reduce emissions to a substantial extent given that high emission rates and low sequestration rate.

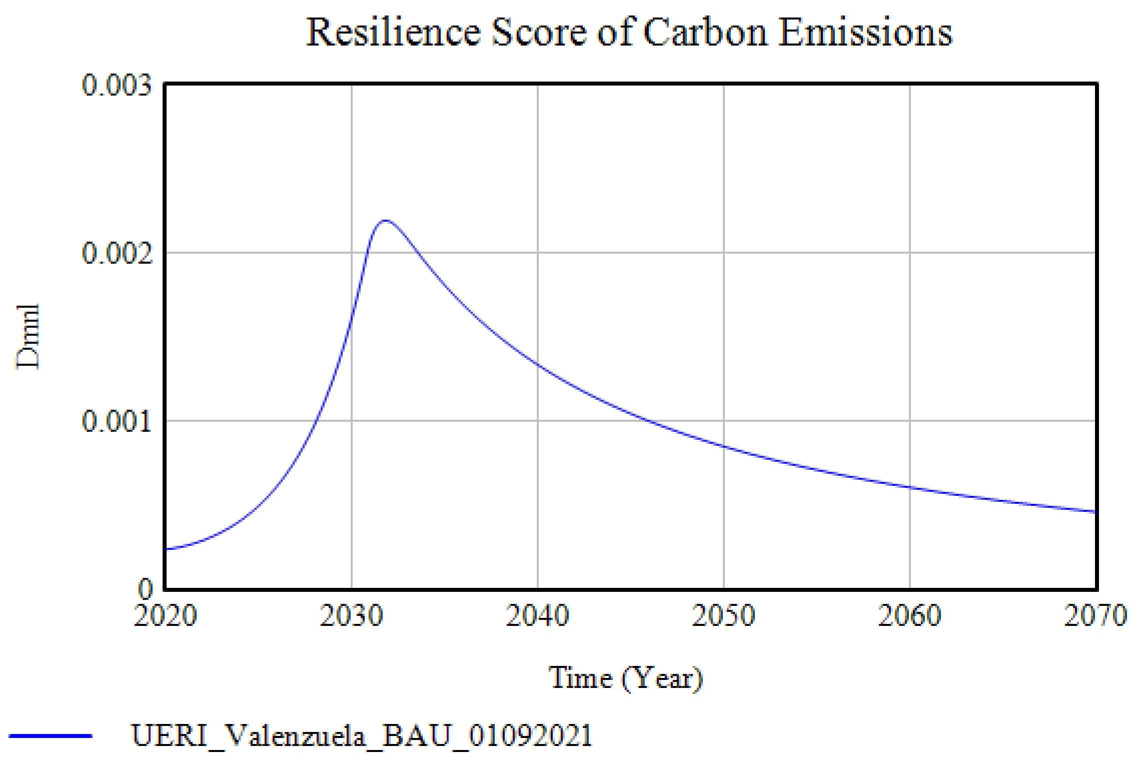


Figure 63. Resilience Score for Carbon Graph in Valenzuela City

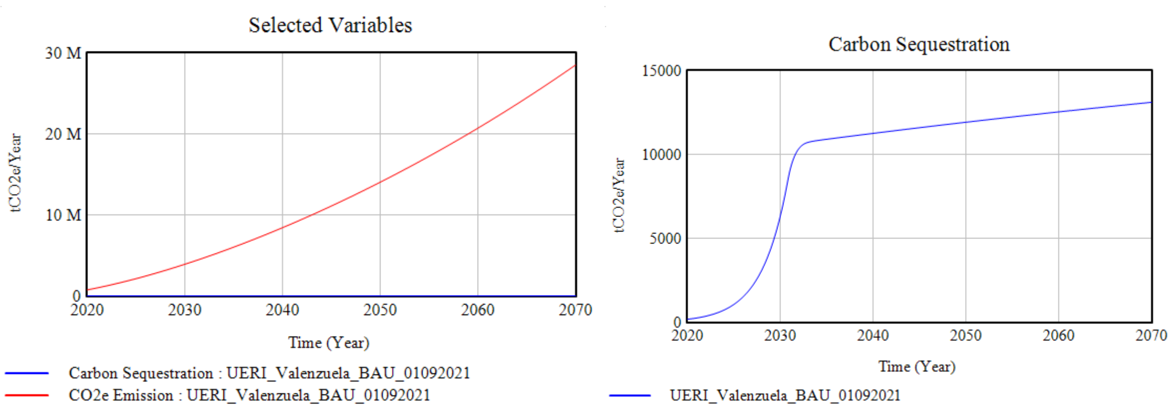
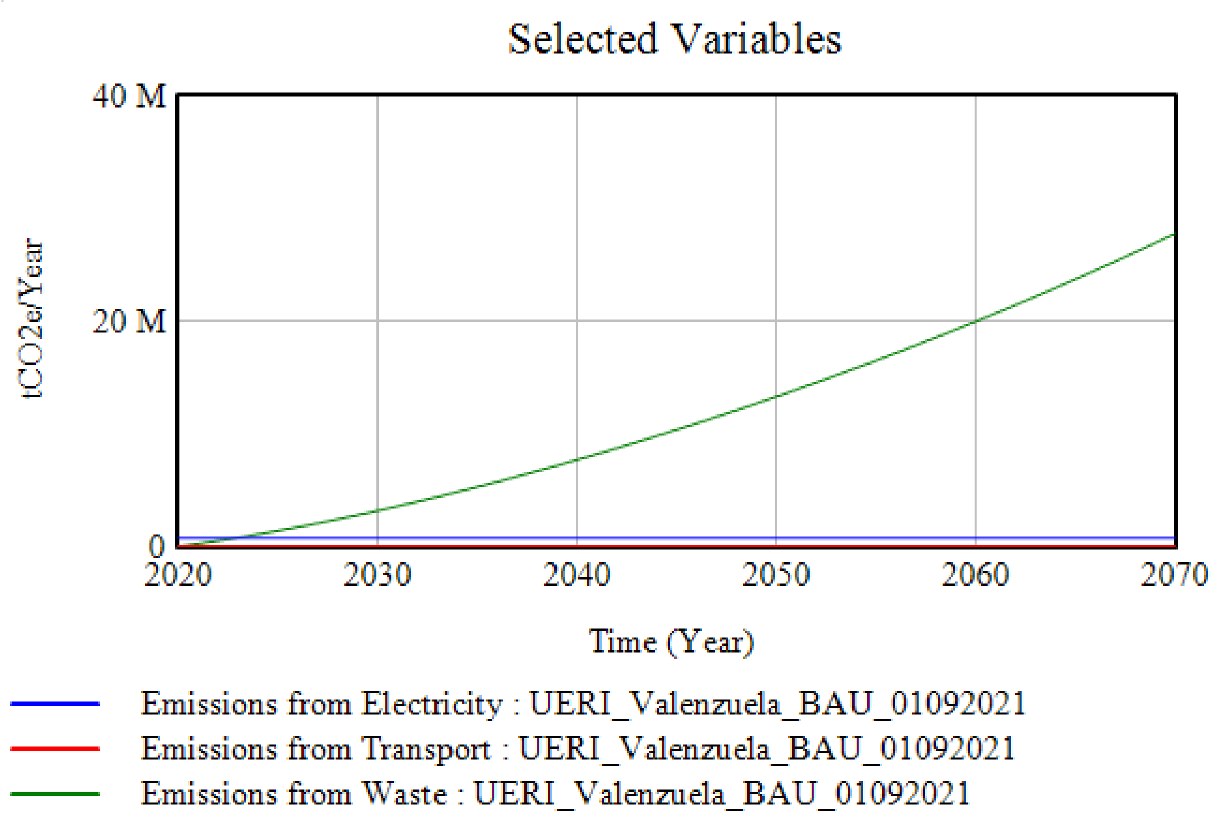


Figure 64. Carbon Sequestration vs. CO2e Emissions Graph for Valenzuela City with Adjusted y-axis for Carbon Sequestration (Right)

In terms of the different sectors that contributed to the overall emissions in Valenzuela city, the model considered only four given the available data sets provided by the city mainly and as represented in the model; *Emissions from Electricity, Emissions from Transport, and Emissions from Waste* as seen in the graph of Figure 65. As observed from the graphs, most of the contribution for emissions were from the *Emissions from Waste*, followed by *Emissions from Electricity*, and lastly, *Emissions from Transport* which appears almost negligible compared to the rest. The high observed value from WW and SWM were due to the methane emissions which have a higher global warming potential as compared to carbon dioxide. This resulted into higher tCO_2e when converted in the model. Based on the partial assessment reflected in the result of Figure 65, there was a need to deal with the emissions from WW and SWM via proper treatment, as well as reduce energy consumption via providing alternative accessible and renewable energy for the city. This also indicated a trade-off between the electricity provisioning service and carbon regulation given that increasing supply to meet city demands would result in higher consumption values and higher emissions.

Introducing mitigation efforts via city goals would help in reducing generated emissions for the city. This improvement involves lessening inflow to the carbon stock and therefore, improving the *Resilience Score for Carbon*. This involved targeting identified sectors that contribute most to emissions and adding additional mechanisms to reduce them, mainly for SWM and WW. In terms of improving the outflow or the mechanism that regulates emissions, adding more greenspaces in the city would improve the amount of carbon sequestrated. But as based on the graph, reducing emissions would have a much bigger effect on increasing resilience score for carbon given that the values computed for the inflow were much higher compared ones obtained from the outflow given that the score is a ratio of both values. Valenzuela only has limited land with which can be converted to spaces that could sequester carbon. Based on the results of the model, it could be said that attempts to mitigate emissions from the outflow would be far less effective as compared to efforts to reduce inflow emissions. The contribution of land use change, as a supporting service, in increasing regulatory performance was an observed synergy among services.



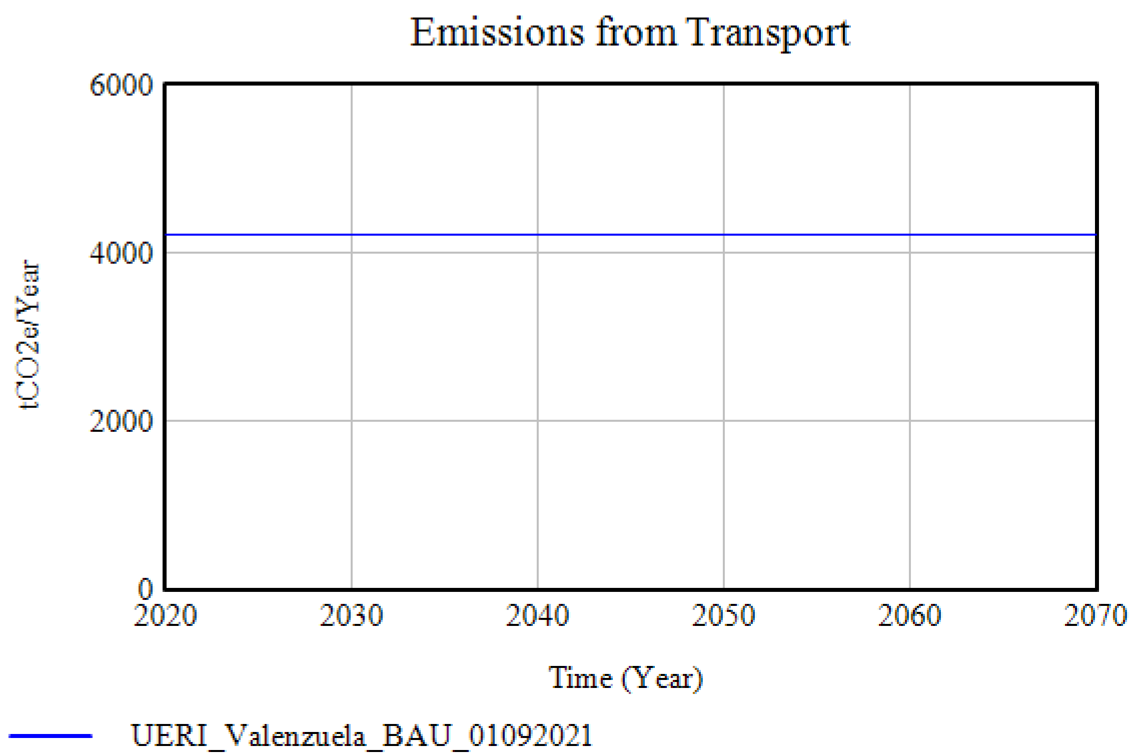


Figure 65. Graph of Carbon Emissions from Different Sectors Graph for Valenzuela City with Adjusted y-axis for Mobility tCO2e (Bottom)

4.1.1.2.5 River Rainwater Conveyance

The value for the *Resilience Score for River Rainwater Conveyance*, as seen in Figure 66, changes slightly in the earlier years before increasing steadily from year 2032 onwards as seen in the projections. This was a result of land use change which affected the graph of one of two components used to derive the resilience score. These components were represented as flows named *Surface Run-Off* and *Additional Rainwater Conveyance* in the model. Resilience was framed as a ratio between these two flows whose graphs could be seen in Figure 67. The model was limited to measuring only the amount of surface run-off accumulated within the city from a rainfall event that was conveyed to the river, then comparing this to the potential amount that the river can discharge from the rainwater conveyed.

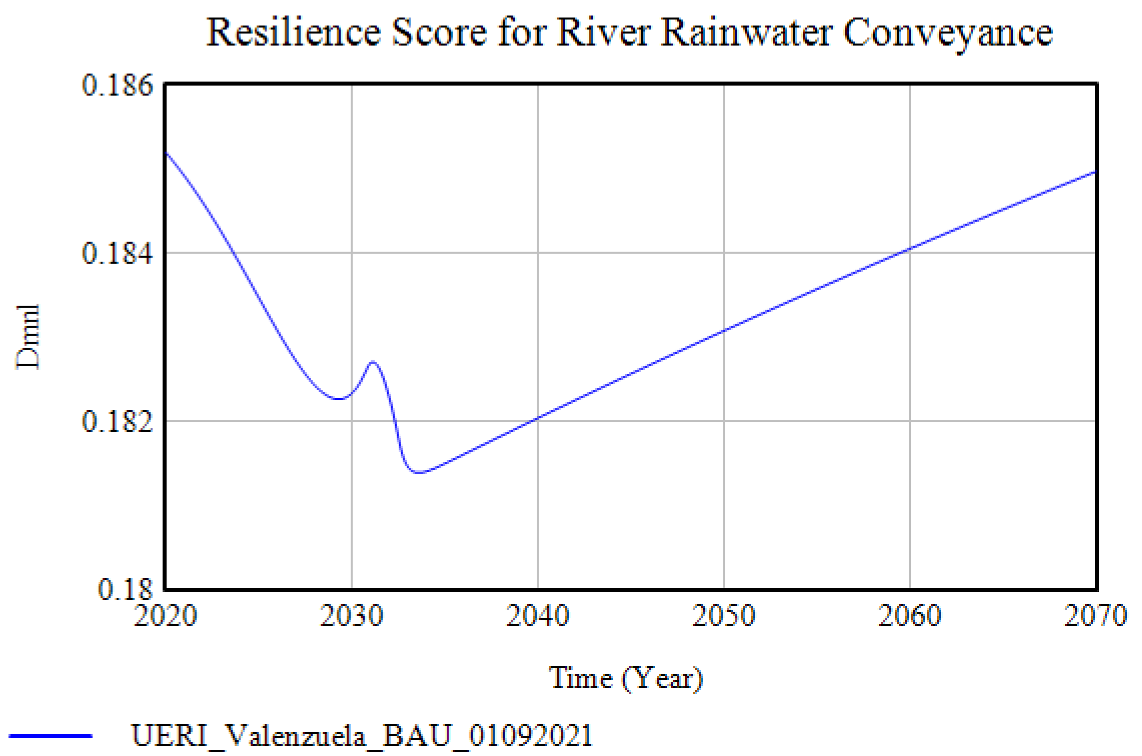


Figure 66. Graph of the Resilience Score for River Rainwater Conveyance for Valenzuela City

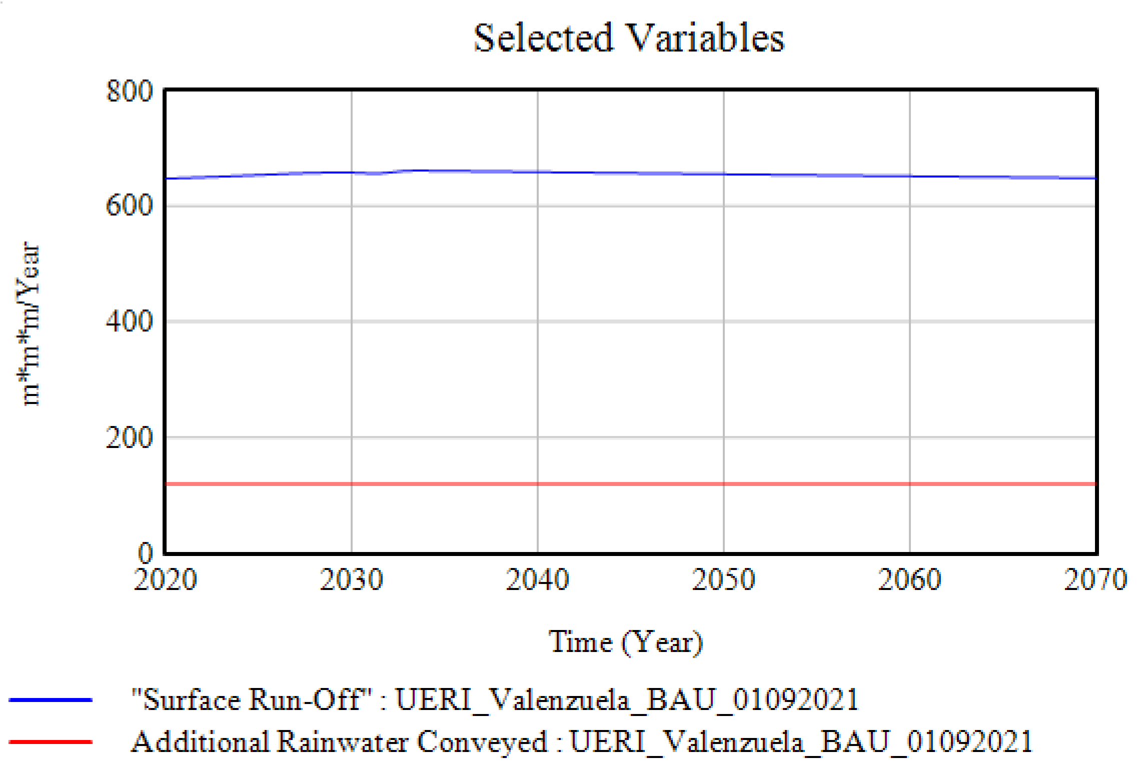


Figure 67. Components of Resilience Score for River Rainwater Conveyance for Valenzuela City

The behavior of the graph of *Resilience Score for River Rainwater Conveyance* was mainly influenced by the *Surface Run-Off*. The changing values for *Surface Run-off* was a result of the change in the *Average Run-off Coefficient* of the whole Valenzuela city due to land use change as seen in Figure 68. Around the earlier part of the projection, land use change was focused on paved development given prioritization in infrastructure. This resulted in an increase in the average run-off coefficient. But, as the priority shifted towards building more agricultural and greenspaces, the value decreased. This was reflected in the Surface Run-off given that a part of the computations was based on this average run-off coefficient. This is indicative of the contribution of the land use supporting service in improving flood regulation showing the synergy between both services.

The low value observed for the *Resilience Score for River Rainwater Conveyance* was indicative of the need for more flood control actions in the city. Approaches that the city could incorporate include efforts to reduce surface run-off via land-use change or facilities to improve natural water circulation and infiltration, or to reduce siltation via dredging purposes. Additionally, adding flood control infrastructures would help in limiting the inflow of water to match the outflow or the discharge capacity of the river.

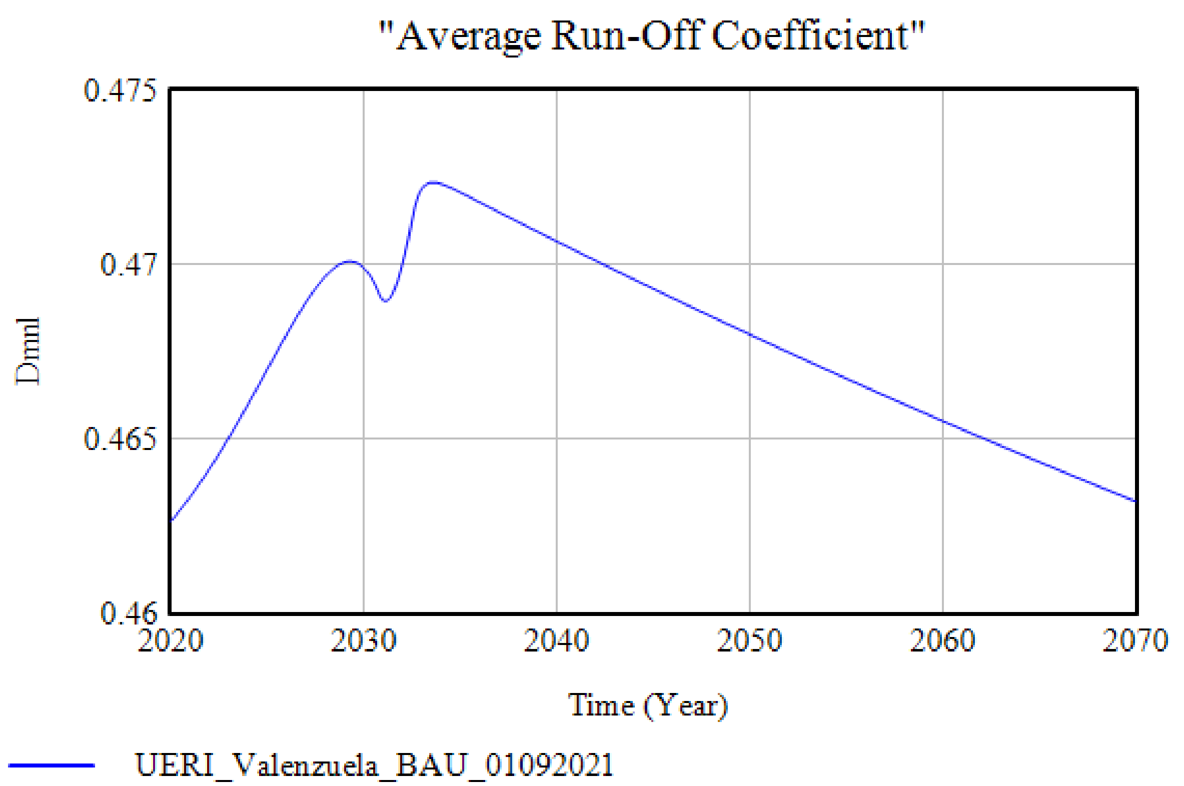


Figure 68. Average Run-Off Coefficient Graph for Valenzuela City

4.1.1.3 Supporting Services for Valenzuela City

The different land use types for Valenzuela City as well as their respective changes over the years were presented in Figure 69. Based on the graph, the city was initially composed of mostly built-up area and available land as seen in the earlier years of the projection. Over time, both values were reduced to allow for more land for other purposes. As reported by the planning office (Acurentes, 2020), there have been little development for housing, commercial, and industries over the years. This was reflected in the development plans of the city which involved shifting the priority from socio-economic development towards mobility and greenspace related development (Acurentes, 2020). Housing, which contributed mostly to built-up area, was limited within the city which resulted in out of city relocation. Given this, more roads and greenspaces were added over the years. Parks and recreation had the lowest devoted land area and exhibited downward trend over the years.

In the long-term, Valenzuela plans to convert all available land, especially those near riverways, into buffer zones or greenspaces to reduce potential flooding. Given that several services are affected by certain land use types, most synergies and trade-offs are derived from how the land use service was configurated. Trade-offs exist between socio-economic needs of the city and ecosystem service needs. Synergies refer to the contribution of land-use, which is a support service, to improving the other urban ecosystem services. The impact of these changes to the respective services would depend on the amount of land that could be allocated to a service. This would mean that there would be less other land types that could be increased when a certain type of land is more prioritized. This would have certain implication in the score of other services.

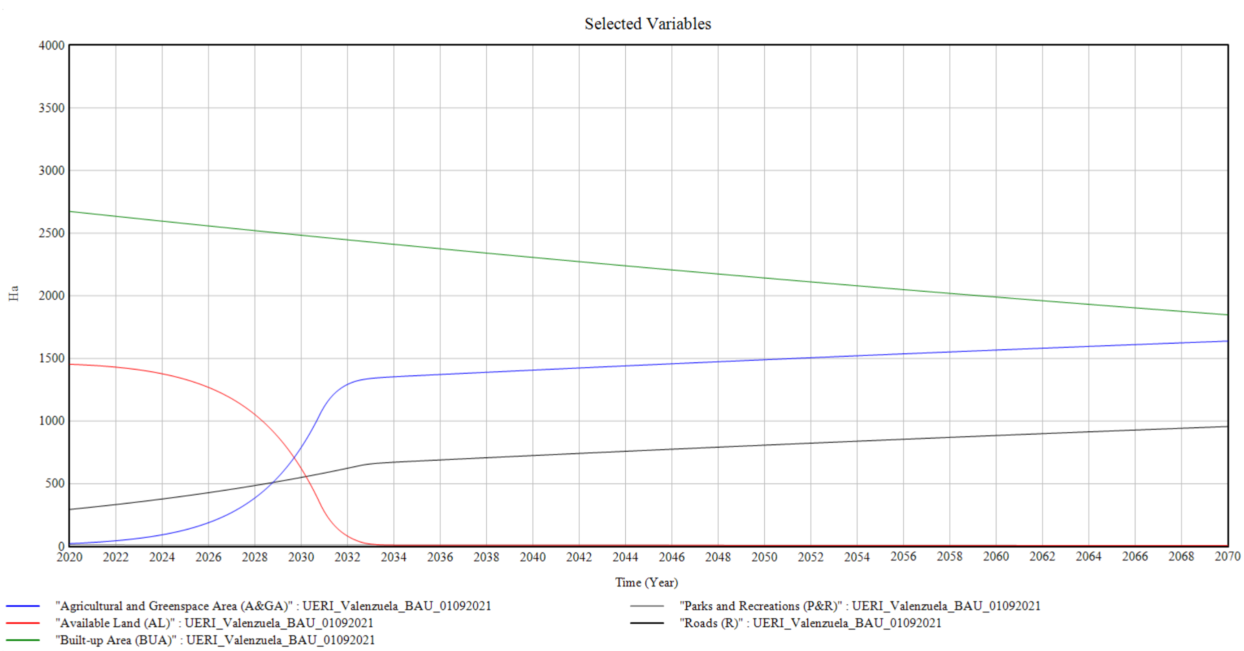


Figure 69. Different Land Use Types and Changes Graph of Valenzuela City

4.1.1.4 Cultural Services for Valenzuela City

The values of the *Cultural Resilience Score* for Valenzuela city, as seen is Figure 70, exhibited an exponential increase in the initial part of the projections reaching a peak value of 0.80 for the year 2033 before resulting to a decreasing trend for the rest of the projection. The behavior of the graph was influenced by the different services under the cultural module namely: *Resilience Score for Recommended Greenspace*, *Resilience Score for Recommended Parks*, and *Resilience Score for Recommended Sports and Playgrounds*.

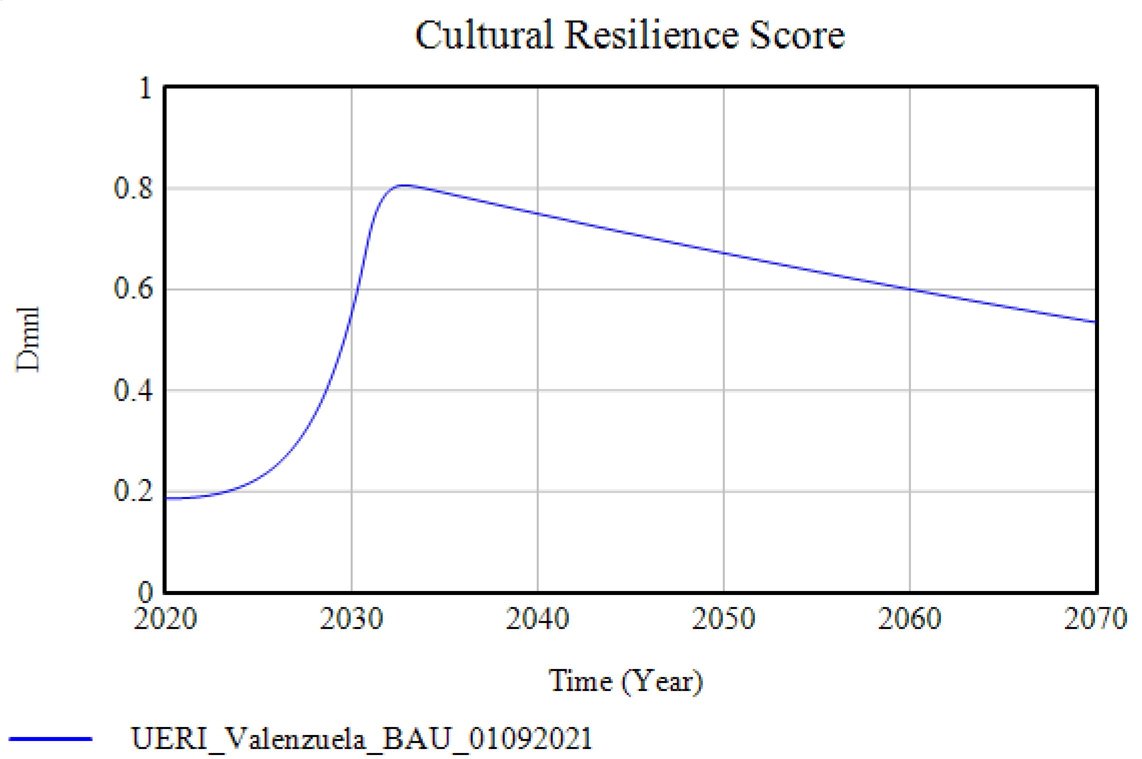


Figure 70. Cultural Resilience Score for Valenzuela City

The graph of the three resilience scores can be seen in Figure 71. *Cultural Resilience Score* was observed to behave similarly to the *Resilience Score for Recommended Greenspace*. The *Resilience Score for Recommended Parks and Sports and Playgrounds* differed as their values decreased over time all throughout the projections. The land use type of the resilience score for agricultural and greenspace area differs from the one for recommended parks and sports. This indicates a certain trade-off between the two components depending on which source of cultural benefits was more prioritized in the city. In this case, based on the values for the different cultural resilience services, the city was more focused on A&GA development. Therefore, land use changes mainly for the land types of *Parks and Recreations (P&R)* and *Agriculture and Greenspace Area (A&GA)* had respective effects on the cultural resilience scores.

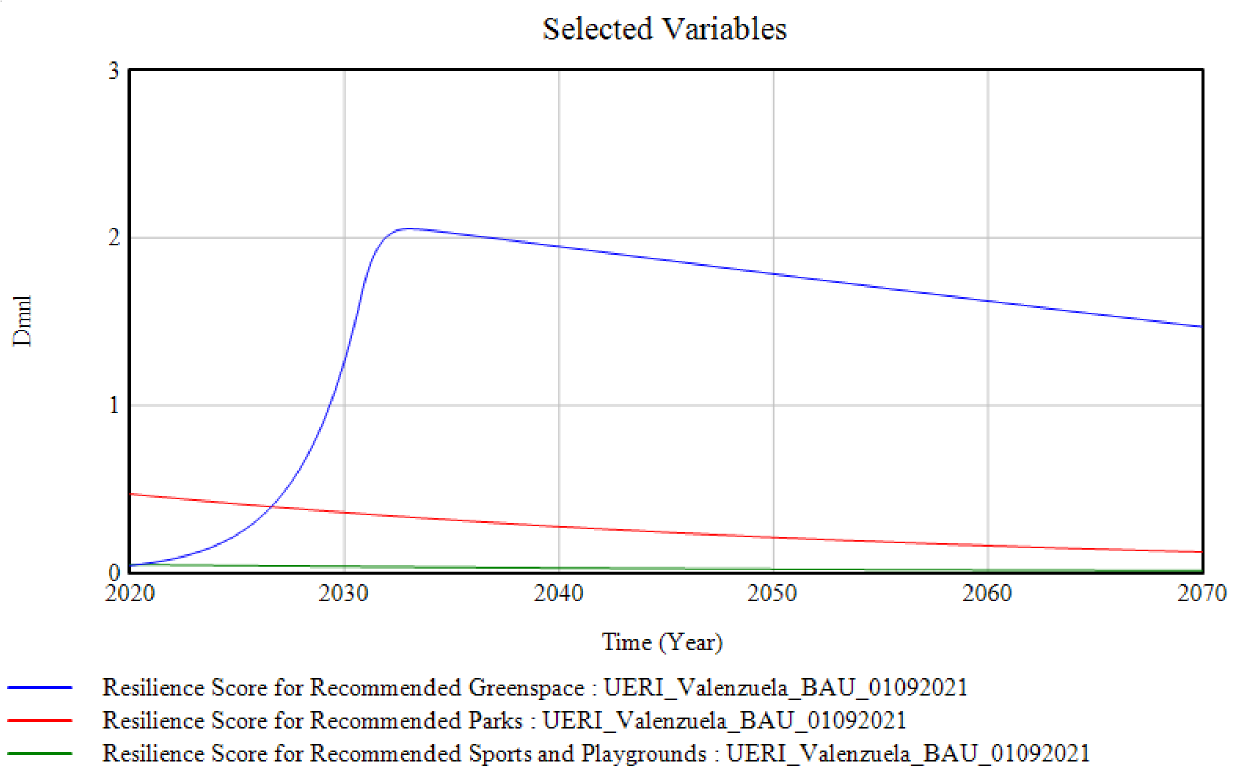


Figure 71. Components of Cultural Resilience Score for Valenzuela City

The variables compared for the *Resilience Score for Recommended Greenspace* were the *Recommended Greenspace Supply* and the *Agriculture and Greenspace Area (A&GA)* whose graphs were displayed in Figure 73. Initially, the city was able to increase the amount of A&GA as reflected in the increasing values. This led to an optimal score for resilience for recommended greenspace given that the city was able to account for the cultural needs of the population. The optimal score led to an overall higher value to the Cultural Resilience Score. This was consistent with the prioritization of city towards increase A&GA, which therefore, also increases cultural resilience service from greenspace.

The decreasing value for resilience score for recommended greenspace was observed after a certain time given the available land running out over the years. Without any land left to convert, the city would no longer be able to generate additional cultural services to account for the increased demand which continues to grow with the population.

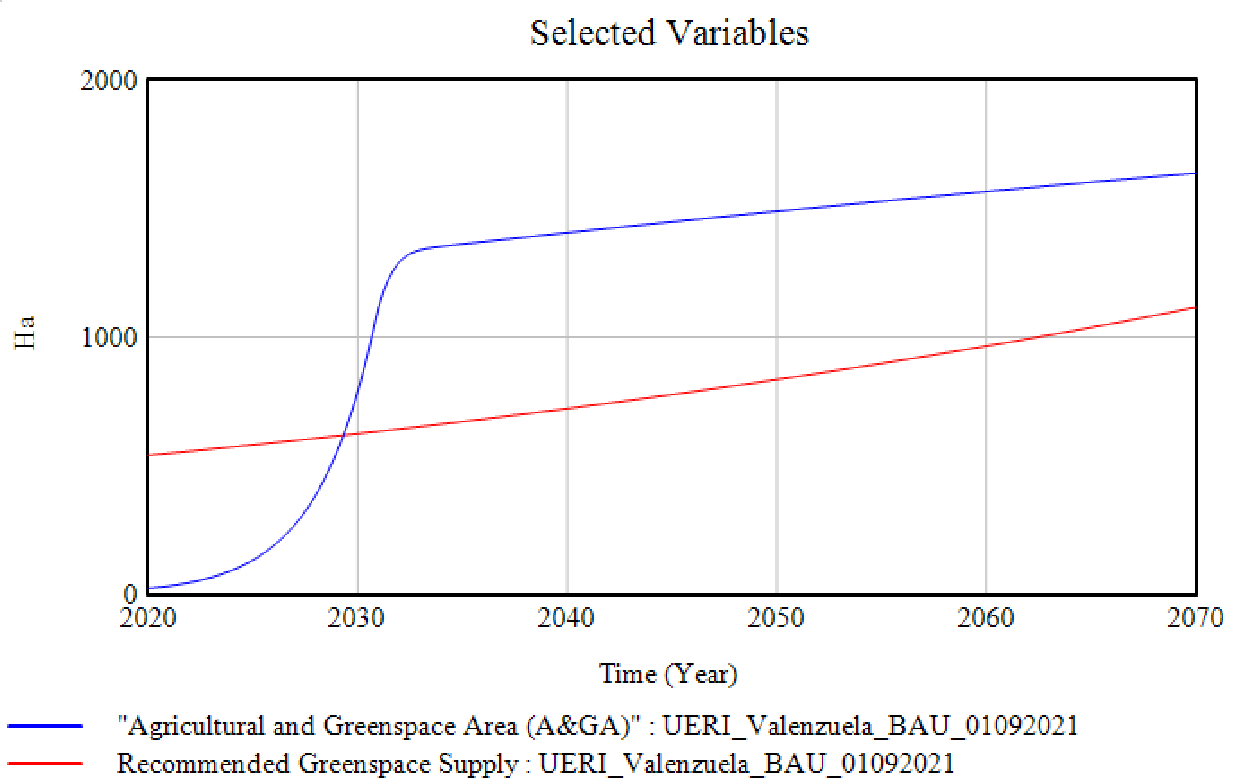


Figure 72. Graph of the Components of Resilience Score for Recommended Greenspace for Valenzuela City

The resilience score for parks and sports as well as for playgrounds were suboptimal given that the value obtained were both less than one as seen Figure *71*. The difference in magnitude for the required space was what led to the difference in the resilience score with the score of sports and playground being lower than parks. The required space needed for sports and playgrounds is much higher than the space needed for parks. This resulted in a lower *Resilience Score for Sports and Playgrounds* which had a maximum of 0.046 as compared to the *Resilience Score of Parks* which had a maximum of 0.46 both at the start of the projections.

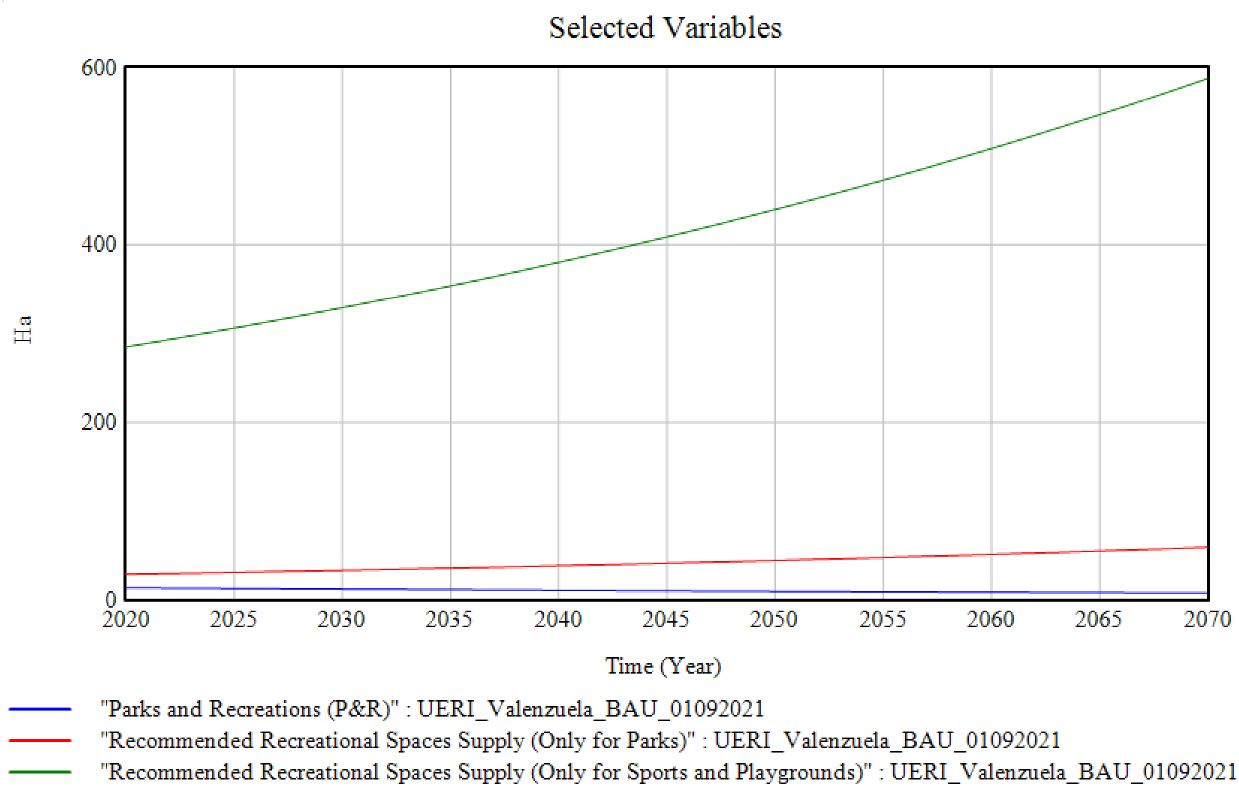


Figure 73. Recommended Recreational Spaces Supply versus Parks and Recreations Graph for Valenzuela City

The overall trend for the *Cultural Resilience Score* was indicative of the limitations set by land use in improving resilience given that the increase in score was proportional to the increase in the respective land type. Therefore, trade-offs could be seen in land use as given that certain services require different land use types. There are implications with how services are prioritized in cities, as seen in the case of the cultural service.

4.1.1.5 UERI for Valenzuela City under Business-As-Usual

The value of the UERI under the Business-As-Usual scenario for Pasig City can be seen in Figure 74. It was observed that there was an increasing trend in the UERI score along the earlier years of the projections. The increase in resilience is a result of the increase in the land use types such as A&GA as well as P&R earlier in the development years which improved the overall services in the city such as provisioning, regulating, and cultural. Among the components, the cultural service benefitted the most from land use change that took place in the development of Valenzuela as compared to the other services.

The initial low score observed from Figure 74 is a result of the land use change that took place in the city before the start of projections in the model. Land use was focused on built area infrastructure which benefitted more the socio-economic services rather than the urban ecosystem services making up UERI. This had certain implications as reflected in the values of the regulating and cultural resilience scores observed in the city. This was observed in the low values for all the regulating services in the city. But given the increase in A&GA, the regulating services were observed to go up over the years until the point wherein available land could still be converted. This revealed certain trade-offs in between land use change wherein focusing on a certain type of service, for this case was the socio-economic service assumed from high fraction devoted to built-up area, resulted in the decrease in another, given less A&GA.

Over the years, the value was seen to decrease after reaching a certain peak value of 0.60. This was a result of the widening gap between growing demand for the different services as well as the ability of the city to provide them. What contributed to the increase in demand was population growth as a lot of the indicators used a per capita approach in deriving how much more services were still needed. The score being below 1 implies that the city was suboptimal in terms of being able to deliver the services which was seen to decrease over time. This is indicative of the growing gap between what the city could provide and what they required. There were also implications and observed trade-offs as a result of meeting consumption needs especially for the provisioning services. Higher consumption would mean more emissions which would reflect under the regulating services. Based on the relationship of the components between provisioning and regulating model, the high provisioning resilience score may have resulted in a lower regulating resilience score.

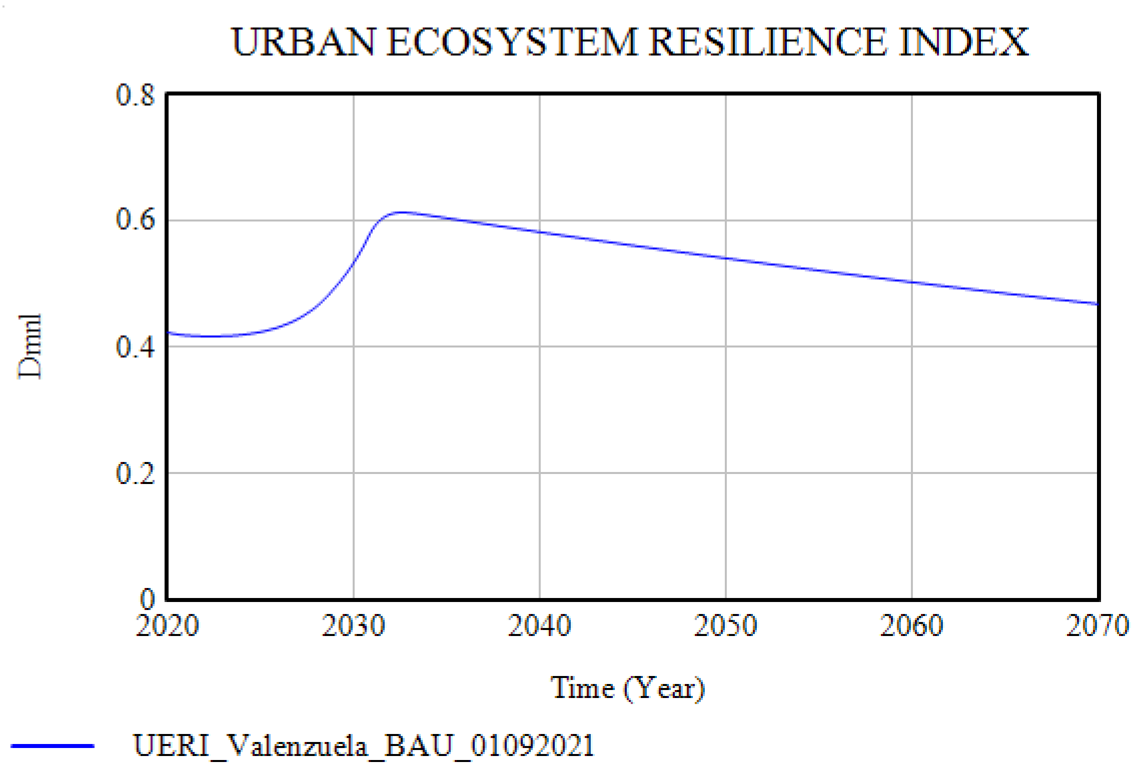


Figure 74. Graph of UERI under Business-As-Usual scenario for Valenzuela City

4.1.1.6 Valenzuela City Self-Sufficiency Scores

4.1.1.6.1 Food Self-Sufficiency Score

The self-sufficiency of food service model was made to measure how much food was outsourced and how much was produced to sustain the population in the city. The score was framed as a ratio between internal production and total food requirement, and was projected over time as seen in the graph of Figure 75. There were three products measured for the city as they were considered the city's main produce mainly, fruits, vegetables, and rice. Fruits and vegetables were represented as the *Self-Sufficiency Score for Fruits and Vegetables* while rice was represented as *Self-Sufficiency Score for Rice*. What influenced the overall trend and value obtained for the self - sufficiency graphs were seen in the graph of their components found in Figure 76 and Figure 77.

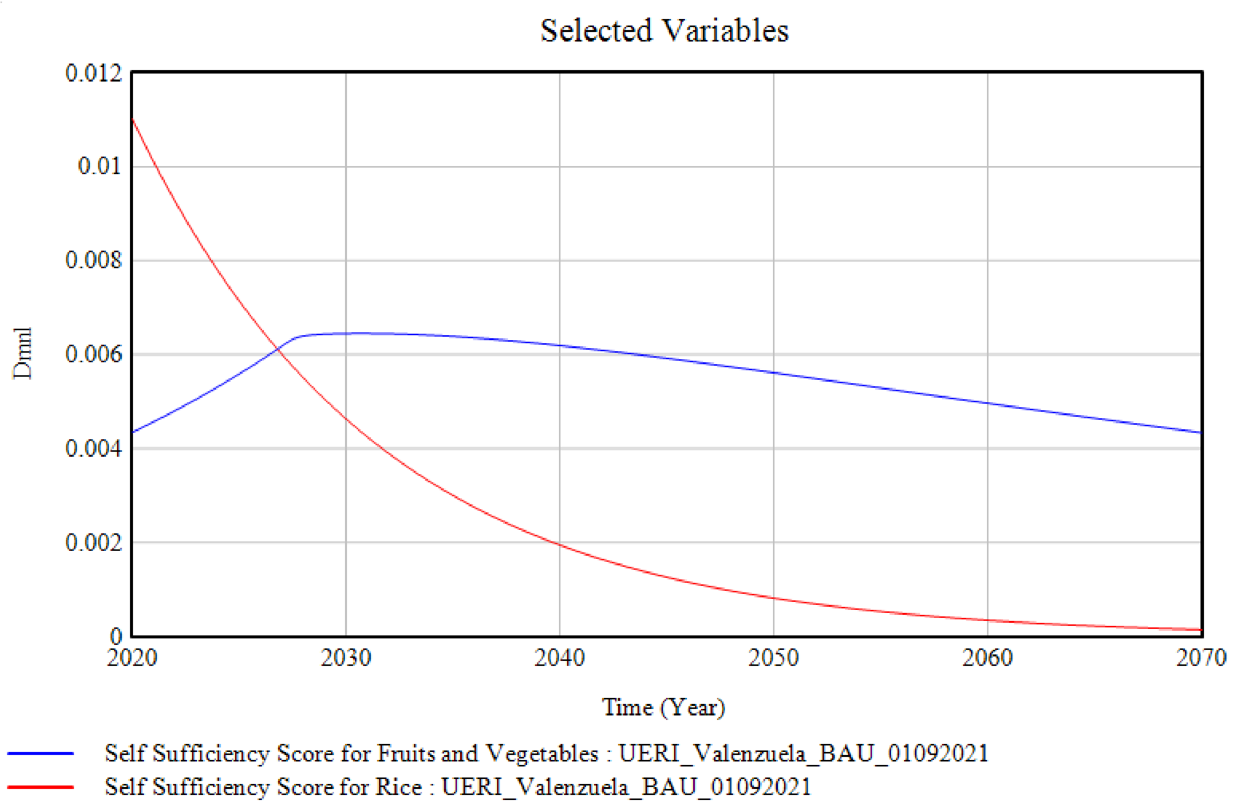


Figure 75. Self-Sufficiency Score for Fruits and Vegetables and Rice Graph for Valenzuela City

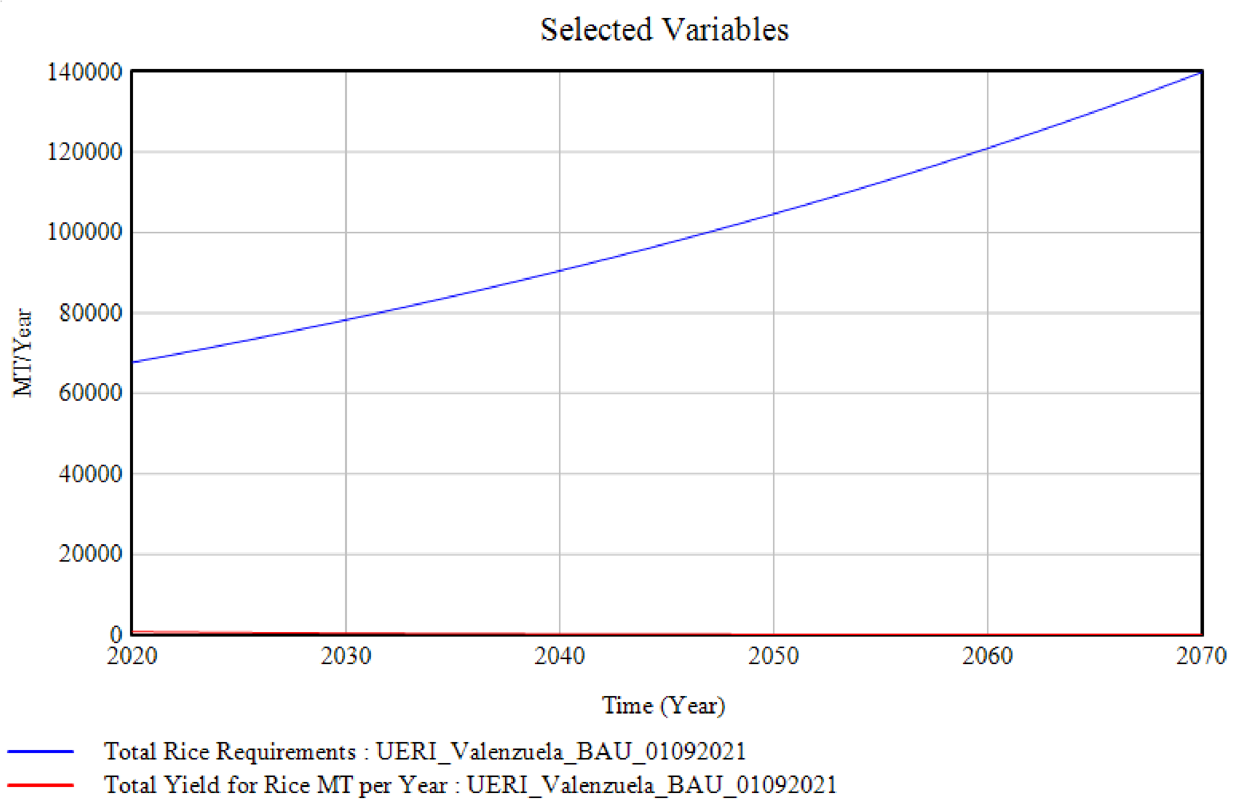


Figure 76. Components of Self-Sufficiency for Rice Graph for Valenzuela City

The *Self-Sufficiency for Rice* was made up of two variables used for the scoring mainly *Total Rice Requirements* and *Total Yield for Rice MT per Year*. *Total Rice Requirements* used a per capita approach with a standard obtained from what was observed in the LGU and compared to a national standard for rice production. Therefore, the value for total rice requirements projected was observed to have an increasing trend given that it was influenced by growing population. *Total Yield for Rice MT per Year* appeared almost negligible given the huge gap between what was required and what could be produced within the city.

The self-sufficiency score obtained was relatively low compared to the resilience of food. This is indicative that most of the rice used to meet the caloric requirement is supplied from outside of the city. Land served as a major limitation to increasing internal production. Constraint in available land for conversion resulted in outsourcing food to meet consumption demands. While the city does not aim to meet all the food requirements internally, there are goals towards increasing the amount they produce in the city via urban farming.

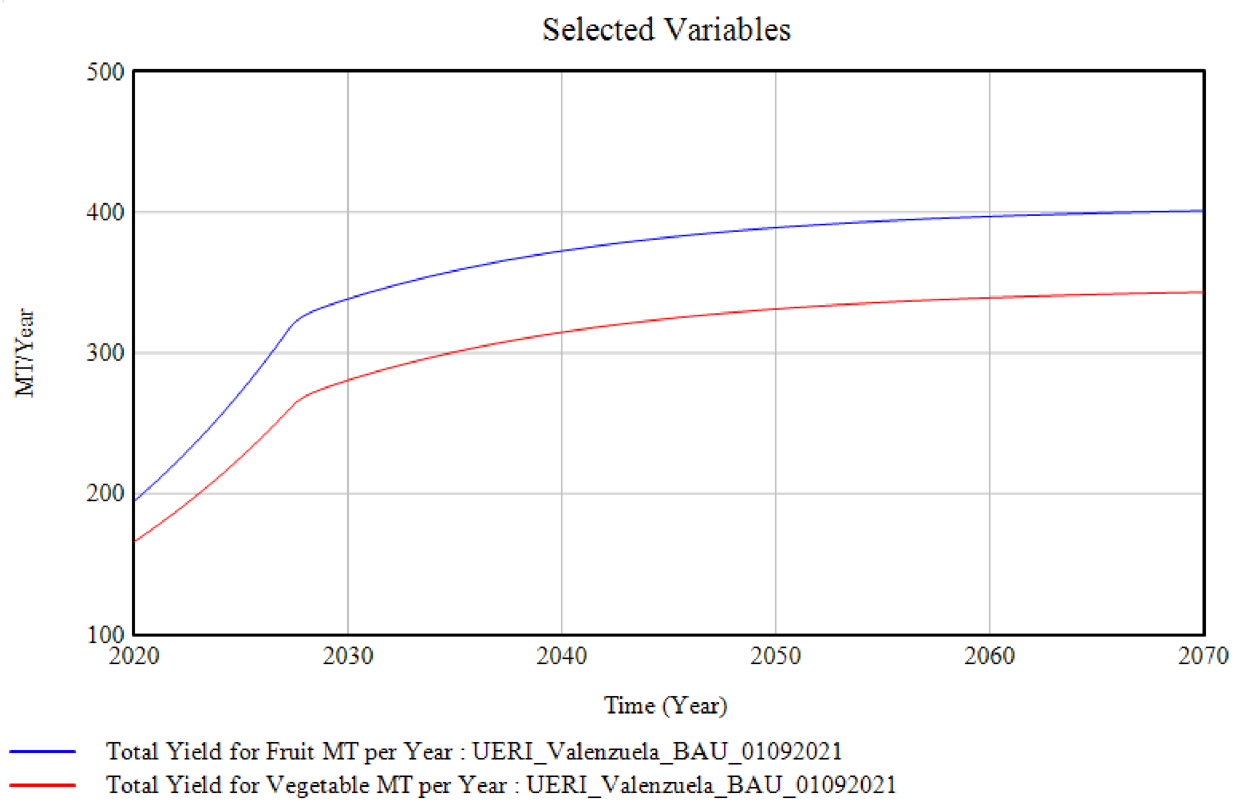


Figure 77. Graph of Components for Self-Sufficiency for Fruits and Vegetables Graph for Valenzuela City.

The *Self-Sufficiency for Fruits and Vegetables* were made up of two components: *Total Fruits and Vegetables Requirement* and *Total Yield for Fruit MT per Year*. This followed the same approach as the self – sufficiency for rice using a per capita approach for computing for Total Fruits and Vegetables Requirement. The value of the self-sufficiency index for Fruits and Vegetables decreased over time given that the food produced within the city could was not enough to match consumption demands. Like rice production, locally produced fruits and vegetables appeared almost negligible when compared to the requirement set for recommended consumption. The low self-sufficiency score along with the high resilience score implies that while the city can provide for food needs of the population, this food was not produced within the city and had to be imported from outside. This was seen in the huge gap between the requirement for fruits and vegetables versus the required amount, available land served as the main limitation for increasing internal production given that it would require an amount larger than what the city could provide.

4.1.1.6.2 Solid Waste Management Self-Sufficiency Score

In terms of the *Self-Sufficiency for SWM*, the graph as seen Figure 78 exhibited an trend with the self-sufficiency score increasing over time. What determined the Self-Sufficiency Score for SWM were the behavior of the variables used in computing the value mainly: *Composting and Waste Recycling* to represent waste diverted, compared with the overall *Generated Waste*. The purpose of the model was to show how much waste was treated within the city and how much was transported outside the city and to landfills. The low *Self-Sufficiency for SWM* implies that the current capacity of city for treating solid waste within the city was not enough to match *Generated Waste*. The value continues to decrease given that generated waste increases simultaneously with population while treatment capacity remains constant. Anything not handled by the capacity was assumed to have been treated outside which was observed when looking at the gap between generated waste and diverted waste. Additionally, there are currently no means to dispose of residuals in the city; therefore, they are automatically sent to landfills. There is also a lack of MRFs in the city as not all have been constructed or are operational. Efforts to improve self-sufficiency would require increasing the capacity of treated diverted waste or installing new facilities to treat residuals inside the city. The gap observed between the values of treated and generated were seen in Figure 79 based on their respective graphs.

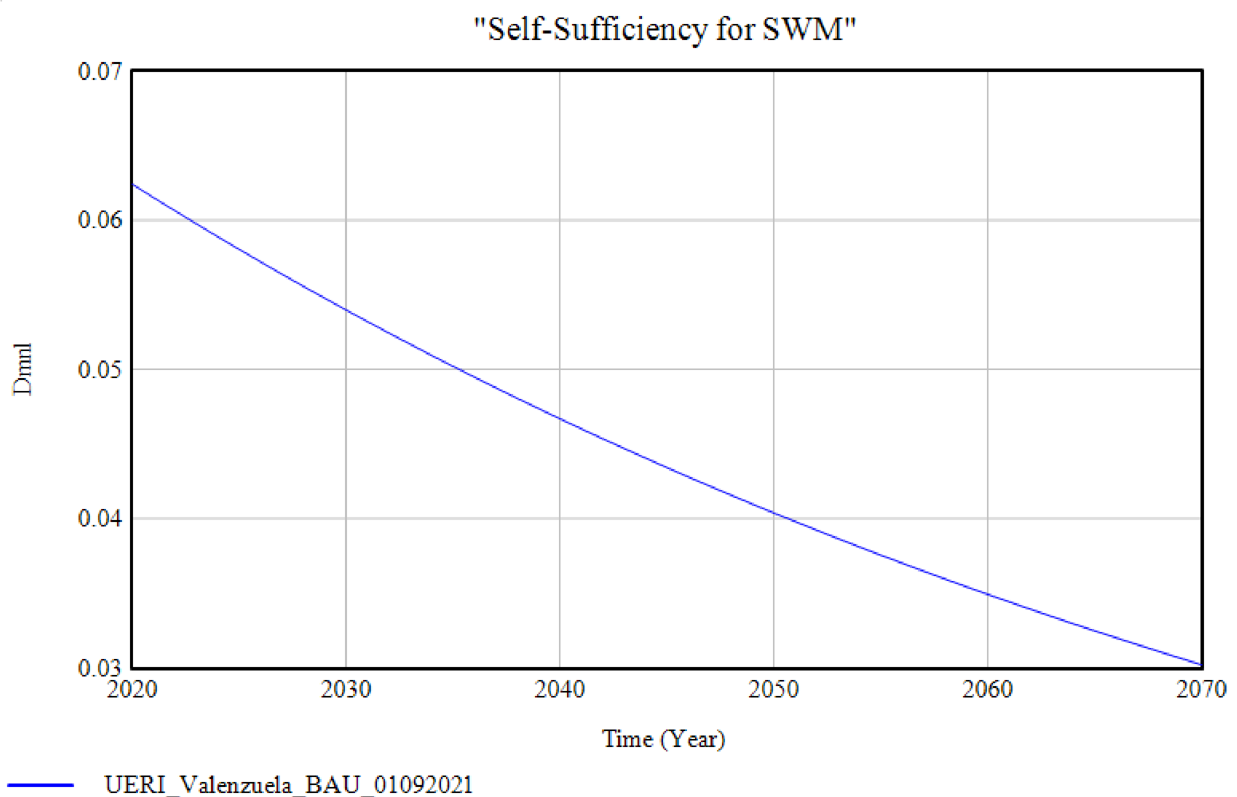


Figure 78. Self-Sufficiency for SWM Graph for Valenzuela City

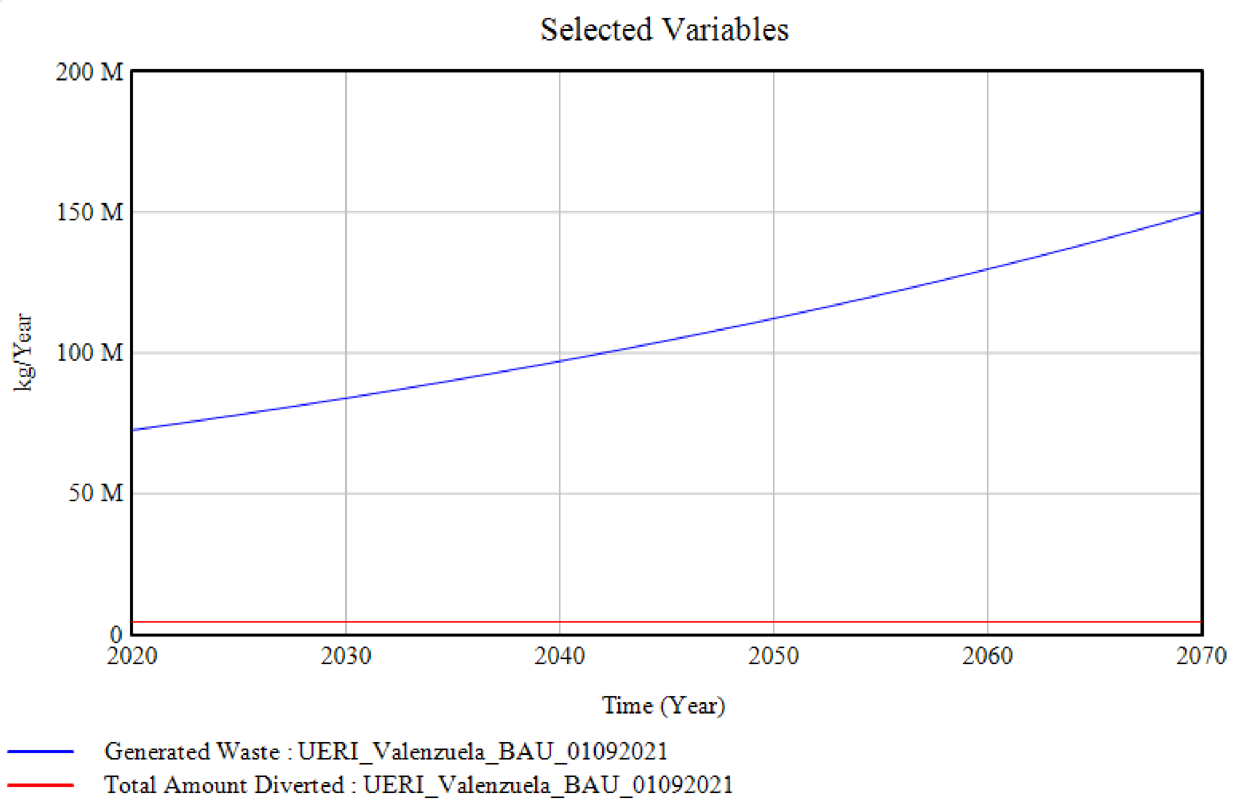


Figure 79. Generated Waste vs. Diverted Waste in Valenzuela City

4.1.1.6.3 Wastewater Self-Sufficiency Score

The value of *Self-Sufficiency Score for WW* remained zero over the years given that there no wastewater was being treated in the city. It was reported that no connections have been made as of now given that the treatment plants are still undergoing construction. Adding more connections to the sewer lines, by increasing the number of functioning WW treatment plants in the city, would also increase the *Self-Sufficiency Score for Valenzuela*. Currently, the city plans on adding 100,000 more connection in the next ten years.

4.1.2 Valenzuela City Siltation Scenario

Flooding was considered a main priority according to the planning department of the city. The siltation Scenario applied to the city was done to determine more accurately the effects of sediment yield to the *Additional Rainwater Conveyed*. This scenario was selected to provide more information given that siltation was not accounted for in the monitoring reports of the flood control office. This would serve to guide the LGU on the effects of dredging and whether it would result in significant changes to *Resilience Score of River Rainwater Conveyance* and correspondingly, to the UERI of the city.

4.1.2.1 Regulating Services under Siltation Scenario

When applied, as seen in Figure 80, the *Additional Rainwater Conveyed* was observed to be less in Siltation Scenario as compared to the value for business-as-usual. This resulted in a lower value for the *Resilience Score for River Rainwater Conveyance* as seen in Figure 81.

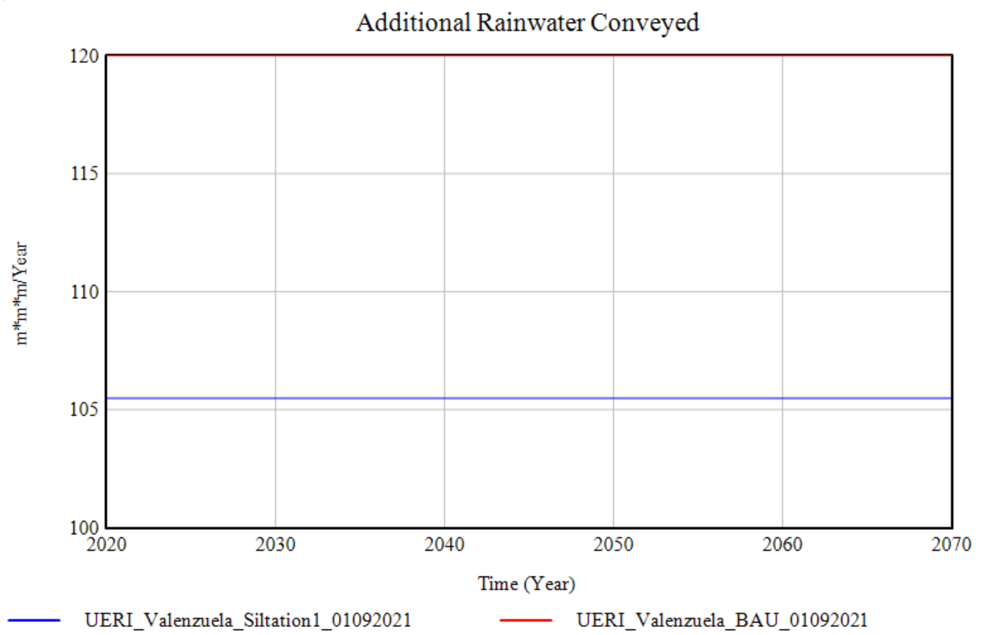


Figure 80. Graph for Additional Rainwater Conveyed under Business-as-Usual and Siltation Scenario

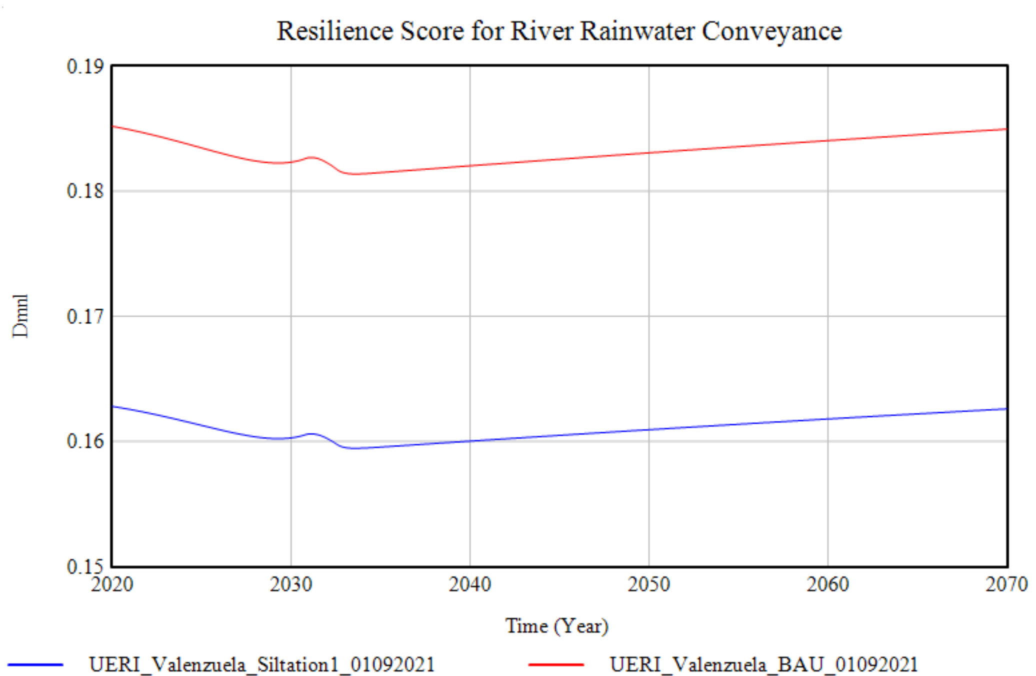


Figure 81. Graph of the Resilience Score for River Rainwater Conveyance under Business as Usual and Siltation Scenario for Valenzuela City

4.1.2.2 UERI under Siltation Scenario (Valenzuela)

The graph of the UERI under the siltation scenario was compared to the UERI under the Business-As-Usual scenario as seen in Figure 83. The slight difference implies that the contribution of siltation is minimal when reflected in the UERI. This is consistent with the results from the change in the resilience score for river rainwater conveyance. The purpose of showing the impacts were to determine whether the contribution of added siltation was enough to justify any intense dredging active in the area given that the act of dredging itself may result to additional problems as it is destructive in nature. Only the siltation was accounted for and not the contribution of trash. With the given results, should siltation alone be the basis of dredging, then the investment would not be rational given that the cost outweighs the benefits given the small contribution of siltation to the discharge rainwater conveyed.

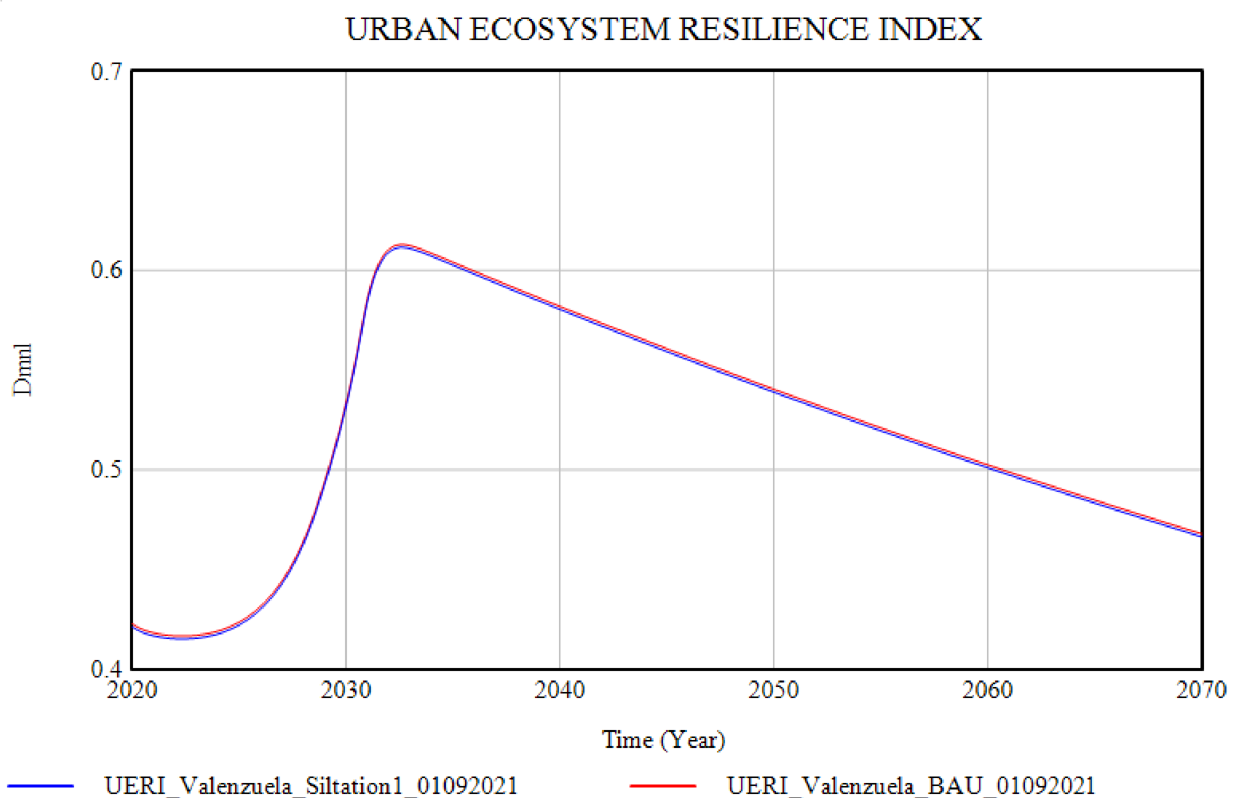


Figure 82. Graph for UERI for Siltation Scenario for Valenzuela City

4.1.3 Valenzuela City Land Use Scenario

The Land Use Scenario was applied to the city to determine the effects of changes in development, based on the Comprehensive Land Use Plan and city goals, to the UERI in terms their land use types. Different services require different land types which result to land use changes in the city. Therefore, the scenario would serve to guide the LGU on the effects of these changes to the respective services and to the overall UERI.

4.1.3.1 Provisioning Services under the Land Use Scenario (Valenzuela)

There was an observed increased in the *Total Yield for Fruit* and *Total Yield for Vegetables MT per Year* given more A&GA as seen in Figure 83 and Figure 84. The conversion rates for the land use types were assumed to be the same from the Business-As-Usual scenario. As such, total yield for rice did not change. This resulted in changes for the *Self-Sufficiency Score for Fruits and Vegetables* from the business-as-usual scenario to the different Land Use Scenarios as seen in Figure 85. The minimal increase in the self-sufficiency score implied that the change in land use was not enough to yield significant results given the limitations of available land that could be converted. The results obtained from the model are indicative of the difference between population of the city and land requirement to sustain them.

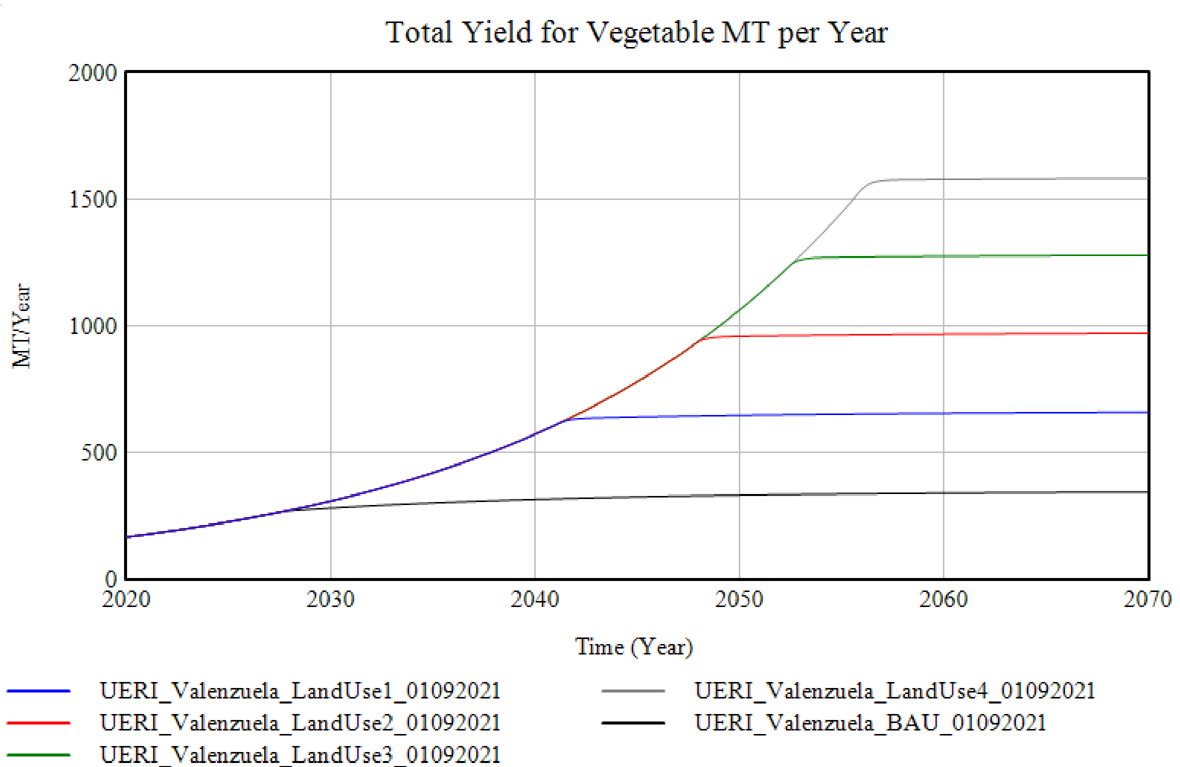


Figure 83. Graph for Total Yield for Vegetable MT per Year Under Business-As-Usual and Land Use Scenario

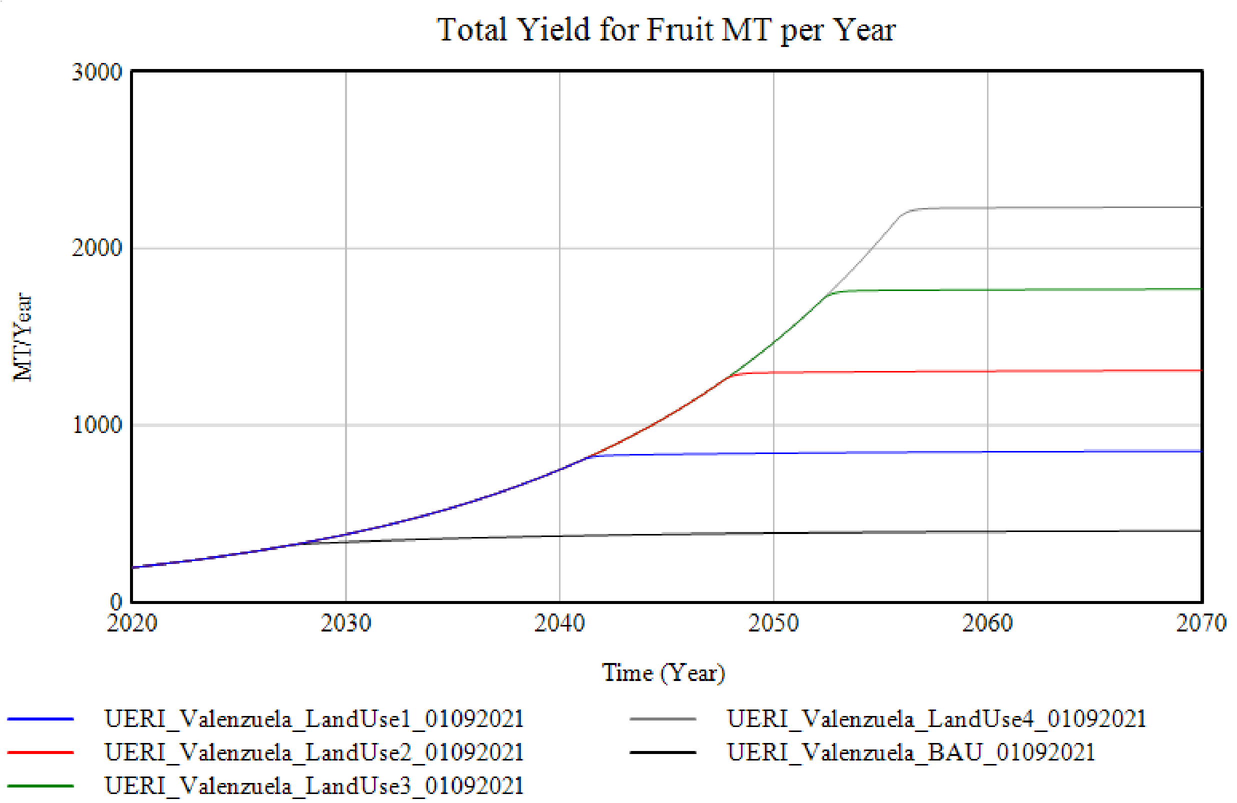


Figure 84. Graph for Total Yield for Fruit MT per Year Under Business-As-Usual and Land Use Scenario

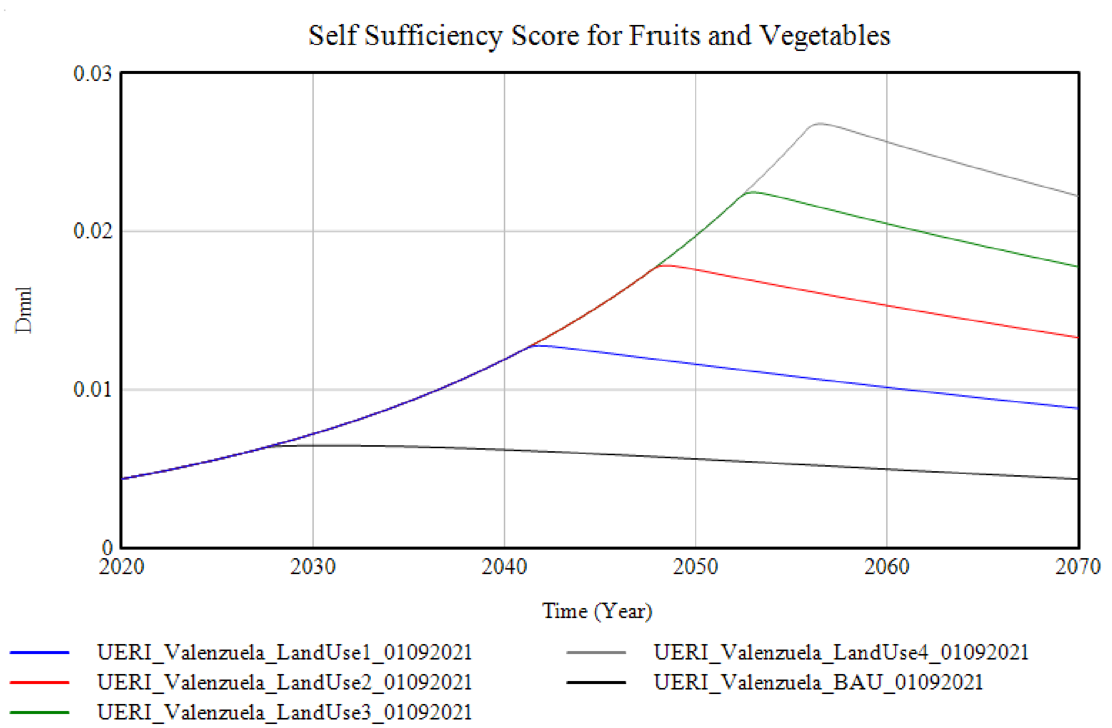


Figure 85. Graph for Self-Sufficiency Score for Fruits and Vegetables Under Business-As-Usual and Land Use Scenario

4.1.3.2 Regulating Services under the Land Use Scenario (Valenzuela)

Increase in A&GA would have certain implication to the regulating performance of certain services in the city such as *Pollutant Removal* for air quality, *Carbon Sequestration* for carbon emissions, and *Average Run-Off Coefficient* for surface run-off as seen in Figure 86, Figure 87, and *Figure 88* respectively. The increase in A&GA would result in an increase in the amount of PM2.5 naturally removed along with Carbon sequestered given more distribution potential for greenery. Additionally, added A&GA results in a smaller *Average Run-Off Coefficient* value given that it allows for more infiltration.

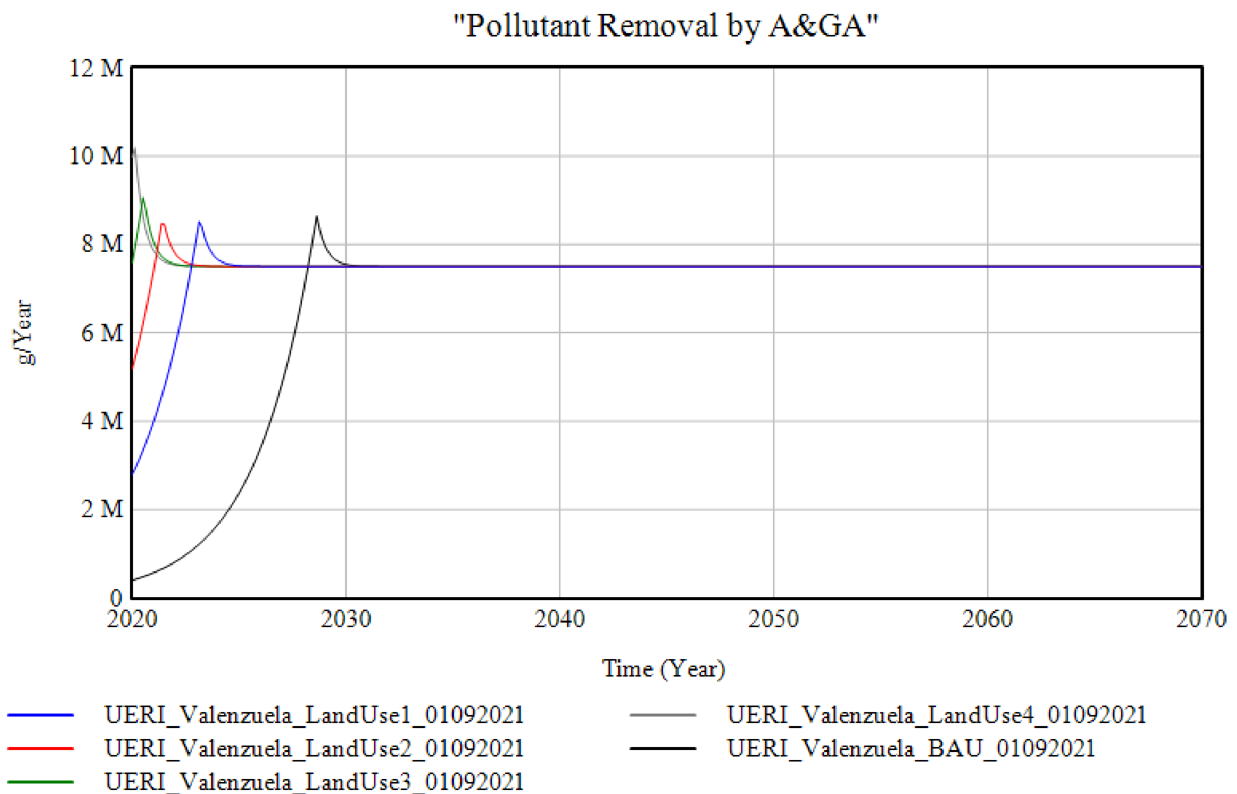


Figure 86. Graph of Pollutant Removal Under Business-As-Usual and Land Use Scenario for Valenzuela City

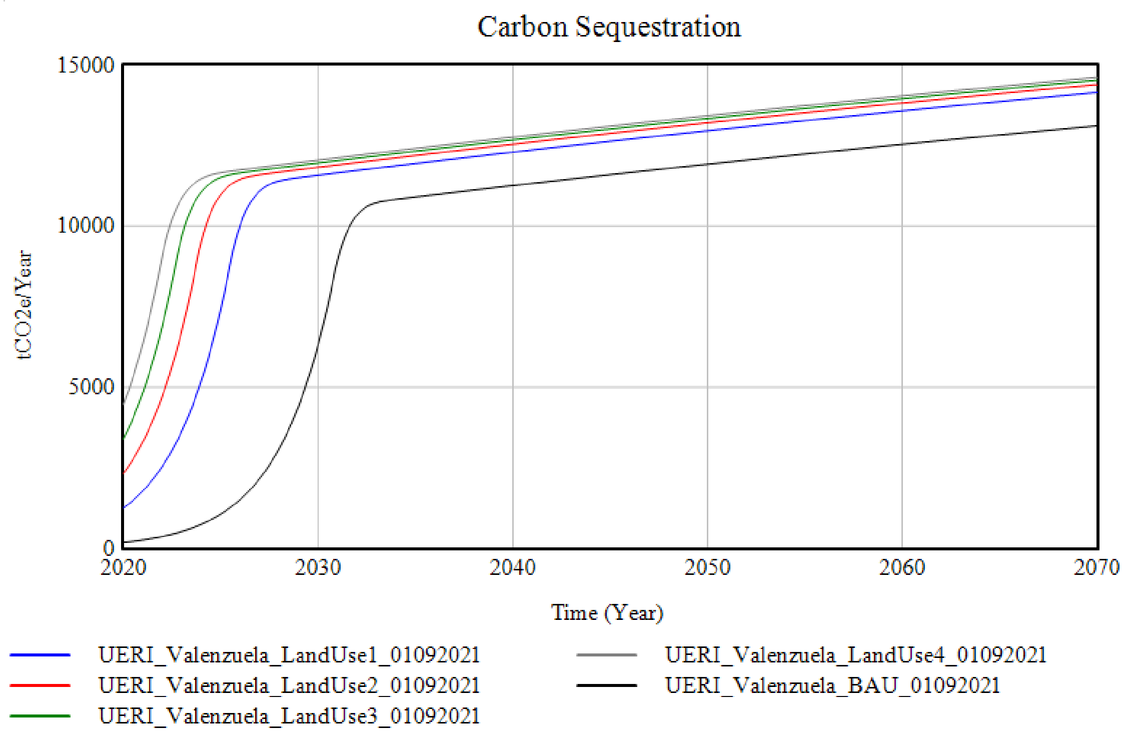


Figure 87. Graph of Carbon Sequestration Under Business-As-Usual and Land Use Scenario for Valenzuela City

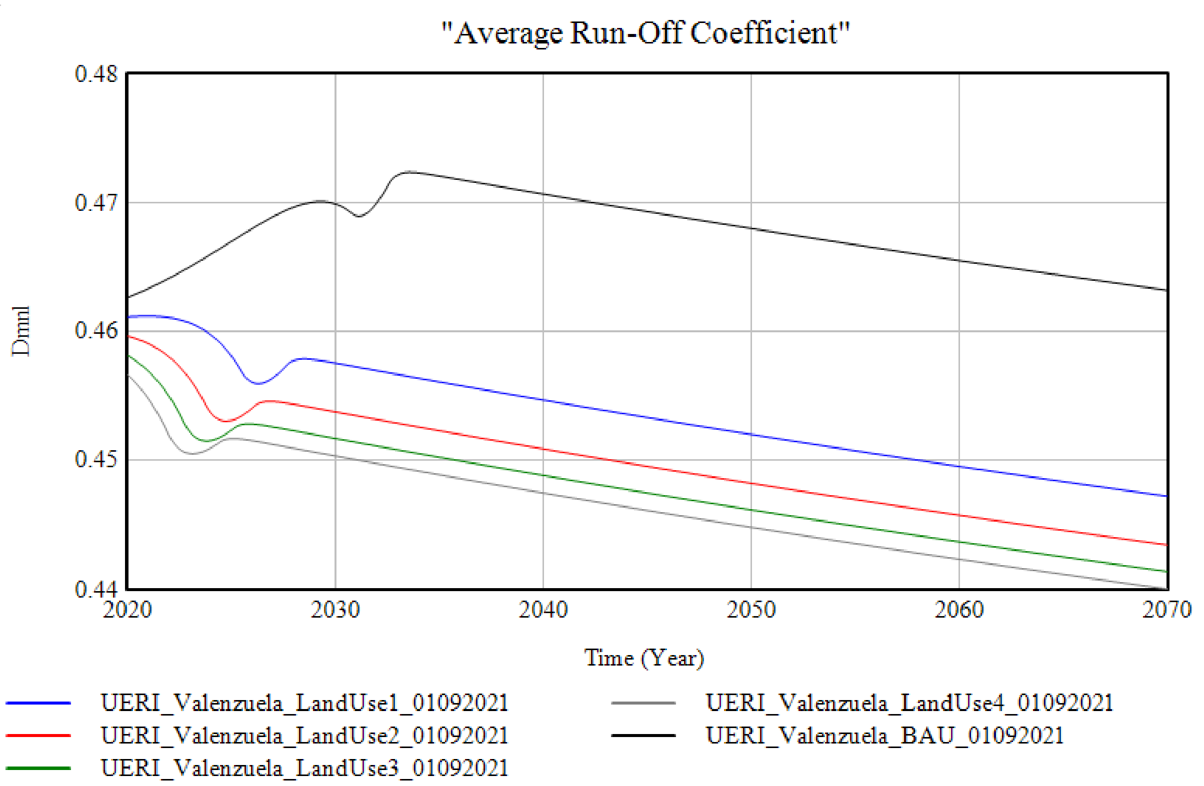


Figure 88. Graph of Average Run-Off Coefficient Under Business-As-Usual and Land Use Scenario for Valenzuela City

Improved performance in regulation for the mentioned services resulted in the slight increase in the initial part of the projections for the *Resilience Score of Air Quality*, *Resilience Score for Carbon Emissions*, and *Resilience Score for River Rainwater Conveyance* as seen in *Figure 89*, *Figure 90*, and *Figure 91* respectively. This implies a synergy between the land-use component and the regulatory service. Given only the slight changes in the resilience score among scenarios, the effects of land use change were seen to be minimal for all three services. But in terms of the regulatory service component itself, slight land use change resulted in significant increases for both pollutant removal and carbon sequestration making land-use change a leverage point for regulatory service components but not resilience itself. This implies that the conversions made, while contributing to better regulatory performance as seen from the business-as-usual to the Land Use Scenario, are not enough to offset the disturbed conditions in the environment in order to reach a prescribed value. This also implies that the values for emissions generated for both air and carbon were still much higher than the regulatory mechanisms of the city despite significant changes. In terms of the average run-off coefficient, the slight change implies that for land use to have an effect, more amounts of land must be converted.

Air quality benefitted the most from the scenario, followed by carbon and river rainwater conveyance as seen in their respective resilience score graphs. The graph of the resilience score for air quality showed that improvements were mostly seen in the initial part but could not be sustained over time. This was like the case for the *Resilience Score for Carbon* that eventually exhibited a decreasing score. The *Resilience Score of River Rainwater Conveyance* increased over time under the Land Use Scenario given that the land had less average run-off coefficient as compared to the business-as-usual scenario.

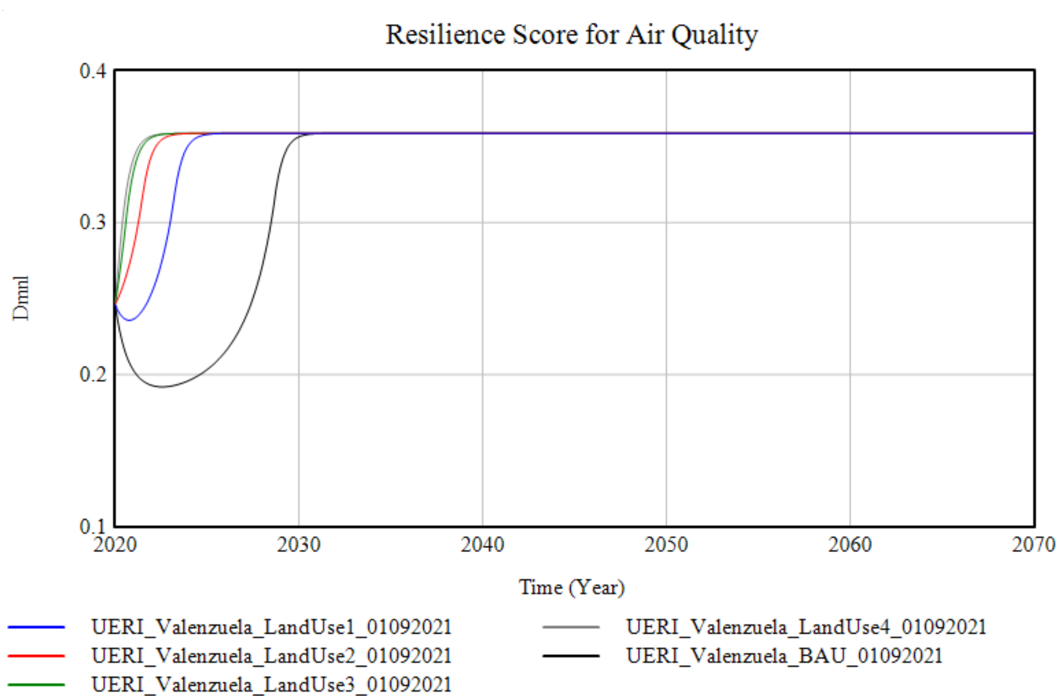


Figure 89. Graph of Resilience Score for Air Quality Under Business-As-Usual and Land Use Scenario for Valenzuela City

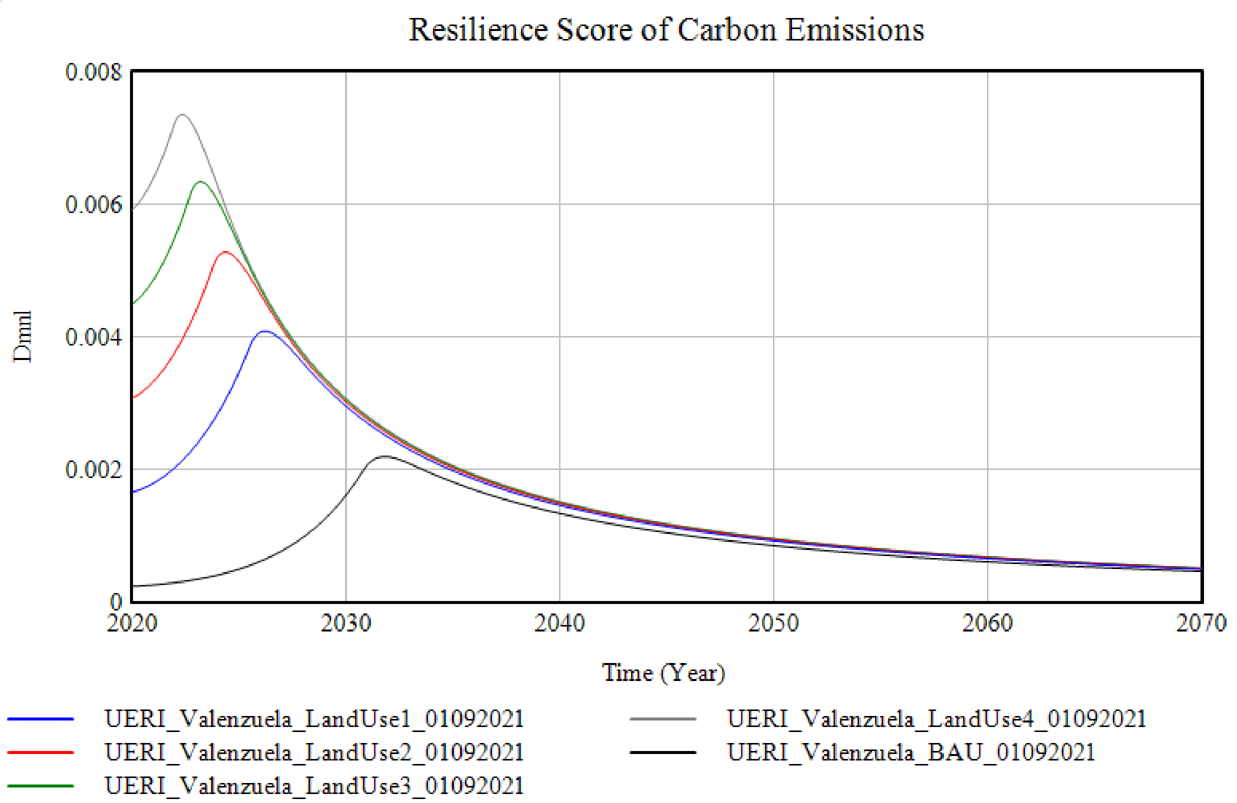


Figure 90. Graph of Resilience Score for Carbon Emissions Under Business-As-Usual and Land Use Scenario for Valenzuela City

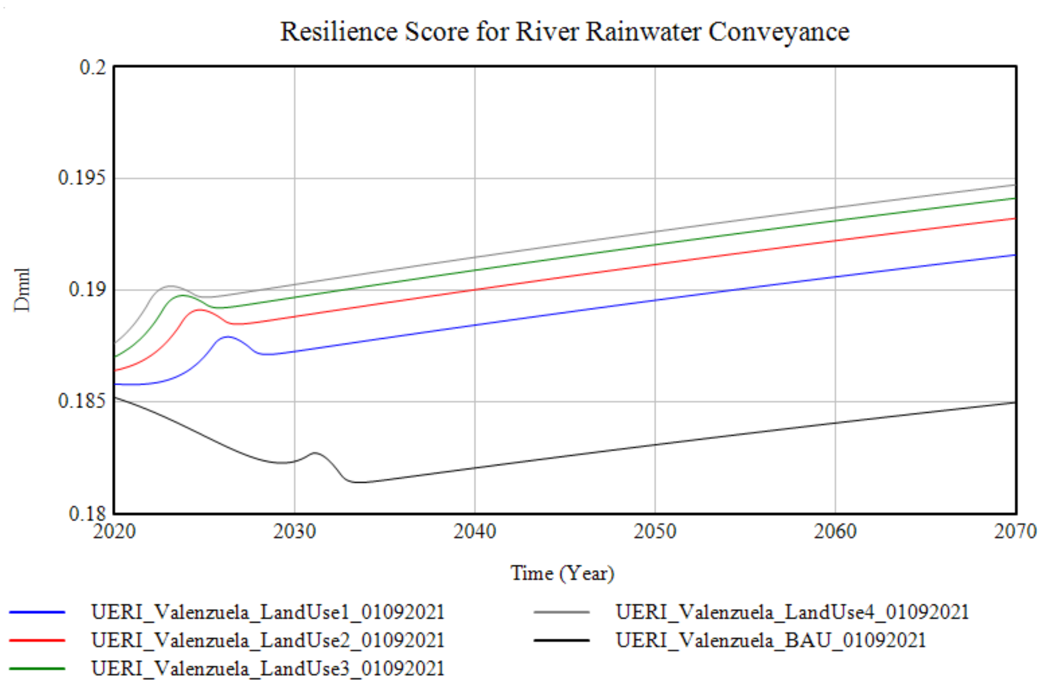


Figure 91. Graph of Resilience Score for River Rainwater Conveyance Under Business-As-Usual and Land Use Scenario for Valenzuela City

4.1.3.3 Supporting Services Under the Land Use Scenario (Valenzuela)

The Land Use Scenario applied to the city included converting more of the *Available Land (AL)* to *Agriculture and Greenspace Area (A&GA)*. The assumption made for this scenario was to allocate more initial land area, by adjusting the fractions of total land allocation, towards A&GA rather than AL. The model assumed that conversion rates remained the same as the ones used for the Business-as-Usual scenario. An implication of this scenario was that there would be less available land that could be converted to other land use types. With that, the scores of the services that depended on other land use types would decrease.

The scenario was done to determine whether there were significant changes among different Land Use Scenarios for certain services. The changes in A&GA are seen in Figure 92.

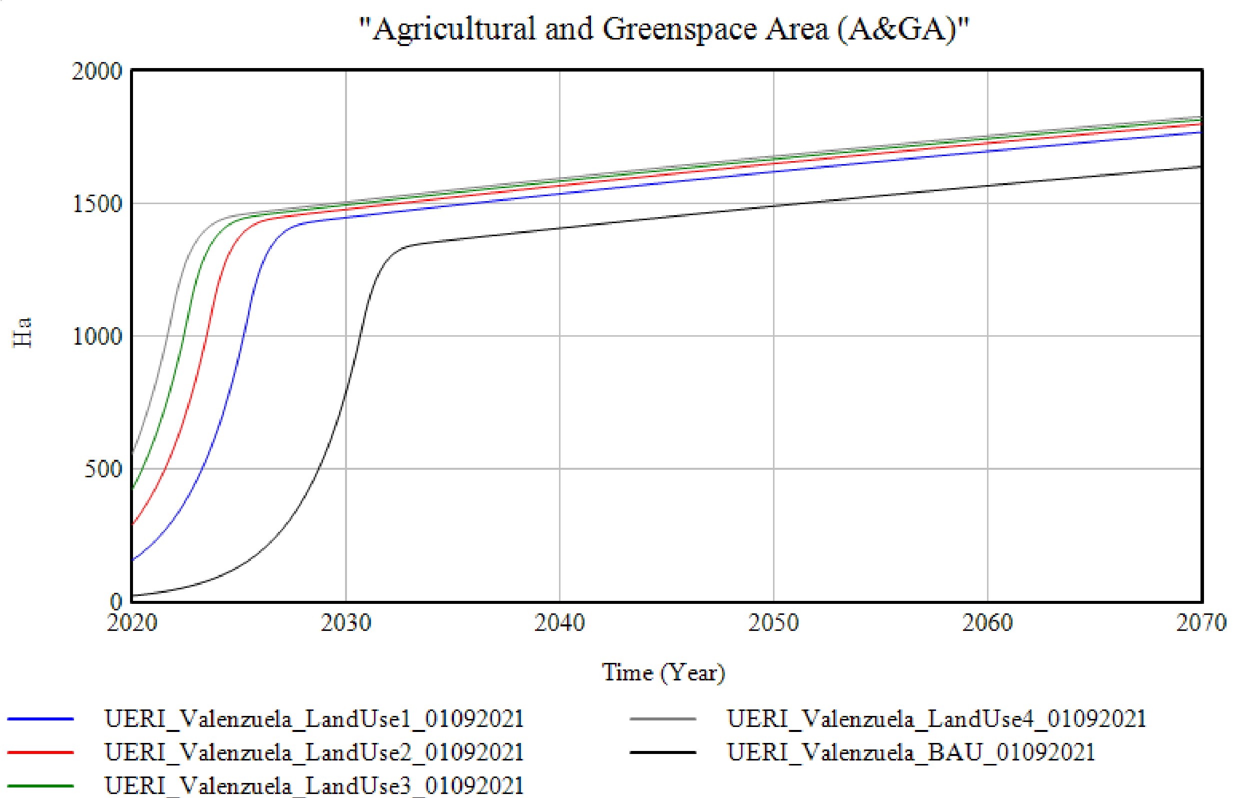


Figure 92. Graph of A&GA Under Business-As-Usual and Land Use Scenario

4.1.3.4 Cultural Services under the Land Use Scenario (Valenzuela)

The *Resilience Score for Recommended Greenspace* was the only resilience score positively affected by the Land Use Scenario as compared to the business-a-usual as seen in Figure 93. Given the Land Use Scenario, the resilience score greatly increased given the increase in A&GA. Therefore, land use change serves as a leverage variable given that slight increase resulted in big changes in the system in terms of meeting cultural services.

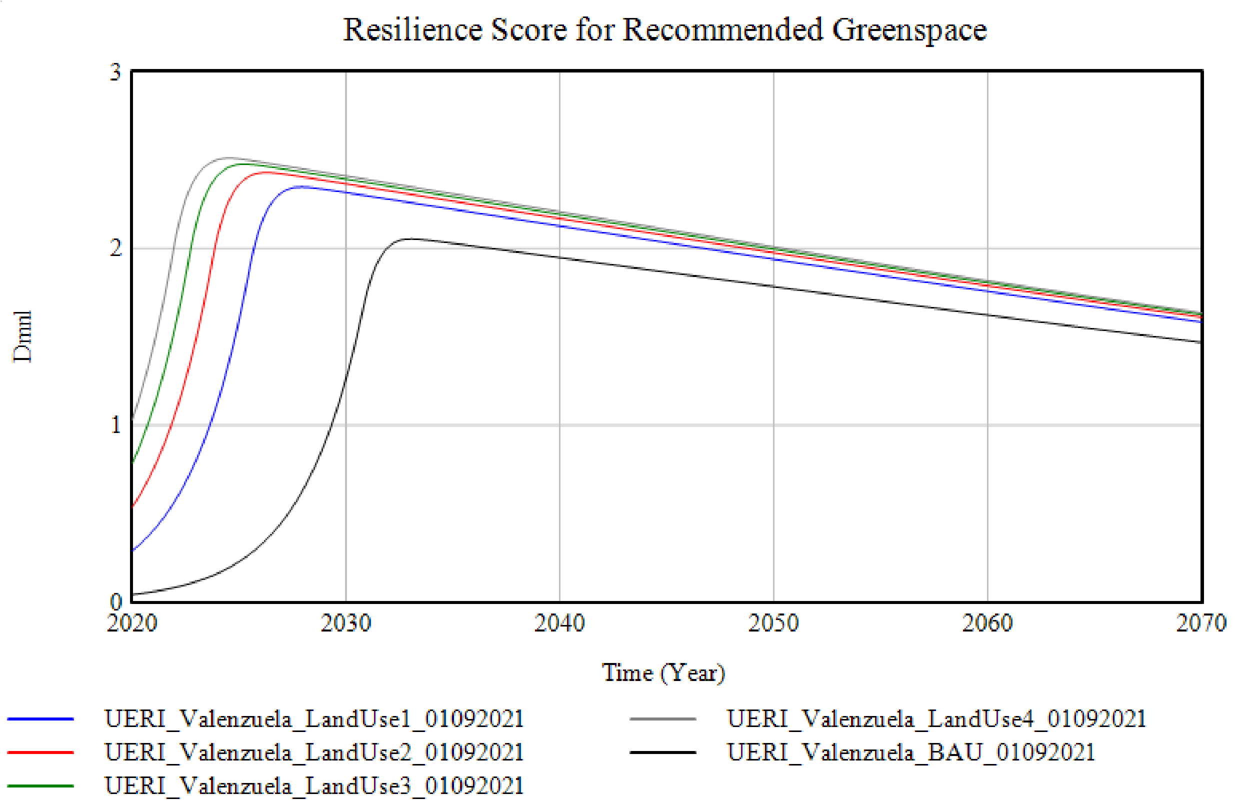


Figure 93. Graph for Resilience Score for Recommended Greenspace under Business as Usual and Land Use Scenario

There was an observed trade-off, although not represented in the model, with regards to the cultural resilience derived from P&R given that more fraction of AL was devoted to A&GA. This resulted in less services derived from P&R given less conversion.

4.1.3.5 UERI Under the Land Use Scenario (Valenzuela)

The UERI score under the Land Use Scenario was compared with the UERI score from the business-as-usual scenario as seen in Figure 96. Based on the values, the Land Use Scenario contributed to a significant increase in the UERI values. The increase in the overall UERI is from the improved score of the resilience for cultural service which benefitted the most from the scenario of increasing A&GA. Additionally, A&GA improved three services under regulating such as air, carbon and river rainwater conveyance. The effects were more felt under the cultural services given that the contribution of land use change to the regulating service were minimal when compared to the emissions generated.

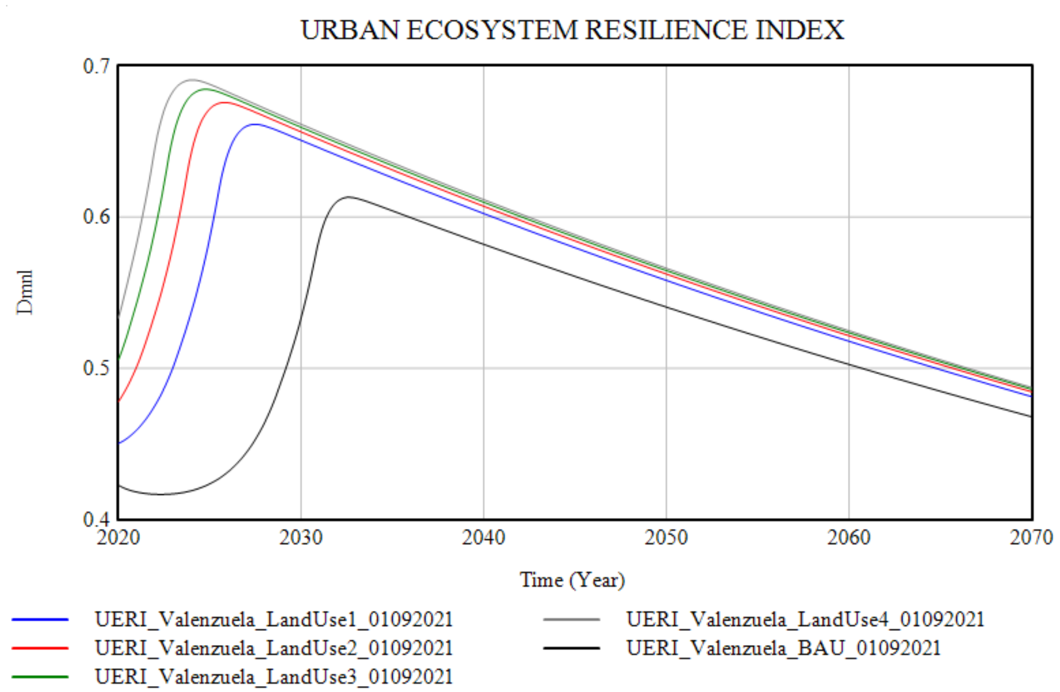


Figure 94. Graph for UERI under Land Use Scenario for Valenzuela City

4.1.4 Valenzuela City UERI under the Land Use and Siltation Scenario

Adding the two scenarios together resulted in an UERI value only slightly different from the Land Use Scenario given the added contribution of siltation as seen in Figure 95. Therefore, this is indicative changes in land use had more effect on the UERI of the city given that its influence to all four categories of urban ecosystem services.

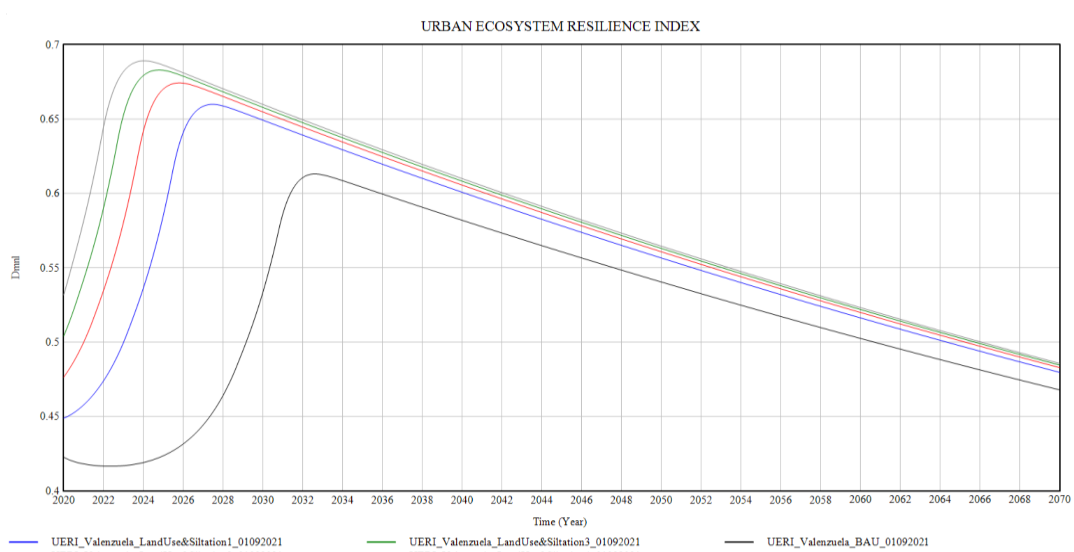


Figure 95. Graph of Land Use and Siltation Scenario on UERI for Valenzuela City

4.2 Pasig City Resilience Index

4.2.1 Business-As-Usual Scenario (Pasig City)

4.2.1.1 Provisioning Services for Pasig City

The *Provisioning Resilience Score* of Pasig City can be seen in Figure 96, while the scores of its components can be seen in Figure 97. The values obtained for the provisioning resilience score was a result of the different scores of its components mainly, *Resilience Score for Caloric Intake*, *Resilience Score for Recommended Electricity Supply*, and Resilience Score for *Recommended Water Supply*. Initially, the city was optimal in terms of ensuring the flow of provisioning services in the city as observed till the year 2070. The decreasing trend observed from the graph was indicative that the growing consumption could no longer be sustained by the city, as reflected in the suboptimal values in the latter part of the projections. This implied while the current capacity of the city is more than capable of accommodating for provisioning needs, over time there should be corresponding changes made to match growing consumption demands.

The units for the y-axis of the Resilience Score graphs were named Dmnl, short for dimensionless, given that these served as indicator variables in the model which was framed as the ratio between stocks, flows, or auxiliary variables. The x-axis referred to the time set in years.

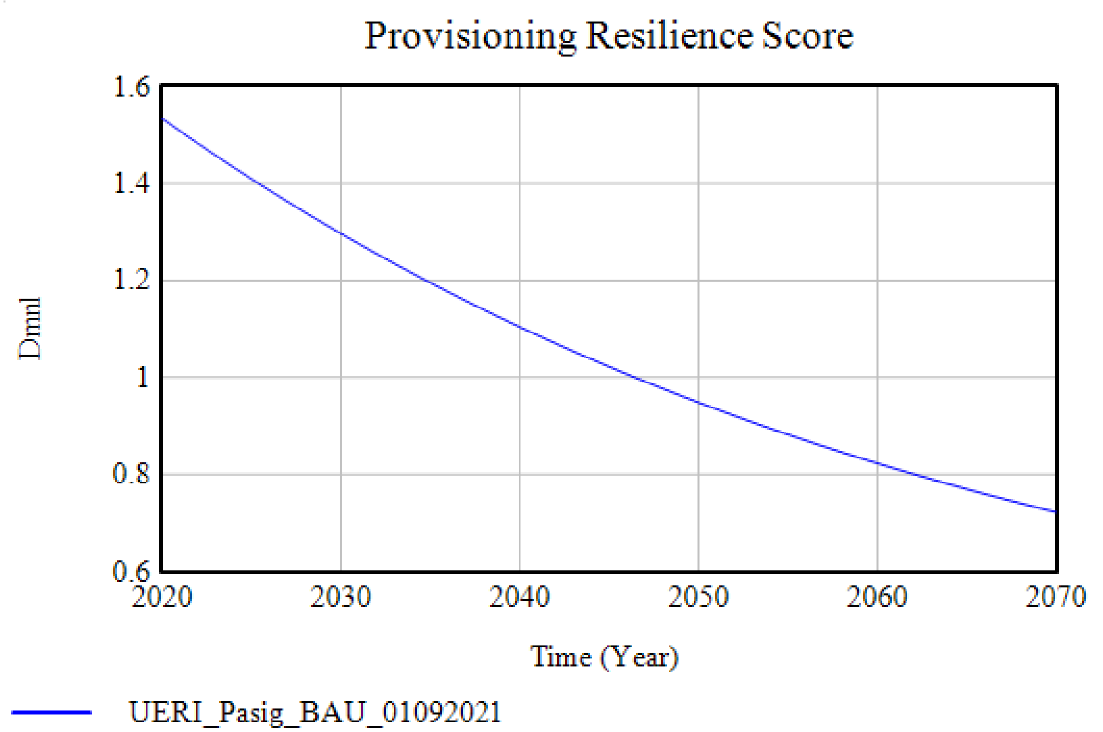


Figure 96. Provisioning Resilience Score for Pasig City

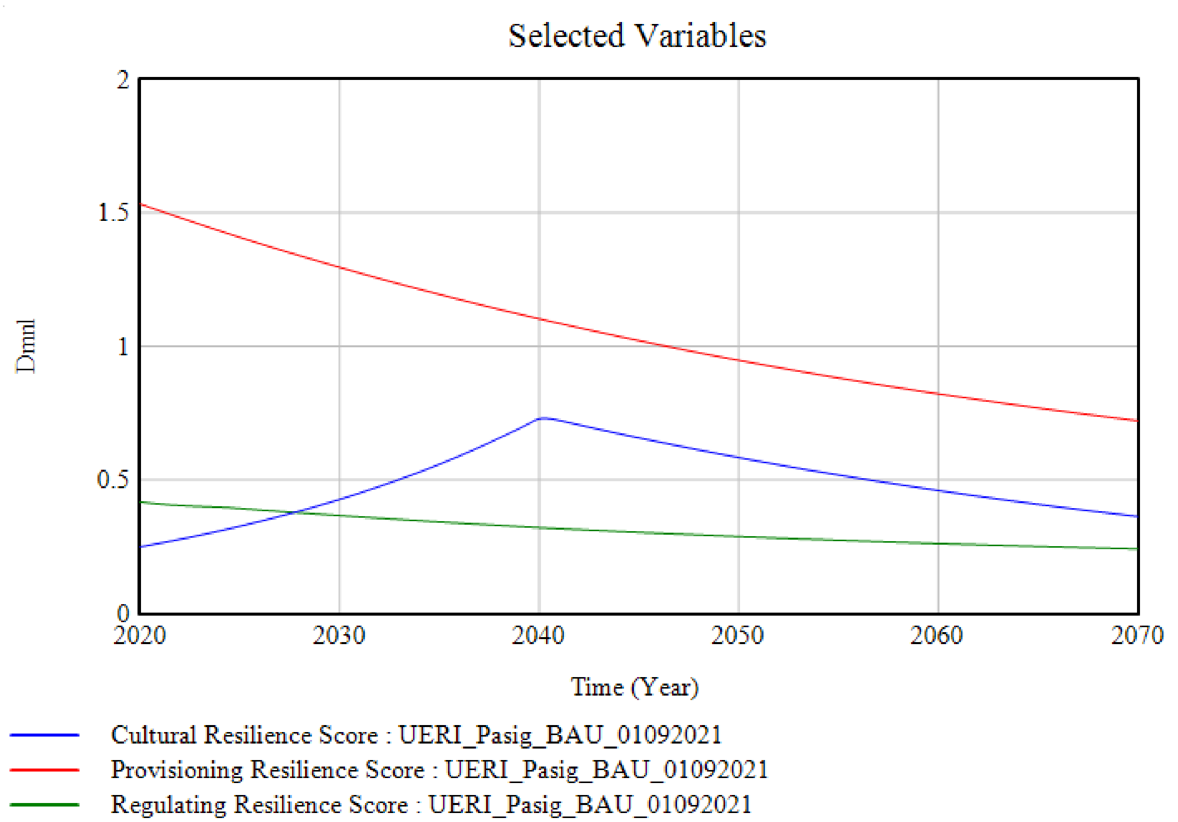


Figure 97. Components for Provisioning Resilience Score for Pasig City

4.2.1.1.1 Water Provisioning Service

The value of the Resilience Score for Recommended Water Supply was seen to decrease over time as seen in the decreasing trend of the graph in

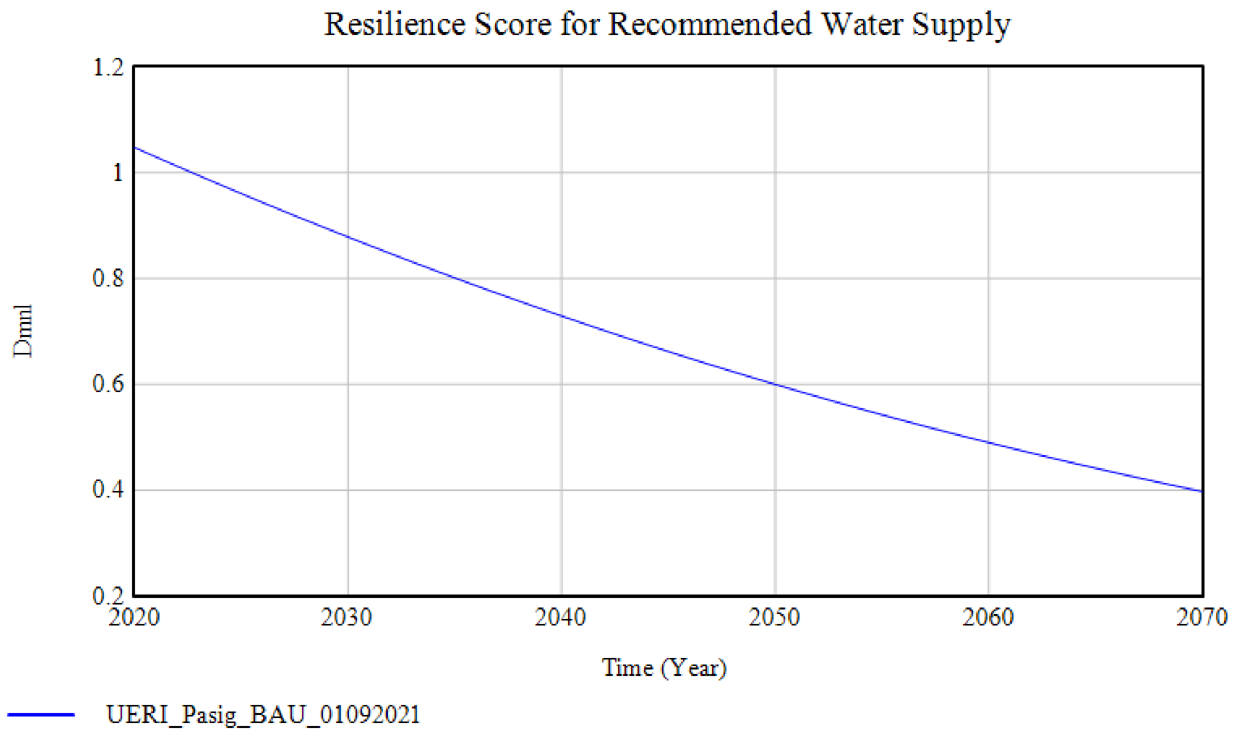


Figure 98. This implies that over time, the supply capacity for water in the city would no longer be optimal in terms of being able to accommodate the consumption of the population. This was derived from the behavior of its components *Total Recommended Supply for Water* and *Current Maximum Water Supply*.

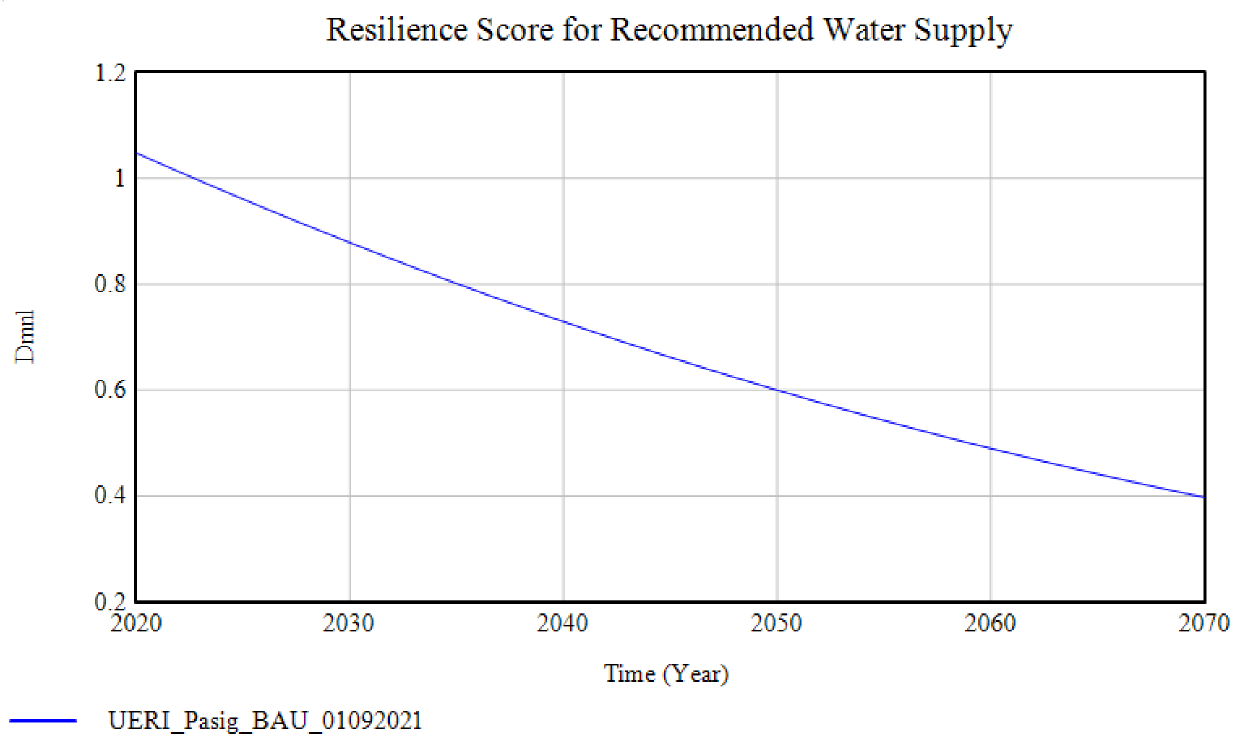


Figure 98. Graph of the Resilience Score for Recommended Water Supply for Pasig City

The resilience score was derived from the gap between total recommended water supply and the current maximum supply of the city as obtained from Manila Water (2020). Given the graph of these components, as seen in Figure 99, the value of *Total Recommended Supply for Water* was observed be increasing over time in contrast to the *Current Maximum Water Supply* which remained constant over time. Similar to Valenzuela city, there were not enough data sets to determine existing trends for the industrial and commercial consumption which resulted in constant values for their graphs. This implies that should the current maximum supply, also referred to as the capacity of the city to supply water, remain constant then the resilience score would continue to go down given that it was not able to cater to the growing consumption. Population growth is the driver of growing consumption of water in the city.

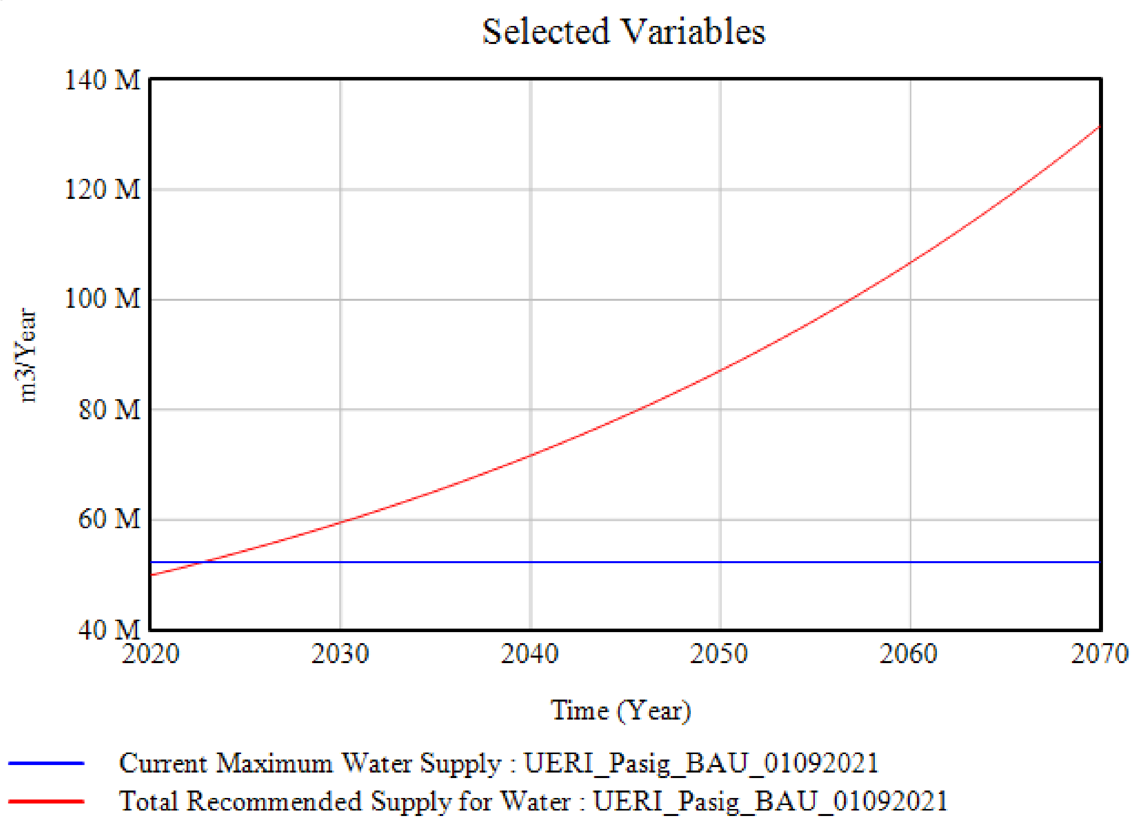


Figure 99. Graph of Components for Resilience Score for Recommended Water Supply in Pasig City

Putting the graphs together resulted into a resilience score that decreases over time. Based on the *Resilience Score for Recommended Water Supply*, the city was optimal up until the year 2023.The decreasing resilience score is indicative of the need to increase the current maximum supply to ensure continues delivery of water service in the city.

4.2.1.1.2 Electricity Provisioning Service

The graph for *Resilience Score for Recommended Electricity Supply*, found in Figure 100Figure 101, displayed a decreasing trend when projected over the years. As such, the value of the resilience score was seen to decrease over time. The computation resulted in high values for the resilience score for recommended electricity supply. This implies that the city is optimal for most of the years in the projection up until the year 2070. This is also indicative that the supply for electricity is mostly optimal in terms of accommodating for the growing demand over the years. The value for resilience was obtained by putting together the scores of its components mainly, *Current Maximum Electricity Supply* and *Total Recommended Supply for Electricity* whose graphs can be seen in Figure 101.

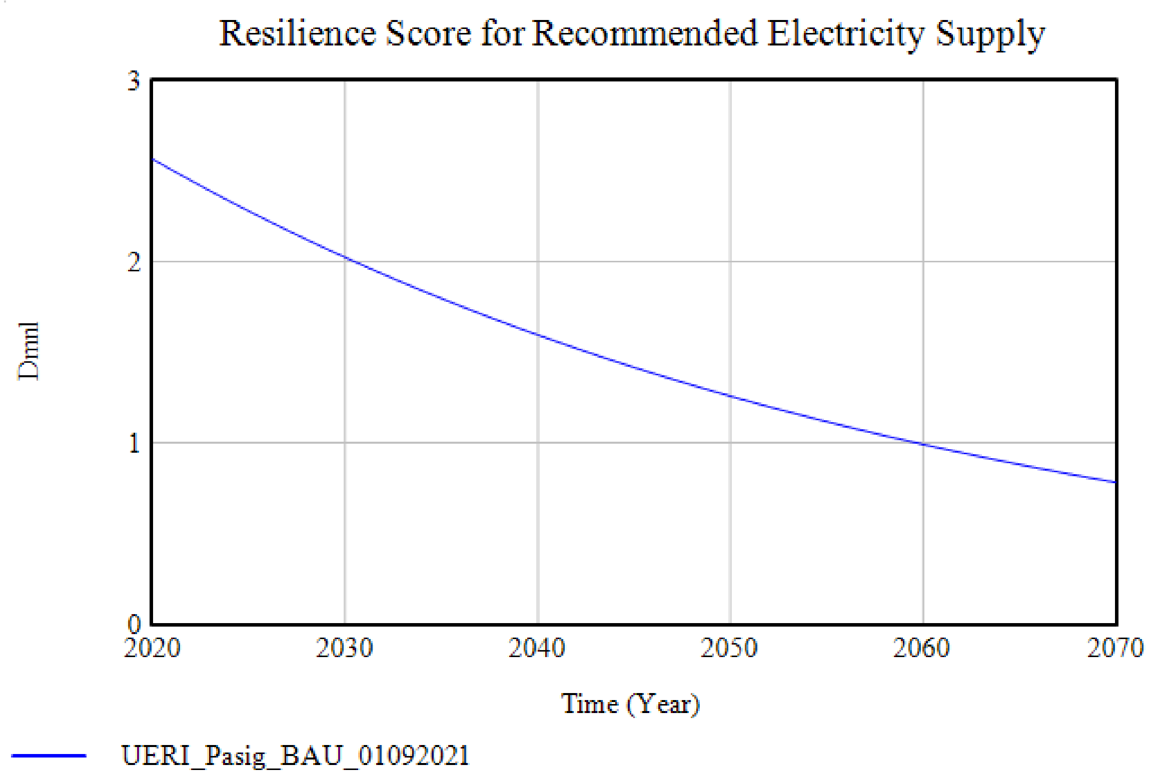


Figure 100. Graph of the Resilience Score for Recommended Electricity Supply in Pasig City

In terms of the behavior exhibited by the components, *Total Recommended Supply for Electricity* was observed to increase, compared to *Current Maximum Electricity Supply* which remained constant over time. The increasing trend from total recommended supply was a result of population growth given that more as population grows, so does consumption in the city. As such, this was measured and compared to the current maximum supply of the city to determine whether the city would be able to accommodate for the increase. The constant trend of the *Current Electricity Supply* was a result of the lack of available data to determine trends that could be used in the model. Assumption could not be made for existing trends observed in the system. The value of the resilience score exhibited a downward trend given that *Current Maximum Electricity Supply* remained constant as total recommended supply grew. Despite this, the resilience score had high values indicating that the city can sustain their delivery of electricity service given its high capacity for supply. Improvements can still be made to account for the suboptimal score observed in the latter part of the projections.

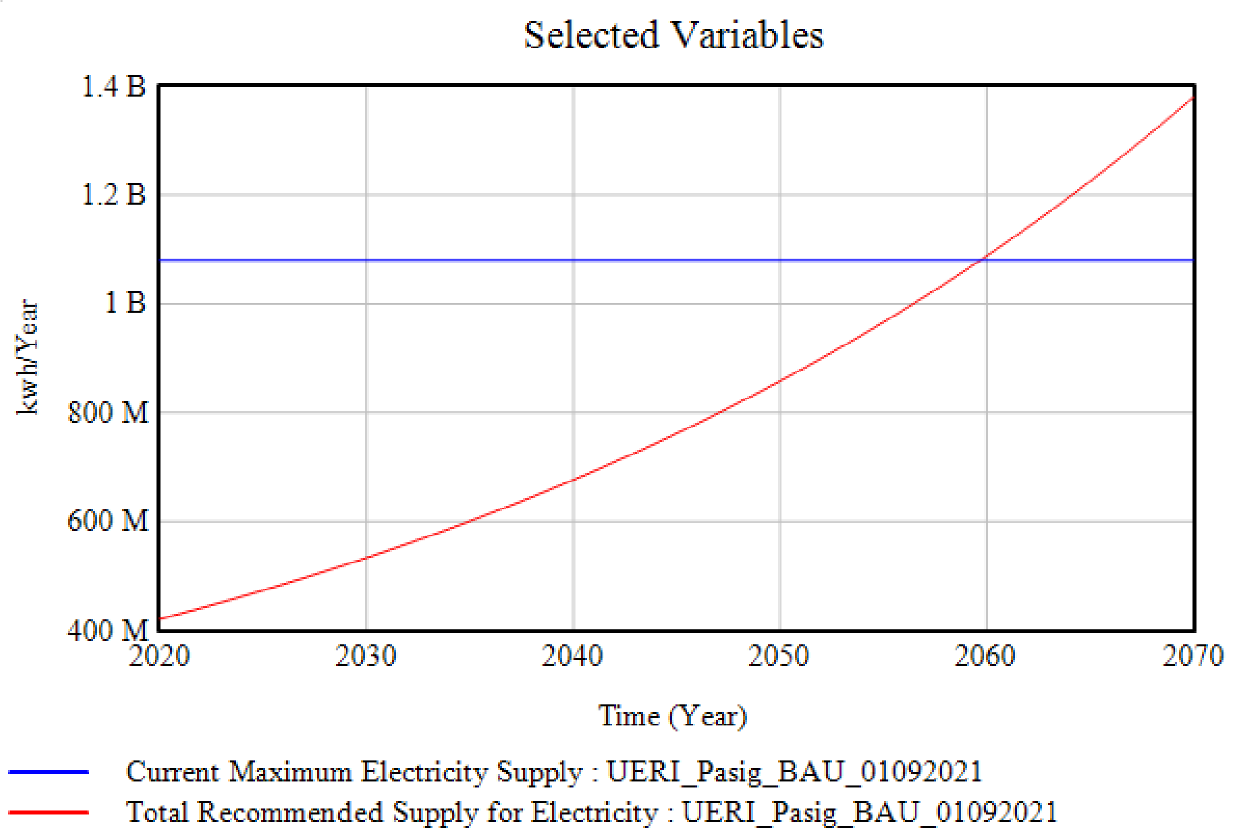


Figure 101. Graph of Components of the Resilience Score for Total Recommended Electricity Supply for Pasig City

4.2.1.1.3 Food Provisioning Service

The value of the *Resilience Score for Caloric Intake* seen in Figure 102 fluctuated over time with minimal incremental change.

The data provided were only enough to show the average people categorized as UW and SUW per year as reflected in the variable *Population Categorized as UW and SUW*. As such, the percentage remained the same for the following years. This was compared with the rest of the population which were assumed to be normal in respect to their food consumption which met the standards set by the City Health office, represented by the variable *Population*. There were no records of any intervention to reduce the number of UW and SUW. Given this, the resilience score remained the same all throughout the year as seen in Figure 103. *Population Categorized as UW and SUW* appears almost negligible even as cases increase per year.

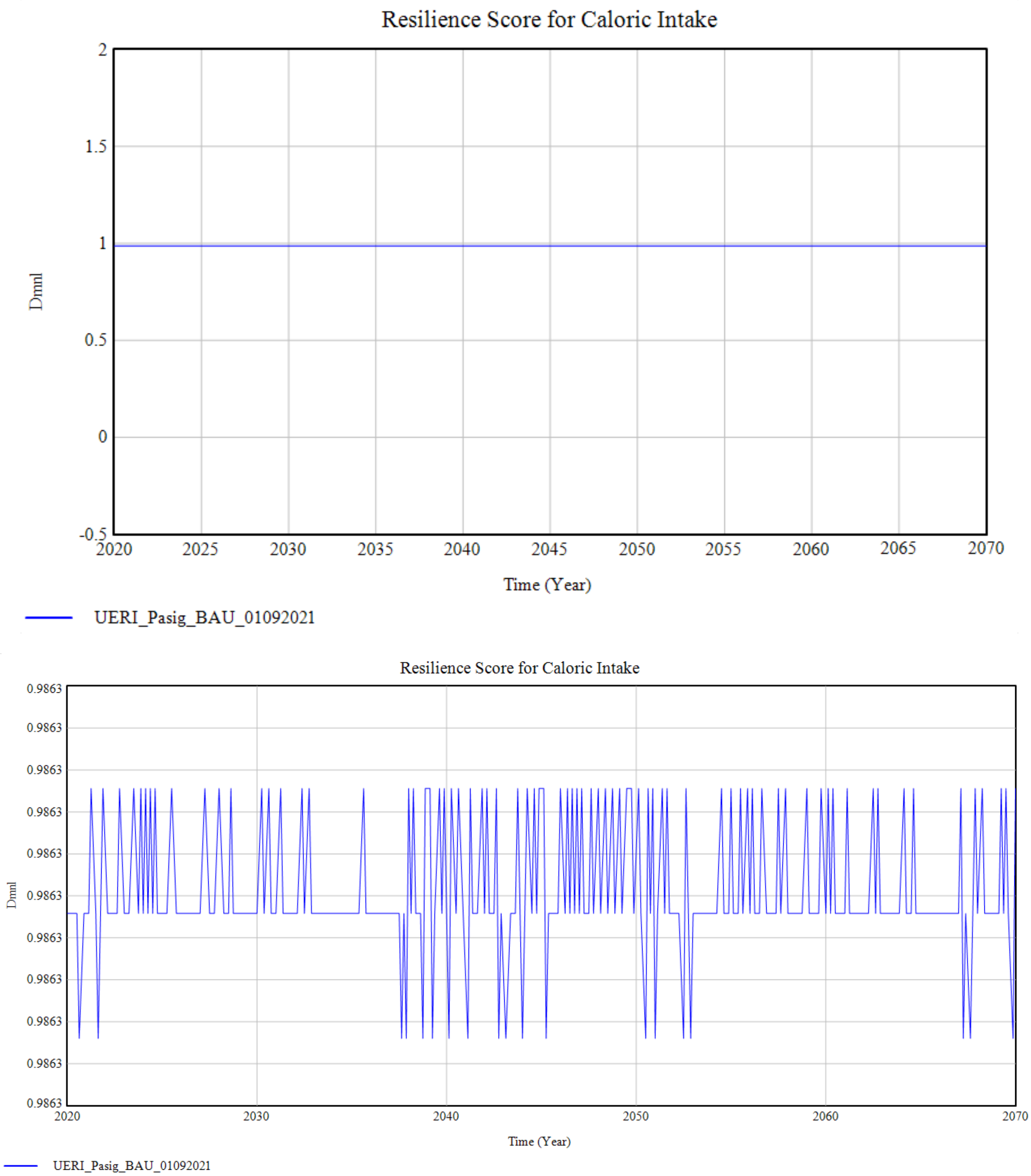


Figure 102. Graph of the Resilience Score for Caloric Intake for Pasig City (Top) with Adjusted y-axis (Bottom)

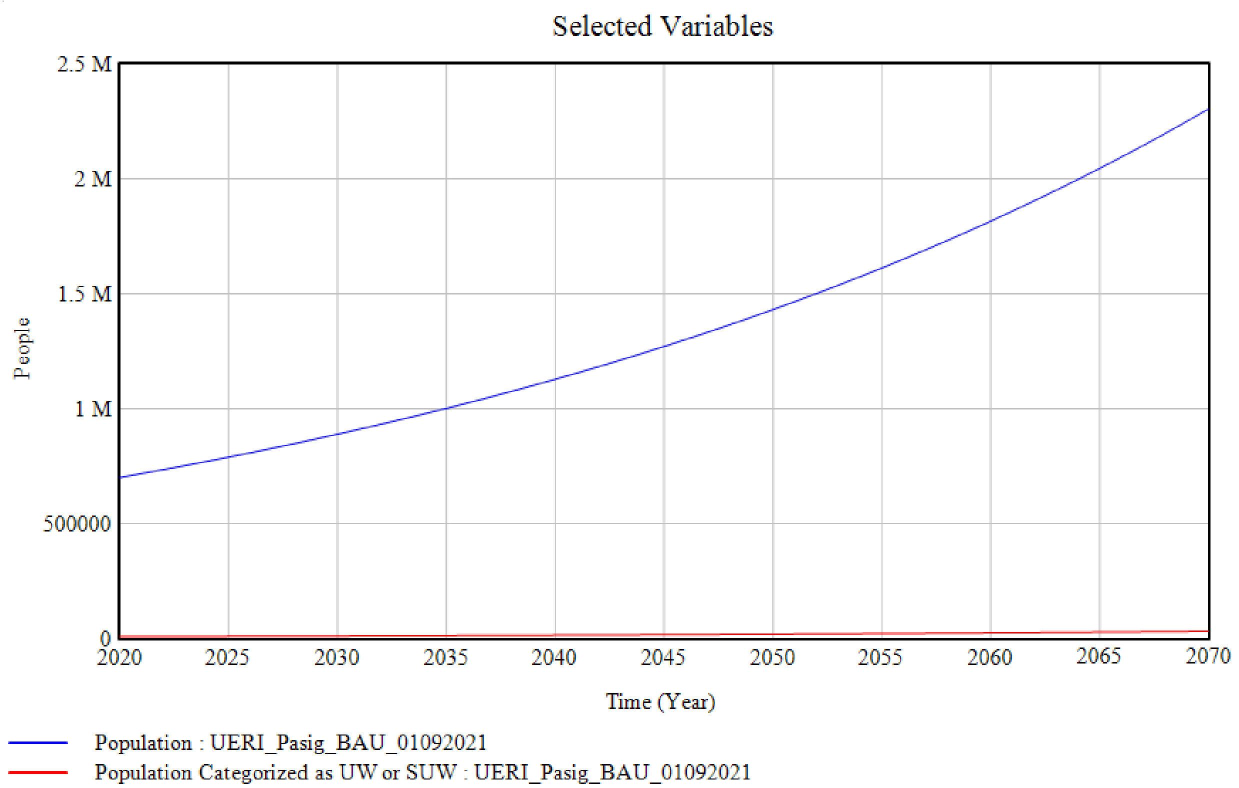


Figure 103. Components of Resilience Score for Caloric Intake Graph for Pasig City

4.2.1.2 Regulating Services for Pasig City

The *Regulating Resilience Score* graph of the city, seen in Figure 104, displayed a decreasing trend when projected over the years. The value for regulating resilience score was observed to be below one implying that the city is suboptimal in terms of its ability in regulating conditions to become natural or within standards set to ensure it is not detrimental to human conditions. The decrease in resilience score over time is also indicative of growing gap between the natural observed conditions in the system versus the performance in regulating the conditions. The score was made up of five components possessing their own distinct graphs seen in Figure 104. This was composed of *Resilience Score for Solid Waste Management*, *Rainwater Conveyance Resilience*, *Resilience Score for Carbon, Resilience Score for Wastewater*, and *Resilience Score for Air Quality*. The behavior of these graphs and their contribution to the *Regulating Resilience Score* were explained in their respective sections. What brought the value of the regulating resilience score lower were carbon, air, and wastewater regulation. While the services that brought the score higher were solid waste management and rainwater conveyance.

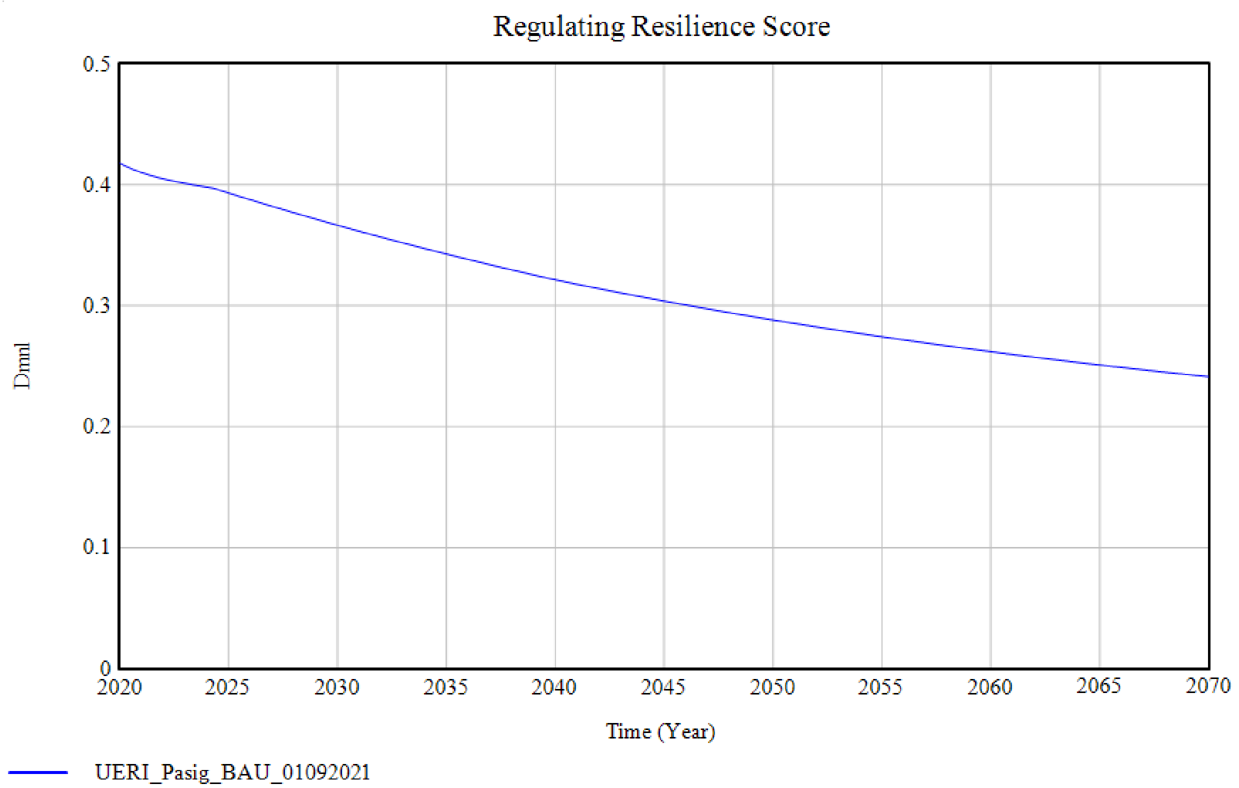


Figure 104. Regulating Resilience Score Graph for Pasig City

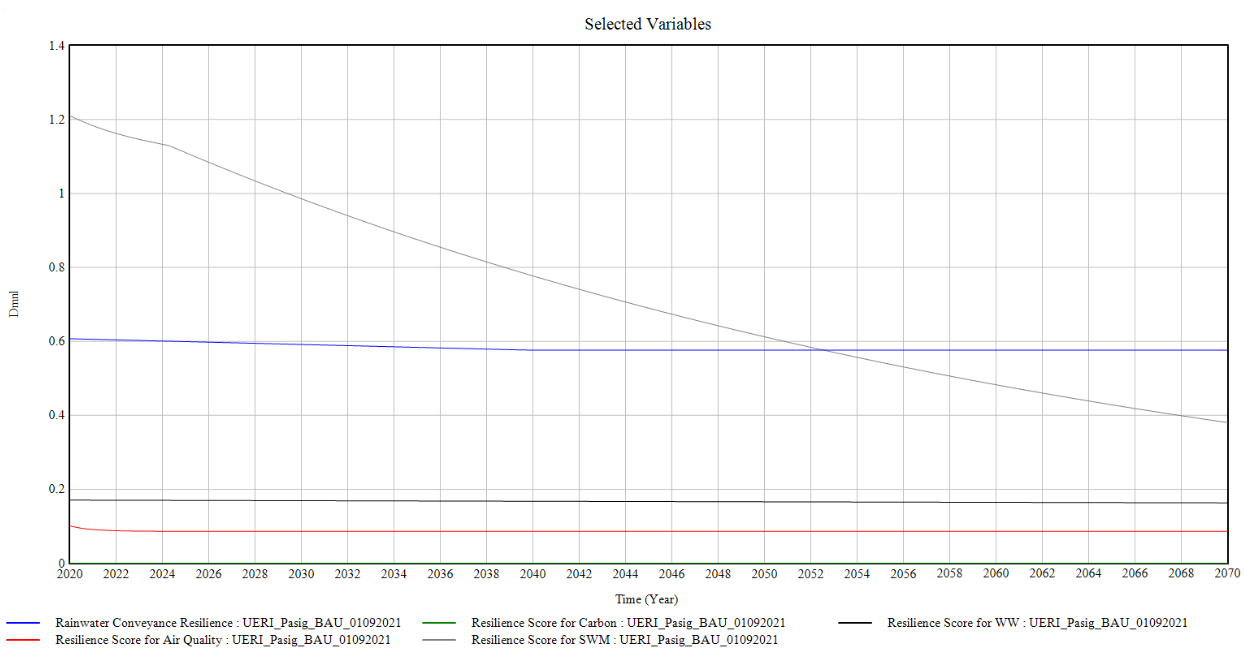


Figure 105. Components of Regulating Resilience Score Graph for Pasig City

4.2.1.2.1 Solid Waste Management

The *Resilience Score for Solid Waste Management,* as seen Figure 106, exhibited a decreasing trend implying that resilience decreases over time. The graph was a result of comparing two components mainly *Composting* and *Waste Recycling,* which represented the waste diverted, and the *Target Diversion* set by the city whose graphs could be seen in *Figure 107*. Based on the overall value seen in the resilience score in the earlier years, it can be said that the city had an optimal score up until the year 2021. After a certain time following the year 2021, the amount of recycled and composted waste was now observed to be much lower than the target diversion which was exhibiting an exponential growth given that it derived the behavior of generated waste. This resulted in the *Resilience Score for Solid Waste Management* to drop below the one value around the time wherein the total diverted waste started becoming less than what the target was for that year. This is a result of the *Generated Waste*, which was used in computing for the *Target Diversion*, having an exponential growth in its value while *Total Recyclables and Compostables* remained constant throughout the projections. *Generated Waste* was observed to have increased over time. As population grows, so do the number of wastes produced which explains the trends observed for generated waste. As for the case of *Total Recyclables and Compostables*, no trends could be derived and used for the model due to the lack of data resulting in a constant value.

In terms of diversion capacity, the current scenario for the model did not consider any increase in the capacity for treating recycled and compostable wastes. Given this, it was observed that the amount of generated waste far exceeded the capacity of the city in treating solid waste. As such, *Resilience Score for Solid Waste Management* continued to decrease over time given no interventions to change capacity. Actions to increase the resilience score would be to increase the diversion capacity of the city. Additionally, introducing policies to regulate waste generation would also improve the resilience of solid waste management.

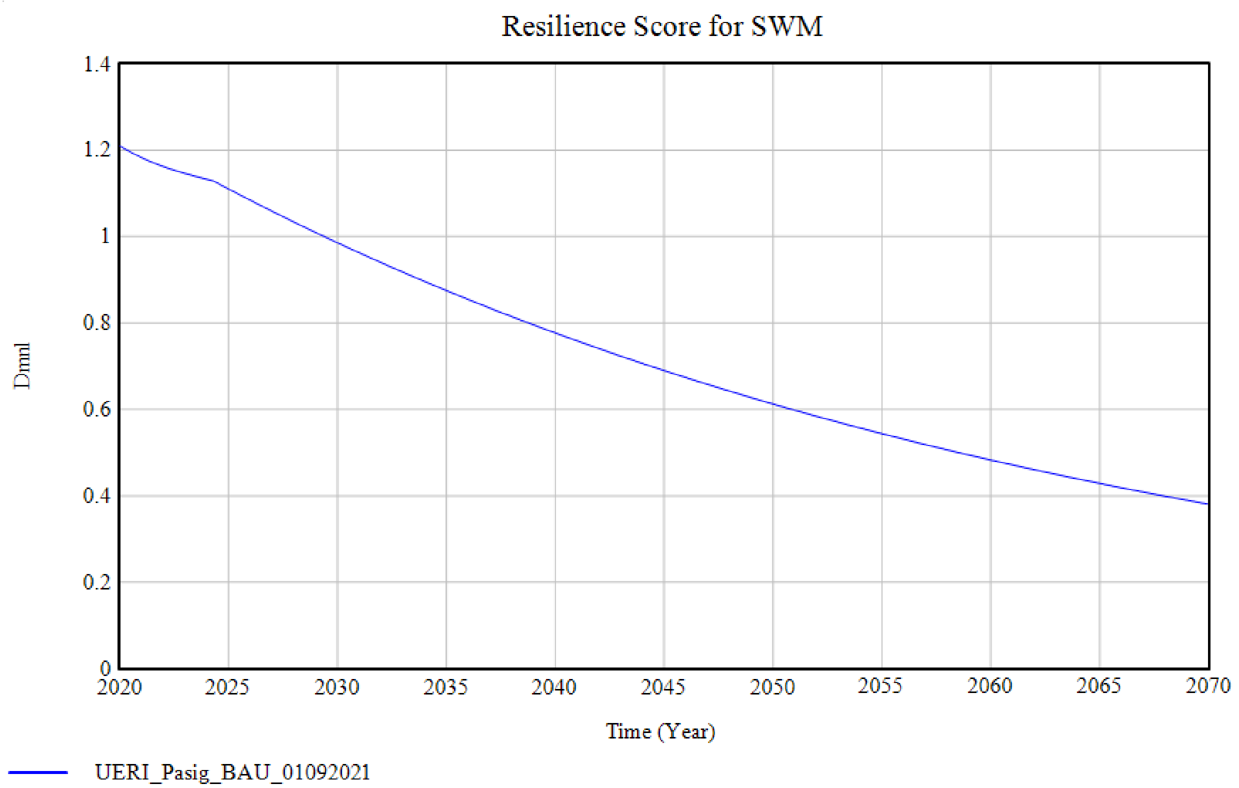


Figure 106. Resilience Score for Solid Waste Management Graph for Pasig City

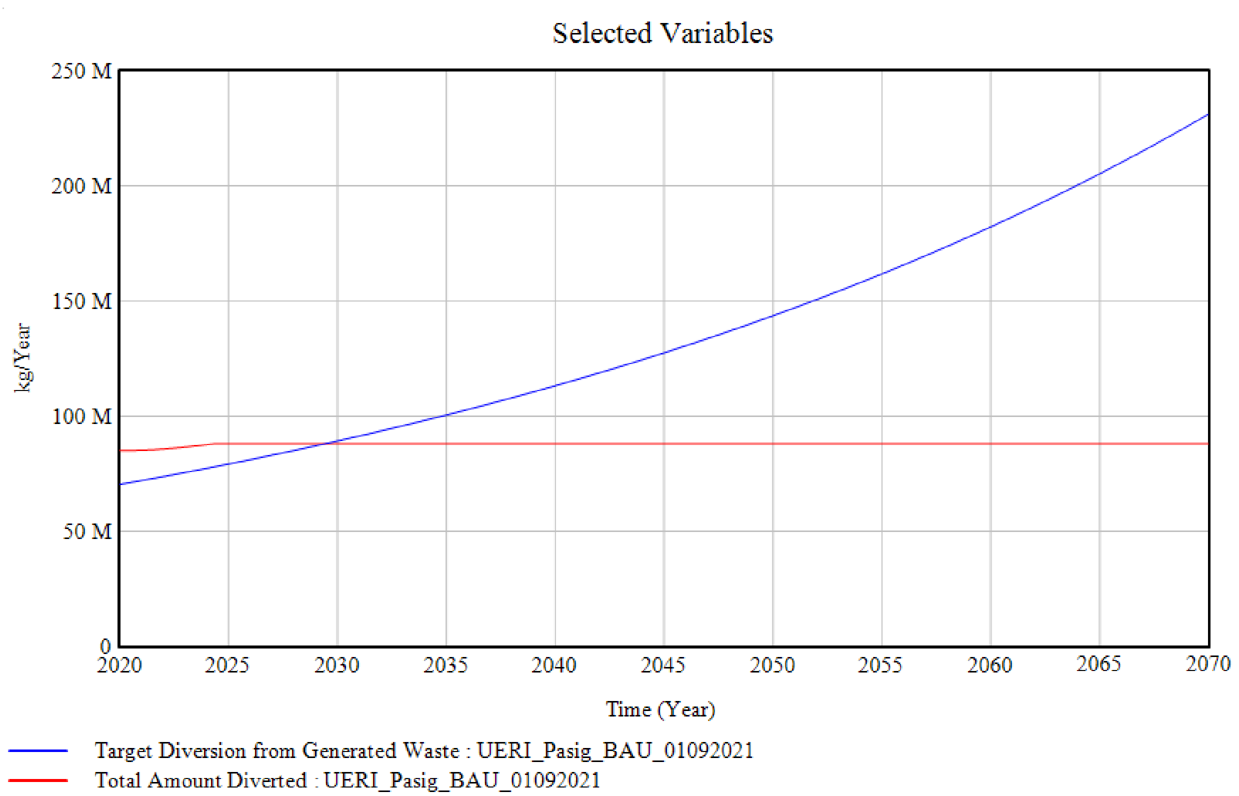


Figure 107. Components of Resilience Score for Solid Waste Management

4.2.1.2.2 Wastewater Regulation

The *Resilience Score for Wastewater* displayed a decreasing trend when projected over time as seen in *Figure 108*. The downward trend is a result of the difference in the rates in between the wastewater generated and the wastewater treated as seen Figure 109. The low *Resilience Score for Wastewater* is due to the huge gap between *Total WW Generated* and the total of the two treatment procedures from initial to end. This implies that, under the Business-As-Usual scenario, *Resilience Score for Wastewater* will continue to decrease given that there are no interventions added in the model to treat more of the *Total Generated Waste*. Additionally, the low value is indicative of the that the performance of the city is suboptimal in terms of being able to treat wastewater produced by the city.

In terms of the behavior of the components used for the computation, the increasing value of total WW generated was derived from the water provisioning service model. As population grows, so do the consumption of water resulting in more wastewater produced. This implies a sort of trade-off, although not direct in terms of the services themselves, but in their components given that improvements made to increase supply and consumption will result to more effluents given no interventions are made. It was assumed in the model that anything not handled by desludging or sewage treatment would be considered untreated wastewater and would end up as wastewater discharged to the river.

Actions to increase resilience score would involve either decreasing wastewater generated through control policies for water consumption or increasing the capacity of treatment facilities. Adding more connections to the sewer lines would increase amount of wastewater treated.

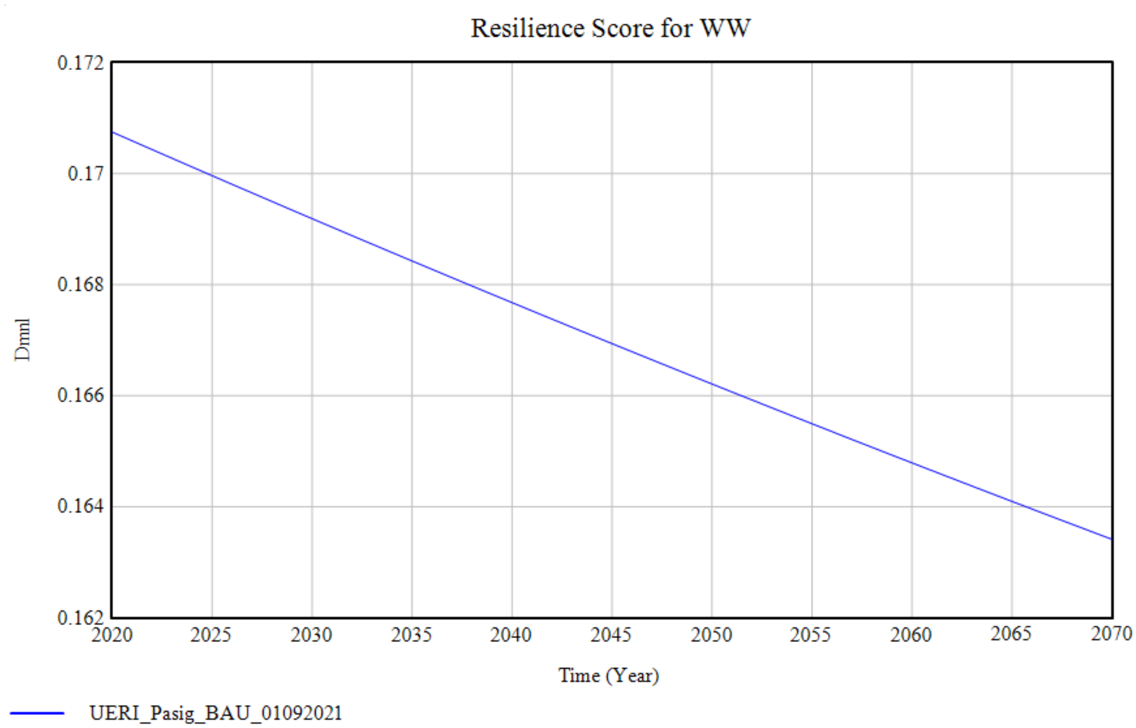


Figure 108. Graph of the Resilience Score for Wastewater in Pasig City

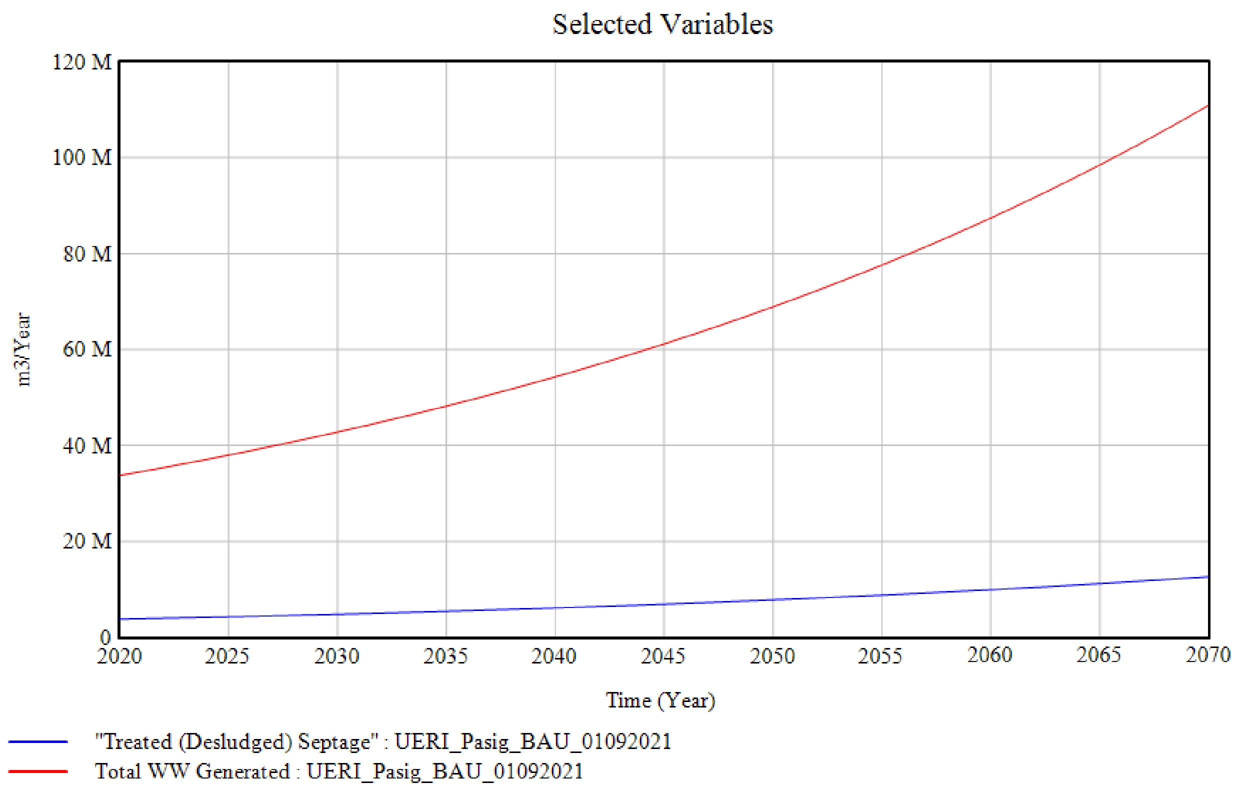


Figure 109. Graph of Components of the Resilience Score for Wastewater in Pasig City

4.2.1.2.3 Air Quality Regulation

The value of the *Resilience Score for Air Quality* was seen to decrease for a short time up until the year 2023 before becoming constant in terms of its value of 0.863 as seen in Figure 110. The value itself for emissions obtained in the model were much higher than recorded standards. This could imply some errors inherent in the empirical formula used. Other reasons could be due to the unaccounted natural outflows given difficulty in measuring them. Given this, the values obtained from the model were assumed to be rough estimates as it only used available data from vehicular activity for the major roads. This also reveals the limits of using a system dynamics approach to project air emissions wherein it is able to diagnose trends in time, but not in space which is needed for modelling air quality given atmospheric transport and mixing.

The resilience score implied that the computed air concentrations were much higher than the standard imposed by the DENR. This means that the city in terms of its performance in regulating air quality, is suboptimal. The trend of the graph of the resilience score becoming linear from the year 2023 onwards is due to the contribution of the regulation services of the city to keep air concentrations lower and constant. Given that there were no recorded greenspace values in the city, the only outflow that contained value was that of the natural outflow rate. But this was not enough to put the emissions within the standard set by DENR. Based on the model, changes made in the land use development of the city would have corresponding implications to the *Resilience Score for Air Quality*.

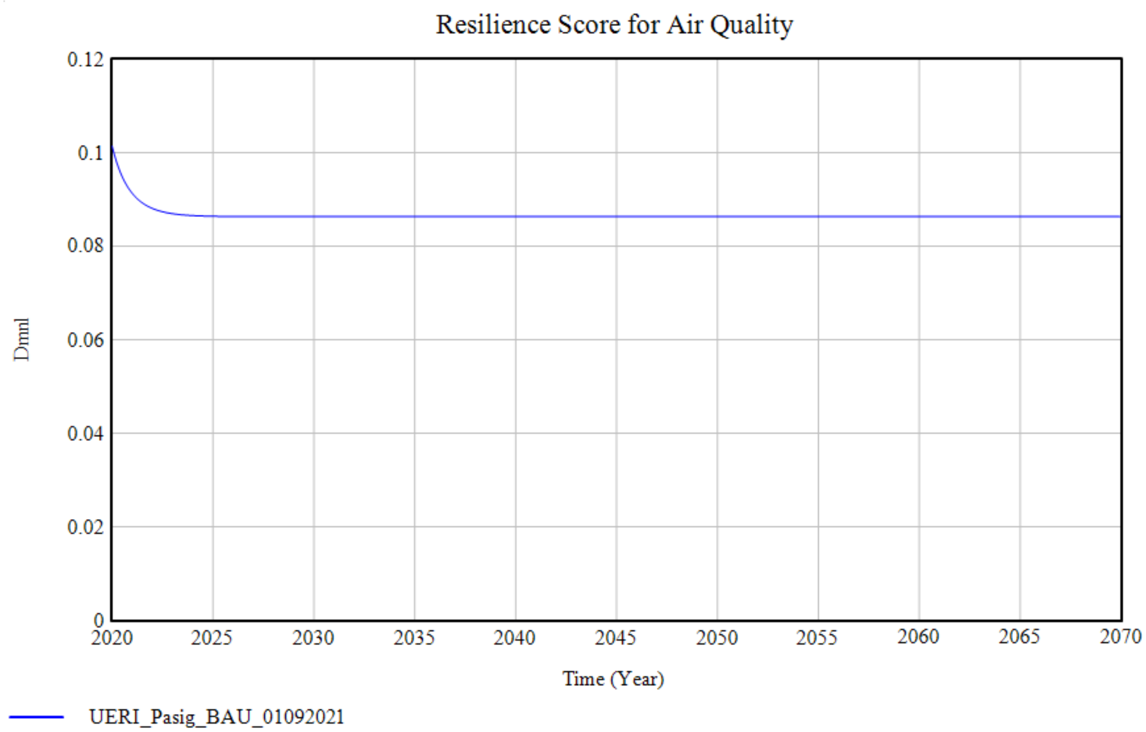


Figure 110. Resilience Score for Air Quality Graph for Pasig City

4.2.1.2.4 Carbon Emissions Regulation

The *Resilience Score for Carbon* had a value of zero all throughout because no amount of carbon was sequestered within the city. No values were set in the model to compute for sequestration given no recorded amount of agricultural land or formally designated greenspace in the city. Because of this, the amount of carbon in the atmosphere would exponentially increase should there be no means of any mitigation efforts implemented towards carbon emissions in the city. The model only focused on three main vehicle types. Additionally, only sectors with time series data such as mobility, solid waste, wastewater, and electricity were used in the model. Given this, the model only showed a partial assessment of carbon emissions in the city.

Further disaggregation between sectors depicted that most emissions came from the methane produced by solid waste and wastewater as seen in Figure 111. Methane has a higher global warming potential as compared to Carbon Dioxide. Vehicular emissions remained constant given that the values used were computed from an average and not based on a per capita approach as compared solid waste and wastewater. The observed trends for car growth were similar in between years with no significant changes observed. Therefore, no growth rates were inserted for the vehicles and only an average value among all years was used. This was a similar case to electricity given the value used in the model was an aggregate value applied to all the years. Based on the model, increasing the capacity of treatment for the other services would result in reduced emissions to be reflected in certain values found in the Carbon model but would not correspond to any changes in the *Resilience Score of Carbon* until the city is able to sequestrate the carbon produced. The reduced emissions will only be factored in the model when a value is placed for sequestration.

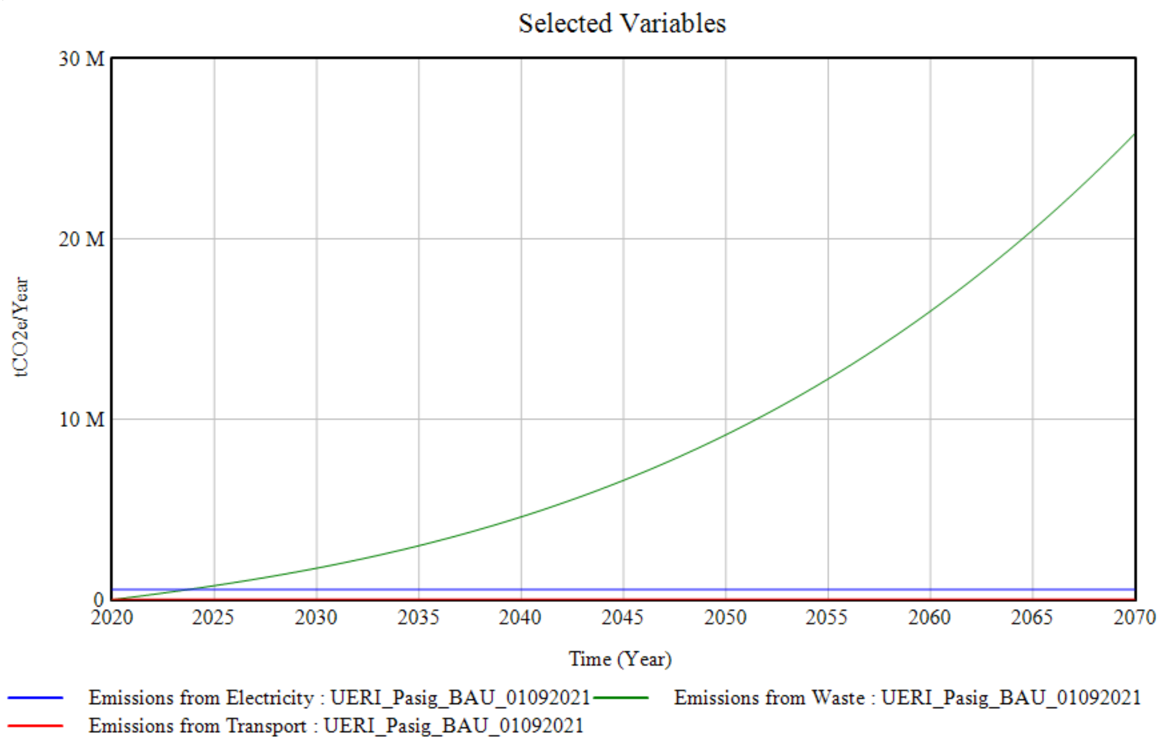


Figure 111. Sector Emissions Graph for Pasig City

4.2.1.2.5 Rainwater Conveyance Resilience

The Rainwater Conveyance Resilience graph was used to measure the capacity of the city to convey and discharge accumulated rainwater. The score was projected over time as seen in Figure 112. The score was framed as a ratio between the Surface Run-Off, measuring how much was conveyed to the river, and Rainwater Conveyance Capacity, which was the amount allotted for rainfall discharge of the river at the selected cross section as reflected in the graph as seen in Figure 113. The value displayed from the resilience graph showed that resilience went down in the initial years until reaching a certain point wherein it became constant throughout. This is a result of the land use that took place earlier in the development of the city which focused built area. Having more built area meant a higher average run-off coefficient leading to less infiltration and more run-off generated from the rainwater. This is reflected in Figure 114 showing the changing value of the run-off coefficient over time. The value stops changing in the years wherein there is no more land to convert. A higher value for run-off coefficient implies less infiltration. This is reflected in the increase of surface run-off as seen in Figure 114.

Based on the value obtained for rainwater conveyance resilience, the overall capacity of the river to convey the excess surface water discharged by the city was not enough to prevent incidences of flooding given the score was less than one. It can be said, based on the observations, that the city is not optimal in terms of being able to regulate rainwater run-off generated in the city which would result in more incidents of flooding.

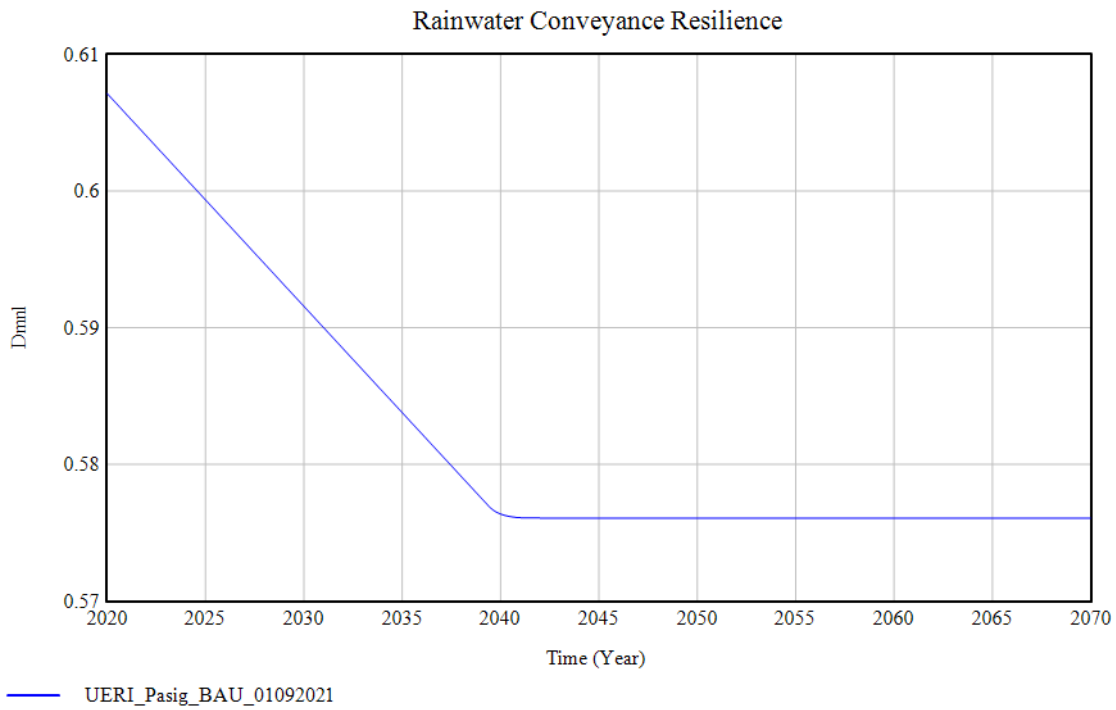


Figure 112. Rainwater Conveyance Resilience Graph for Pasig City

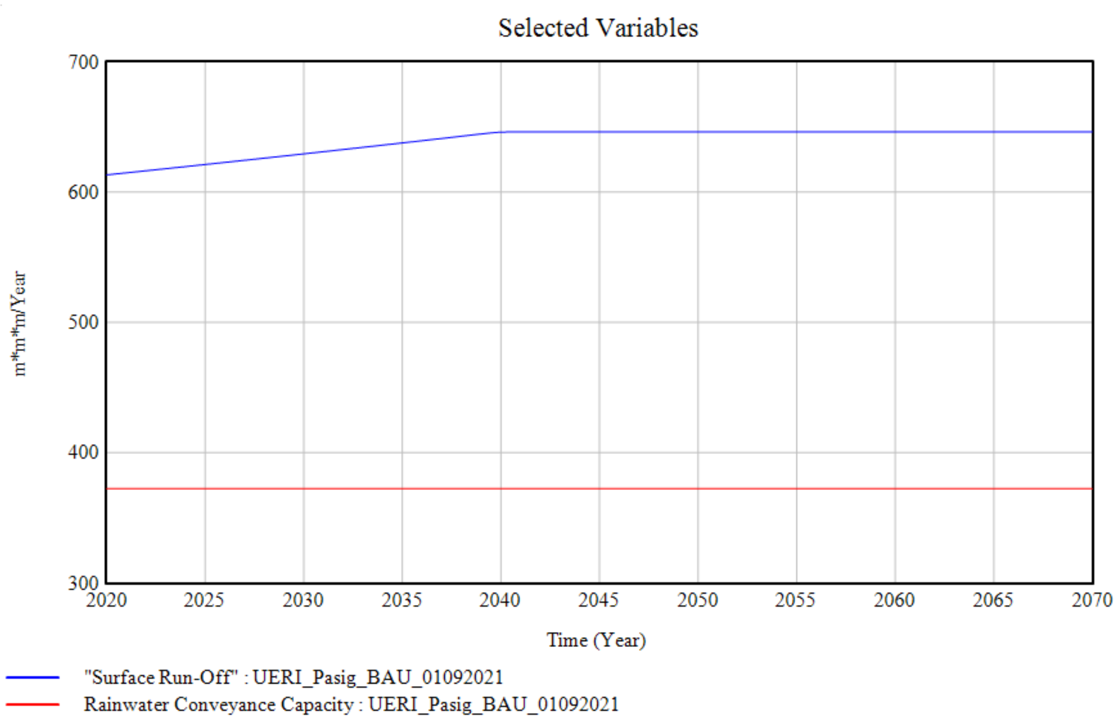


Figure 113. Components of Rainwater River Conveyance Resilience Graph for Pasig City

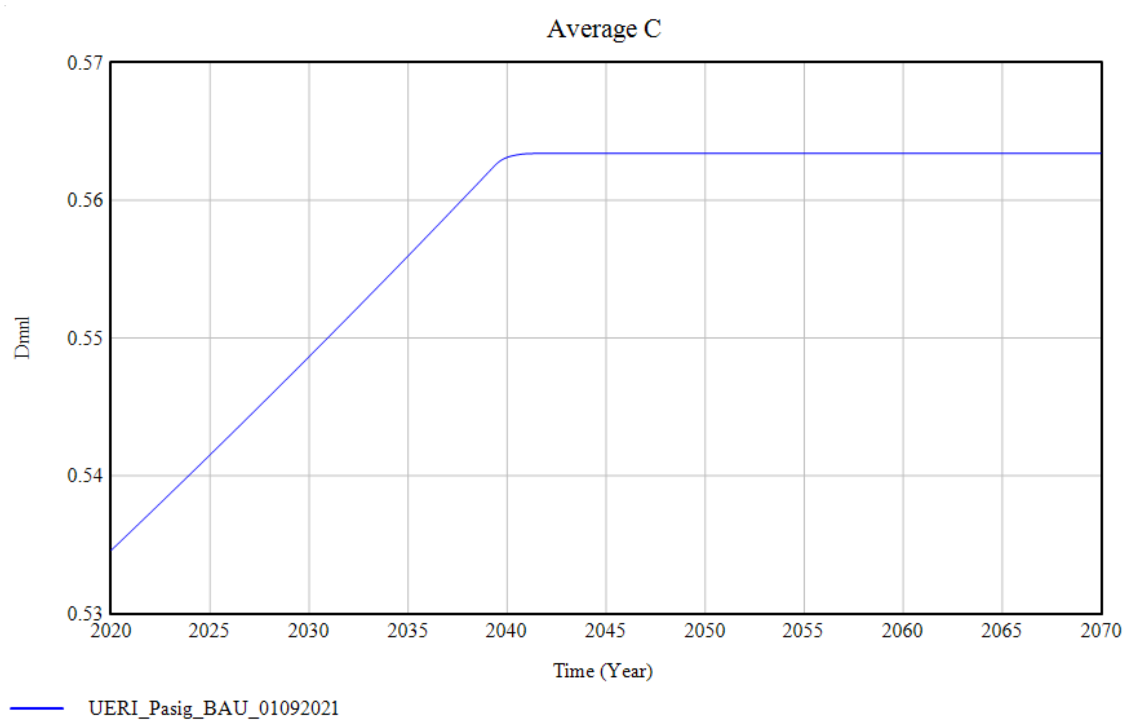


Figure 114. Run-off Coefficient Value Graph for Pasig City

The magnitude of *Surface Run-Off* is determined by both the magnitude of rainfall (value used for the RIDF) as well as the current land use configuration of the city. Both components were considered as the main determinants of how much *Surface Run-Off* would be generated during the typhoon event. In this case, improvements to resilience should involve increasing the outflow, either flood control infrastructure or dredging, or decreasing the inflow via diversion of floodwater conveyed to the river. These factors were not considered in the Business-As-Usual scenario due to a lack of data.

4.2.1.3 Supporting Services for Pasig City

The different land use types for the city as well as their respective changes over the years are seen *Figure 115*. Based on the graph, majority of the land was used for built-up area, represented by *Built-up Area (BuA)* in the graph, as compared to all other land use types. This follows the statement made by the planning office regarding city development (Palermo, 2020) wherein they wanted to prioritize development in infrastructures such as industries, housing, schools, and hospitals which all fall under the *Built-up Area (BuA)* category*.* Currently, there were no mentioned plans of major expansion for the other land use types and changes would only be minimal should there be any. The goal of the city is to be able to convert all available land to land types that will address the socio-economic issues of the city. A big percentage for the built-up area will comprise of housing given that they have no plans for outside relocation. There were also few considerations for greening projects or expansion of cultural areas as last reported.

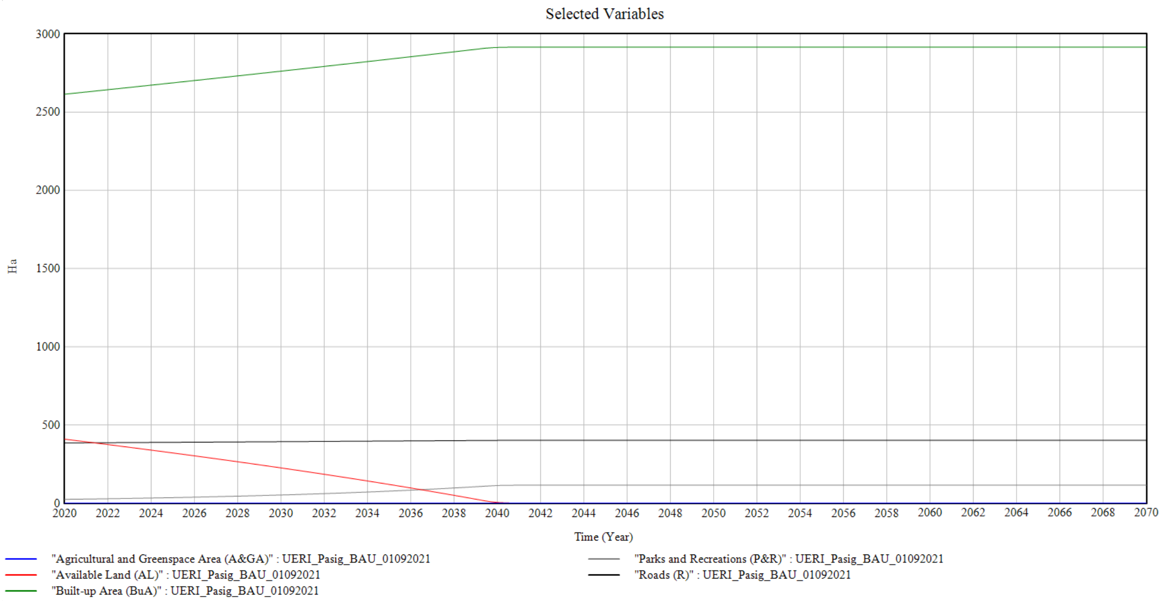


Figure 115. Land Use Types and Changes Graph for Pasig City

4.2.1.4 Cultural Services in Pasig City

The *Cultural Resilience Score* graph, seen in Figure 116, displayed an initial increase in the resilience value after which, was observed to drop starting year 2040. The overall value indicates that the city is not optimal in terms of meeting the recommended cultural service of the city. Components from which cultural services can be derived from were less in this model given the lack of contribution from greenspace. The change between the values is a result of the land use change in the city. The decreasing value observed in the latter part of the projections results from having no remaining available land left to be converted to cater to the cultural services of the city.

The *Cultural Resilience Score* was made up of three different components: *Resilience Score for Greenspace Requirements, Resilience Score for Recommend Sports and Playgrounds*, and *Resilience Score for Parks*. The resilience scores were derived from the ratio between the land type of interest for a specific type of cultural service and the recommended area for that selected land. Cultural resilience was divided between two main land use types, *Agriculture and Greenspace Area (A&GA)* and *Parks and Recreations (P&R).* The graph of these different cultural resilience scores, when projected over time, can be seen in Figure 117.

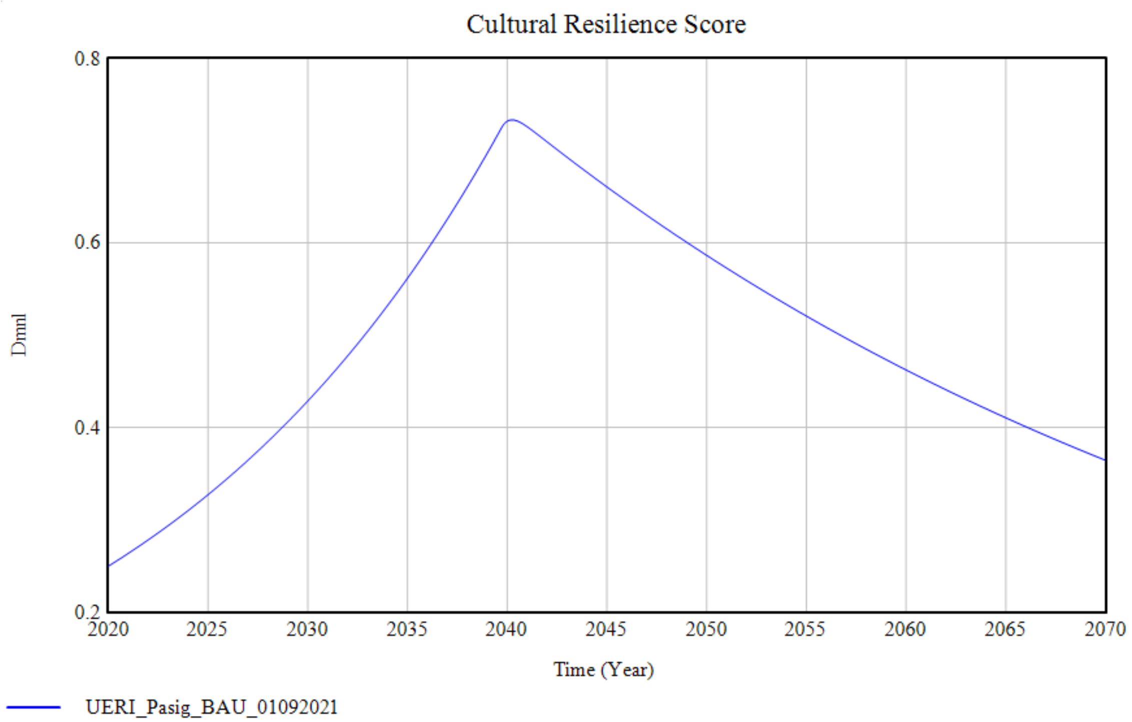


Figure 116. Graph of Cultural Resilience Score Graph for Pasig City

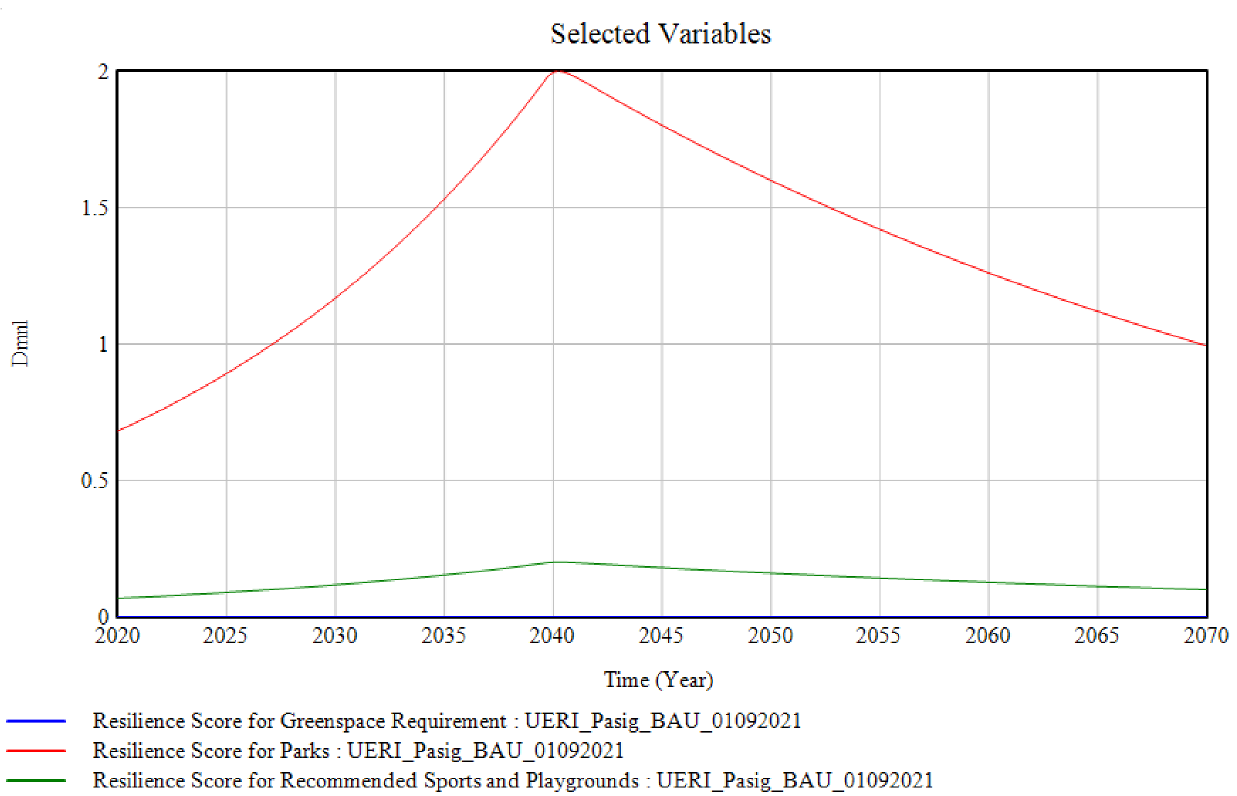


Figure 117. Graph of Components of Cultural Resilience Score Graph for Pasig City

The components contributing to graph for *the Resilience Score for Greenspace Requirement*, as seen Figure 118, were represented by *Agriculture and Greenspace Area (A&GA)* and *Recommended Greenspace Supply*. Given that there were no recorded *Agriculture and Greenspace Area (A&GA)*, the value set was zero. As of the case of *Recommended Greenspace Supply*, the increasing trend as seen in the projections is a result of population growth wherein as the population grows, so do the total requirement for greenspace. The widening gap observed from the graph is reflective of the lack of cultural service for this aspect in the city.

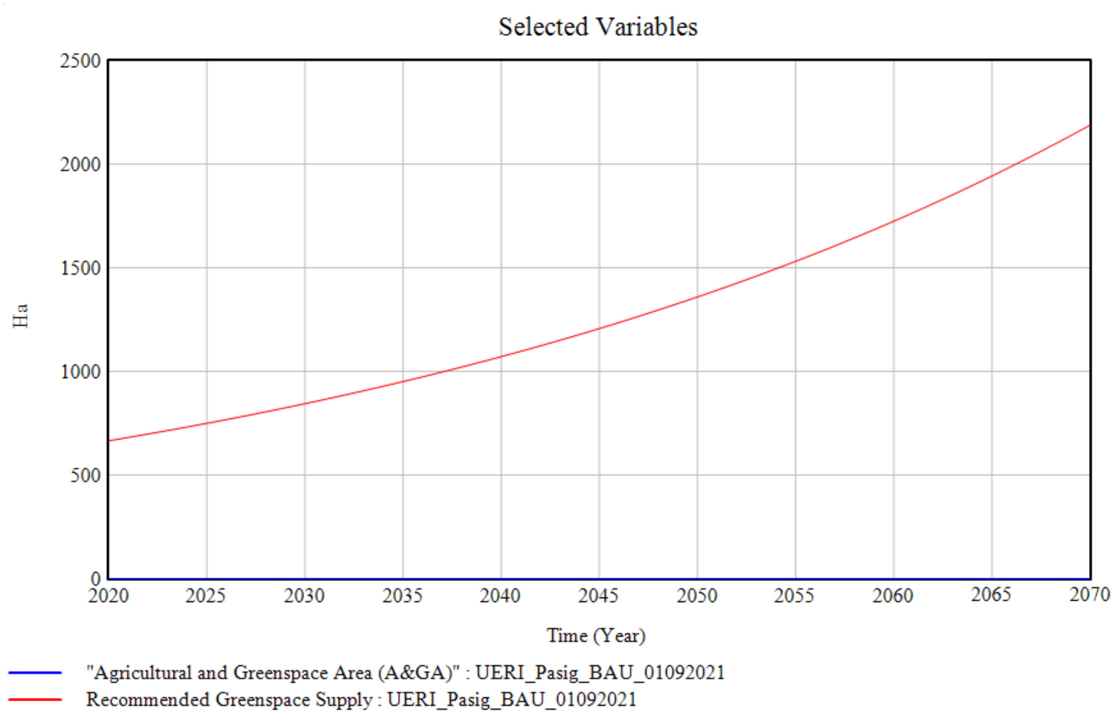


Figure 118. Graph of Components of Resilience Score for Greenspace Requirement for Pasig City

The components contributing to the resilience scores dealing the second land use type are seen in Figure 119. Both resilience scores used the *Parks and Recreations (P&R)* from which cultural benefits are derived from. The main difference between the two is the magnitude of Parks and Recreations (P&R) required which differs by a magnitude of 1,000 for the *Recommended Recreational Spaces Supply (Only for Sports and Playgrounds)* as compared to the *Recommended Recreational Spaces Supply (Only for Parks)*. The resilience scores for both exhibited the same behavior with the overall value being more for the parks given that it required less land per capita as compared to sports and playgrounds as seen in Figure 119. This implies that more cultural benefits could be derived from parks as compared to sports and playgrounds which require more area.

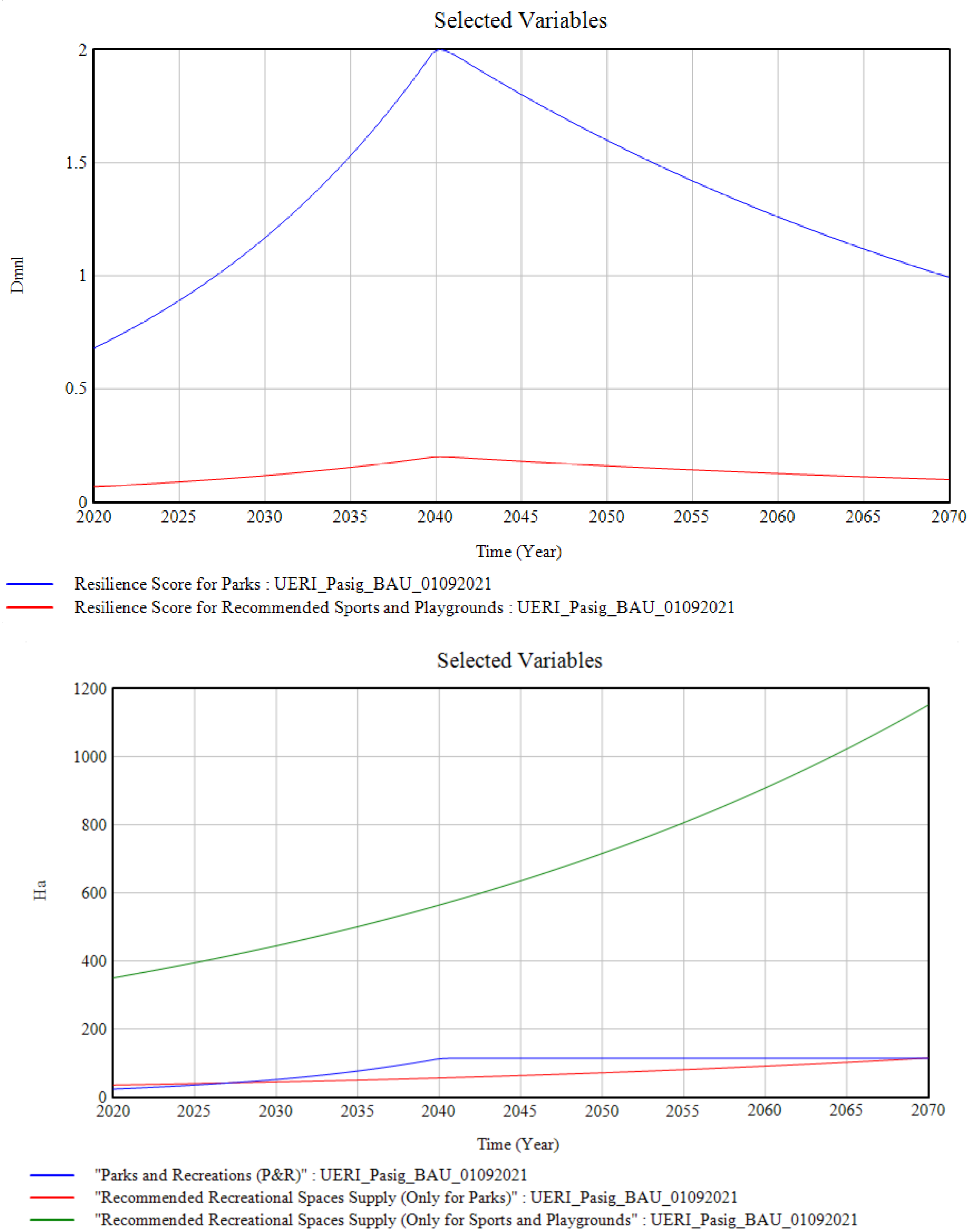


Figure 119. Graph of Components for the Resilience Score of Parks, Playgrounds, and Sports Graph for Pasig City

What contributed to an overall lower value for the *Cultural Resilience Score* was from the *Resilience Score for Greenspace Requirement*. Given the development plans of the city, as well as the lack of available land to convert into new greenspaces, possible developments to increase resilience would be to convert existing parks into greenspace to serve dual purposes given that the not a lot of area are required when it comes to the cultural services for parks.

4.2.1.5 UERI for Pasig City under Business-As-Usual

The UERI value of city, as seen in Figure 120, was based on the results of the different resilience scores of each ecosystem service category. What influenced the behavior of the values under the Business-As-Usual was the land use change of the city. The city prioritized social development which resulted in the increase built-up area over the years. This would explain the decrease in resilience given that a lot of services, such as those in regulating and parts of cultural were influenced by the presence of A&GA. This also affected cultural service given that it was dependent on the amount of P&R as well. The value obtained for the UERI was observed to be below one all throughout the simulation. This implies that the city is still suboptimal in terms of meeting the overall needs of the city for the different services, despite scoring highly in particular services such as provisioning in the initial part of the projection and cultural in the latter part. What led to an overall lower score for the UERI was the regulating service of the city. This was a result of the lack of capacities for certain services such as wastewater, carbon, and air regulation to regulate emissions to natural standards. Specifically, the city was not able to treat carbon and air due to the lack of A&GA. Additionally, the current capacity of the city for treating wastewater was greatly lacking in comparison to the generated wastewater.

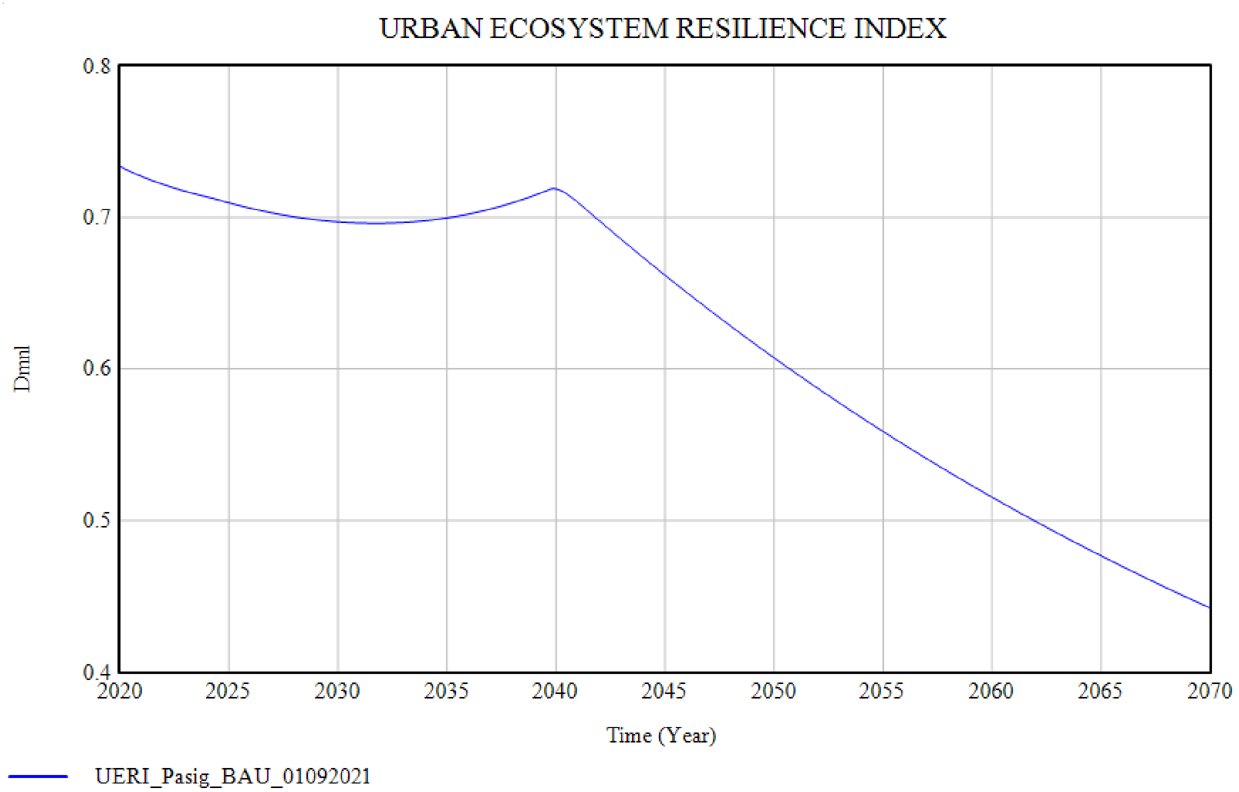


Figure 120. Graph for UERI for Pasig City

It was observed from the results of the resilience scores of city that certain trade-offs exist between services. This includes the trade-off in between the provisioning and the regulating functions of the city. The city exhibited a high provisioning score for both water and electricity resilience. This is translated to the regulating services model under emissions produced. Increasing consumption for either water or electricity resulted in the increase in emissions. This would explain why the resilience score for wastewater regulation and carbon were low given the high consumption values reflected from the provisioning model. There were also trade-offs seen, although not all measured, in terms of land use wherein increase in built up area for socio-economic services led to the decrease in the services derived from more A&GA and P&R.

4.2.1.6 Pasig City Self-Sufficiency Score

4.2.1.6.1 Solid Waste Management Self – Sufficiency Score

The *Self-Sufficiency for SWM* graph, seen in Figure 121, exhibited a decreasing trend. This is because majority of the trash produced in the city is being sent to the landfill as compared to being treated within the city. It was assumed in the model that anything that was not composted or recycled would either be sent into the landfill (90%) while the rest were not accounted for and categorized under uncollected (10%).

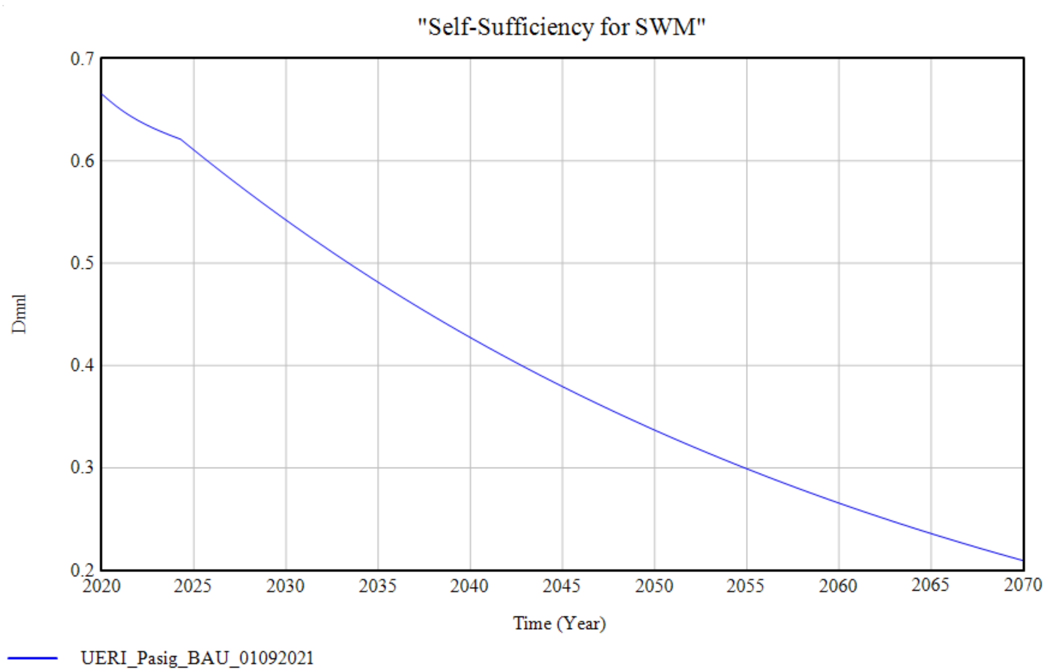


Figure 121. Self-Sufficiency for SWM Graph for Pasig City

The widening gap between the *Generated Waste and Total Recyclables and Compostables* resulted into the lowering of the *Self-Sufficiency for SWM*. Given that there were no reported ways for treating with residual waste inside the city, the main determinant for increasing *Self-Sufficiency for SWM* were in increase the capacity of *Total Recyclables and Compostables*.

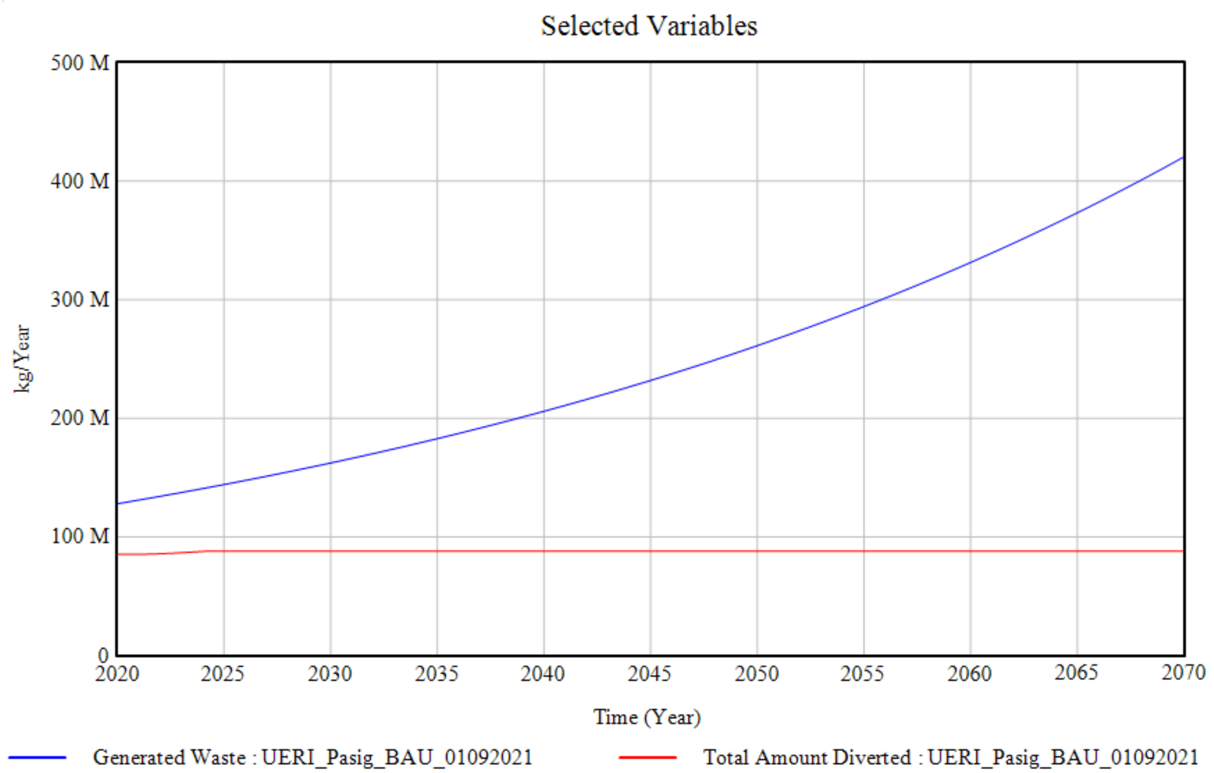


Figure 122. Components of Self-Sufficiency for SWM Graph for Pasig City

4.2.1.6.2 **Wastewater Self-Sufficiency Score**

The *Self-Sufficiency Score for WW* graph, as seen Figure 123, exhibited a decreasing trend with a low starting value. More wastewater was treated via desludging than via sewage treatment plants within the city given the limits of capacity to accommodate for more sewage treatment. The water vacuumed from the septic tanks are treated in facilities outside the city. The amount of these septage treated outside were referred to as *Treated (Desludged) Septage*. It was observed in Figure 124 that the amount of treated septage was always higher than that of the treated sewage water, even when the frequency of once every five years for desludging service availed per household was factored in. The implication of this observation was that there were more households applying for desludging services rather than sewage connections. Having sewage connection meant not requiring any desludging service. This also had a higher capacity for treatment yearly as compared to desludging given its frequency.

The *Self-Sufficiency Score for WW* is indicative of suboptimal performance of the city in terms of being able to provide WW treatment services inside its borders. This stemmed from the situation observed in the graph wherein the current capacity to connect the sewer lines was low given that it could not account for even half of the total household population. This would explain the low *Self-Sufficiency Score for WW* Pasig. The implications of this is that majority of the households in the city would be treated via desludging given that septage desludging only happen once every five years as compared to sewage treatment.

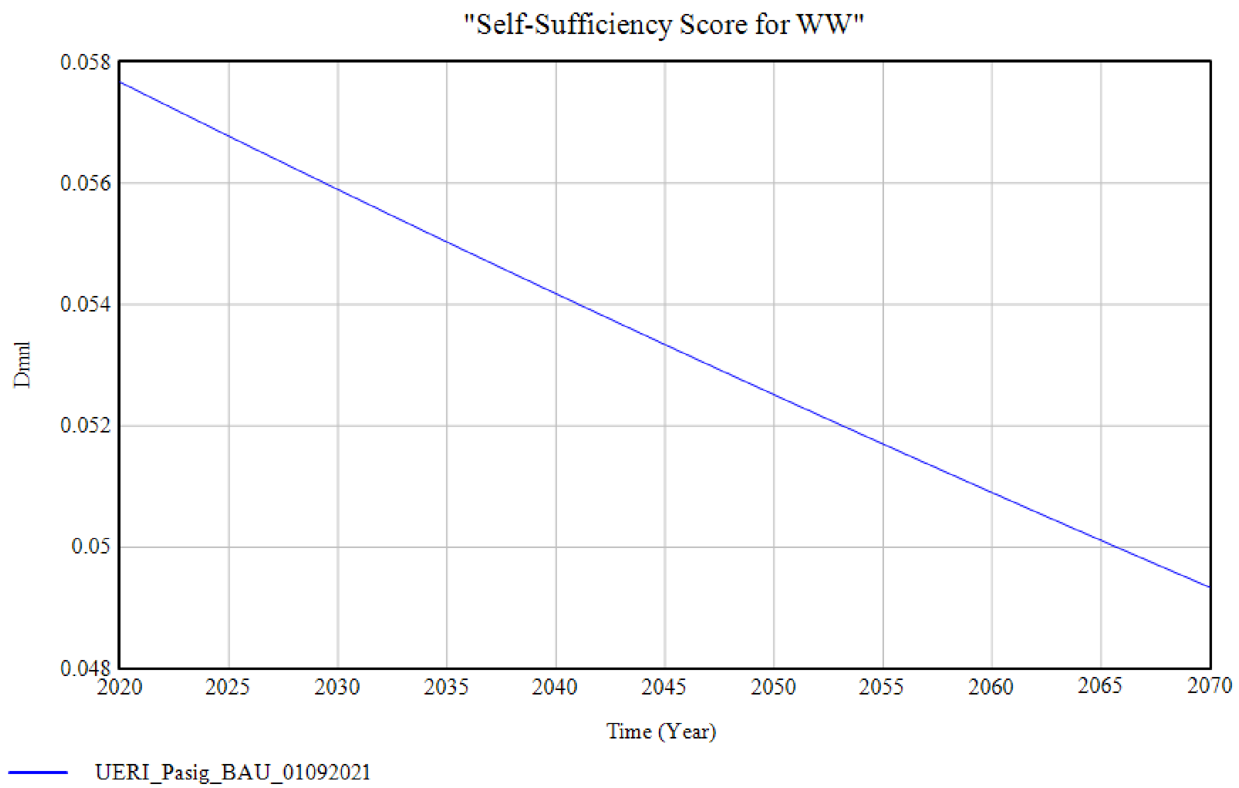


Figure 123. Self-Sufficiency Score for WW Graph for Pasig City

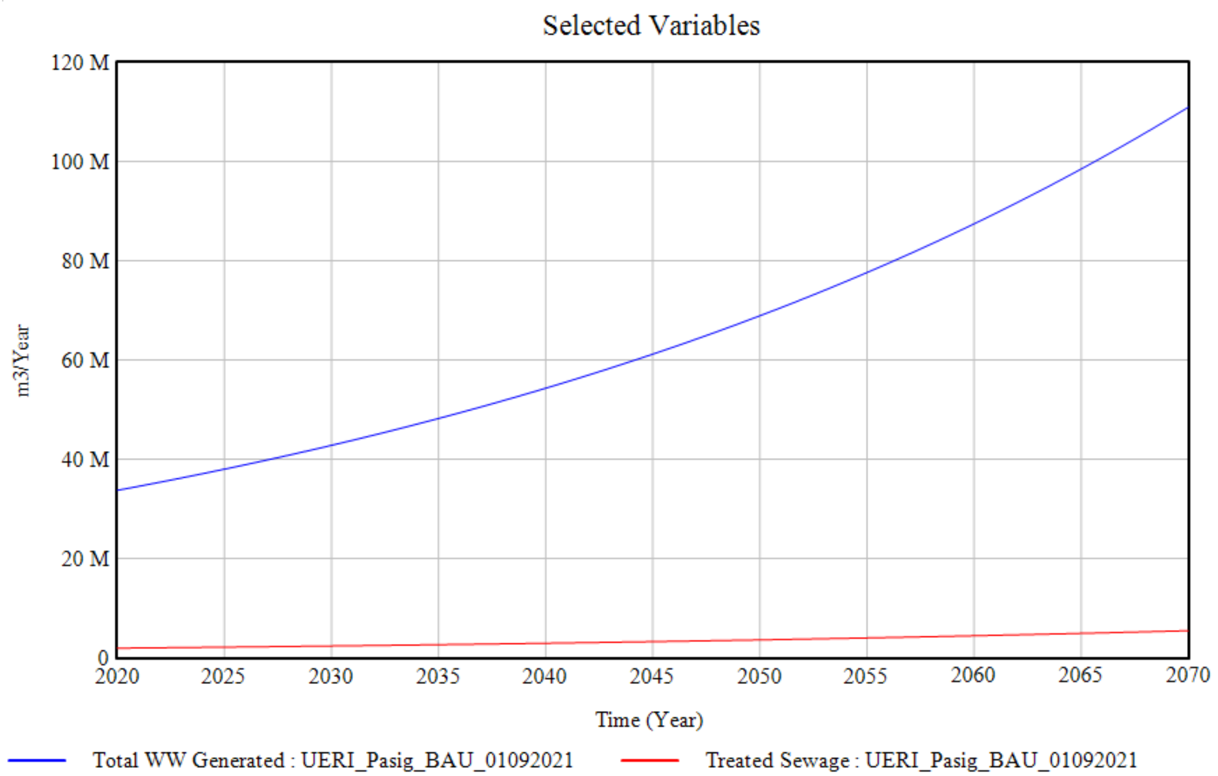


Figure 124. Components of Self-Sufficiency Score for WW Graph for Pasig City

4.2.2 Pasig City RDF Scenario

The RDF scenario assumed the implementation of an RDF system in the city to address issues in solid waste management particularly in finding a way to treat residuals without sending them to landfills. The RDF produced from treating residuals could be used as fuel to provide for electricity. This had certain implications to certain services such as solid waste management from the regulating service and electricity from the provisioning service.

4.2.2.1 Provisioning Services under RDF Scenario (Pasig)

The *Resilience Score for Recommended Electricity Consumption* was affected in this scenario given that RDF produced from the treatment could be used as potential energy. The assumption was that should this energy was be produced and used only for the city; then it would be subtracted from the *Recommended Electrical Consumption* needed for the city. The changes in the *Resilience Score for Recommended Electricity Consumption* are seen in Figure 125. The value obtained for resilience under the RDF scenario was slightly higher than the one obtained from Business-As-Usual. This was indicative that the amount of potential electricity generated from the RDF only had a small contribution in reducing the overall *Recommended Electrical Consumption* of the city. This shows a potential co-benefit in the city wherein the increase in amount of treated waste resulted in an increase in electricity resilience via increasing potential supply as compared to the score from the Business-As-Usual. Despite the increasing amounts of residual waste that could be treated given increasing capacities per scenario, the resilience score remained the same for every scenario from the business-as-usual. This is due to the assumption that the city only processes residuals produced within the city. The proposed increases in RDF capacity were greater than the residuals generated even from the earliest RDF scenario. There were no changes in resilience per scenario given that same amount of waste would be accepted.

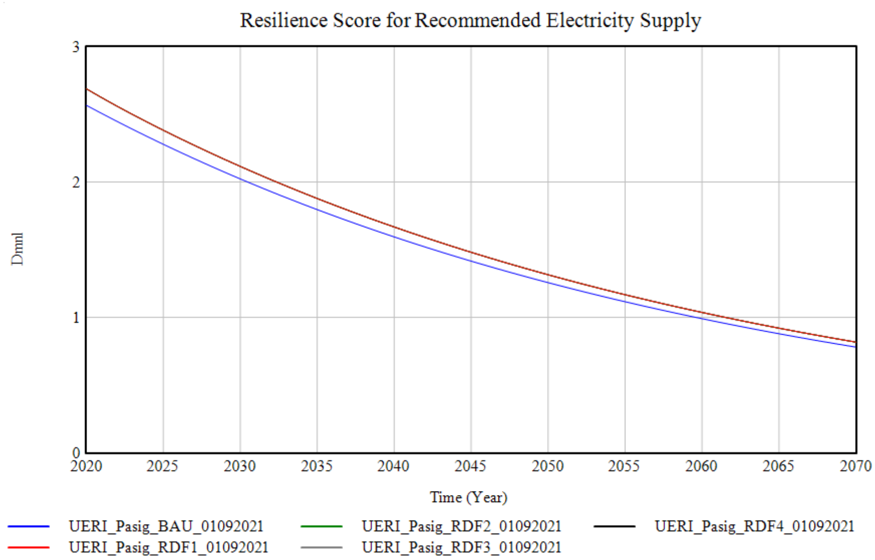


Figure 125. Resilience Score for Recommended Electricity Consumption under Business-As-Usual and RDF Scenario Graph

4.2.2.2 Regulating Service under RDF Scenario (Pasig)

The changes in the *Resilience Score for SWM* were reflected in Figure 126. The different values inputted per RDF scenario are found in Figure 127. The *Resilience Score for SWM* under the different RDF scenarios were observed to be higher than the value from the Business-As-Usual scenario.

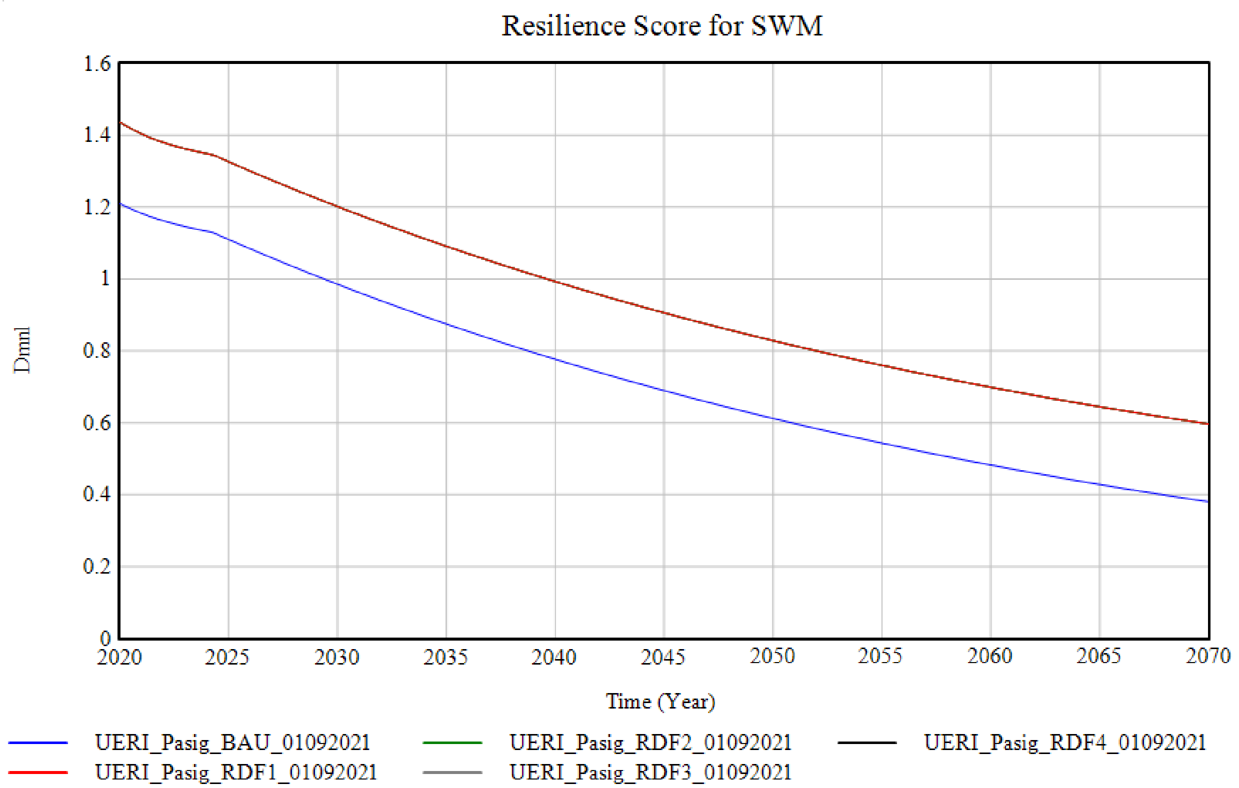


Figure 126. Resilience Score for SWM under Business-As-Usual and RDF Scenario Graph for Pasig City

The increase *in Resilience Score for SWM* from the Business-As-Usual to the RDF scenario was due to the additional trash diverted as a result of adding an RDF system in the city. Different scenarios tested different capacities the residuals that the RDF could accommodate. As the capacity increases, more amount of waste can be diverted. This results in a higher resilience score given that the amount diverted would increase should generated waste follow the same trend from the Business-As-Usual approach. As observed from the graph, RDF Scenario 1 – 4 all exhibited the same overlapping graphs. This was indicative that the proposed capacities all exceeded the total residuals generated within the city. The difference would be in the value for As such, investments in additional capacity can only be rationalized if the were also to cater to the solid waste management needs of other cities in Metro Manila, thus maximizing the additional capacity.

The introduction of the RDF system would also result in an increase in *the Self-Sufficiency of SWM* as reflected in Figure 127 given that the residuals would be treated inside the city rather than brought to outside landfills.

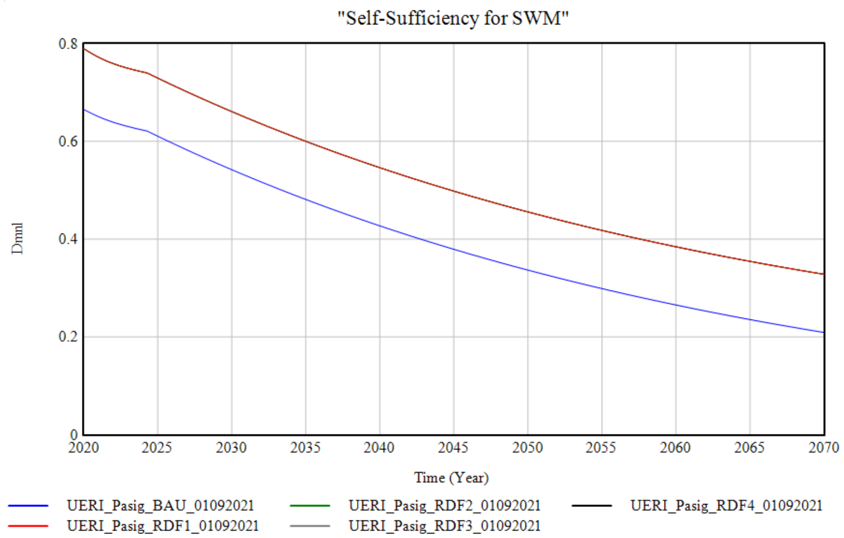


Figure 127. Self-Sufficiency for SWM Under Business-As-Usual and RDF Scenario for SWM

4.2.2.3 UERI Under the RDF Scenario (Pasig)

The change in UERI under the Business-As-Usual scenario to the RDF scenario can be seen in Figure 128. The addition of an RDF system resulted in an increase in the overall UERI score given improvements made to both solid waste regulation and electricity supply. Despite the changes in capacity, the value of the resilience scored under the different RDF scenarios were the same given that all capacities exceeded the residuals produced in the city. The addition of an RDF scenario resulted in a significant increase highlighting the contribution of integrating co-benefits in development planning.

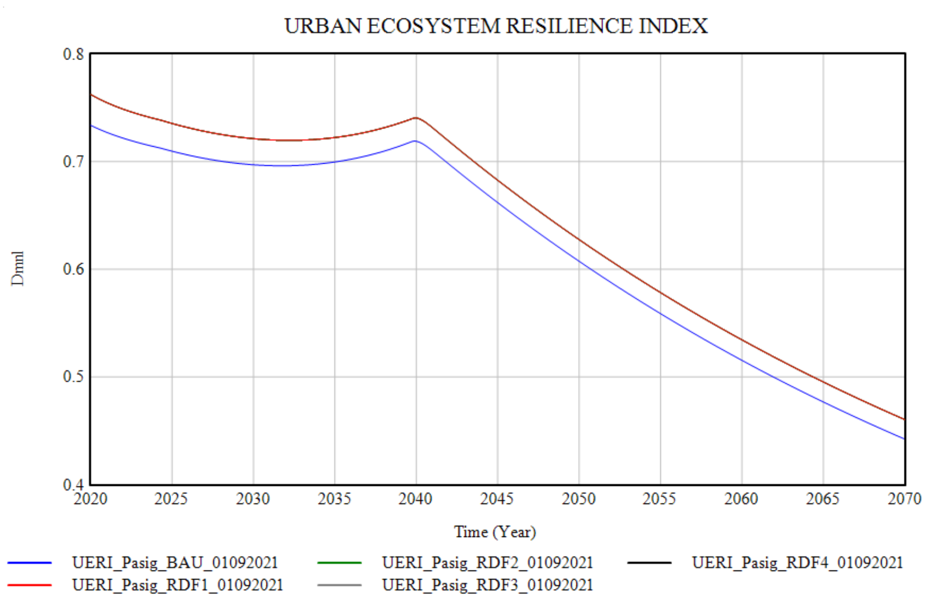


Figure 128. Graph of UERI under RDF Scenario for Pasig City

4.2.3 Pasig City Land Use Scenario

The Land Use Scenario had certain implications across all services. Listed under this section were the implications of converting Parks and Recreations (P&R) to greenspace towards specific cultural and regulating services. The conversion does not remove any existing land area for Parks and Recreations (P&R) but merely allowed it to be classified as part of the Agriculture and Greenspace Area (A&GA) category.

4.2.3.1 Regulation Services under Land Use Scenario (Pasig)

The increase of Agriculture and Greenspace Area (A&GA) resulted in an increase of certain regulating services in the city via improvement one of their components such as the *Pollutant Removal by A&GA* for improved air quality regulation as well as in the *Carbon Sequestration* for improved carbon emission regulation as seen in Figure 129 and Figure 130. Increased in A&GA results in more potential for increased distribution of greenery, from which regulatory services are derived from, that can be planted in this land type. Given the increase of regulating performance, the *Resilience Score for Carbon and Air Quality* also increased as compared to the value seen in the Business-As-Usual scenario, although very minimally, as seen in Figure 131 and Figure 132.

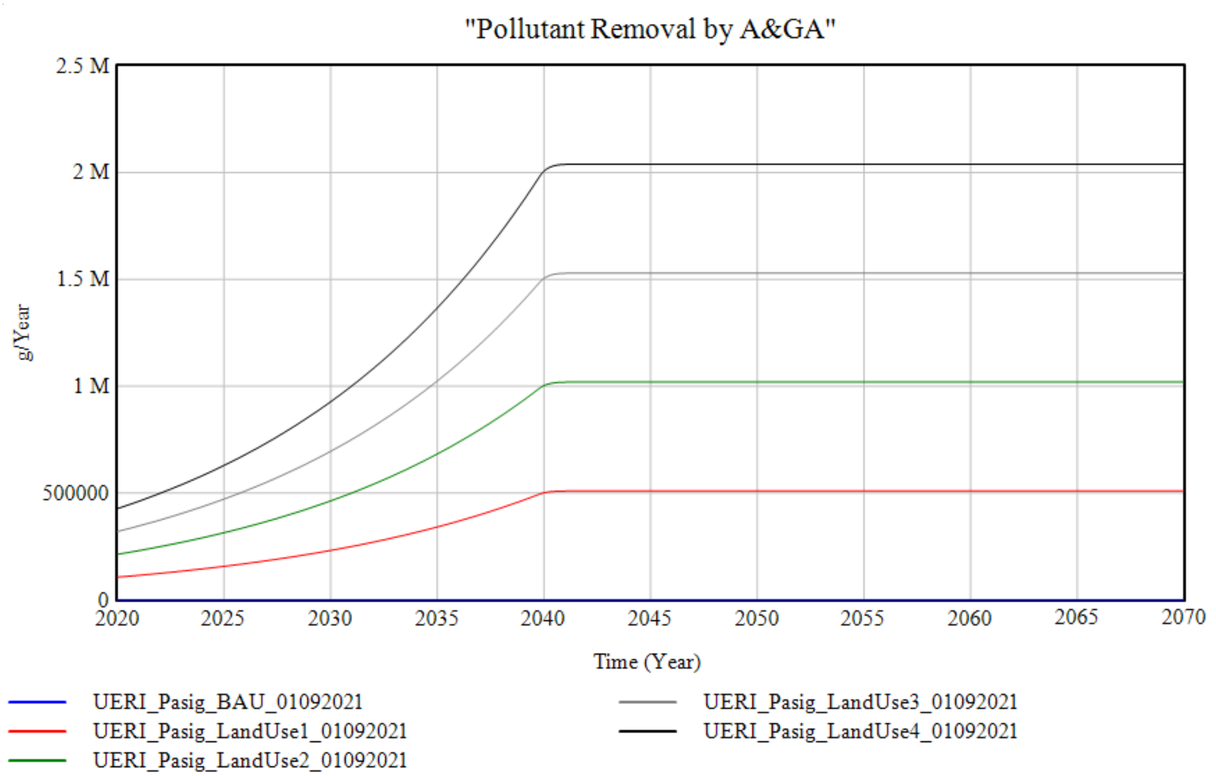


Figure 129. Graph of Pollutant Removal by A&GA under Land Use Scenario

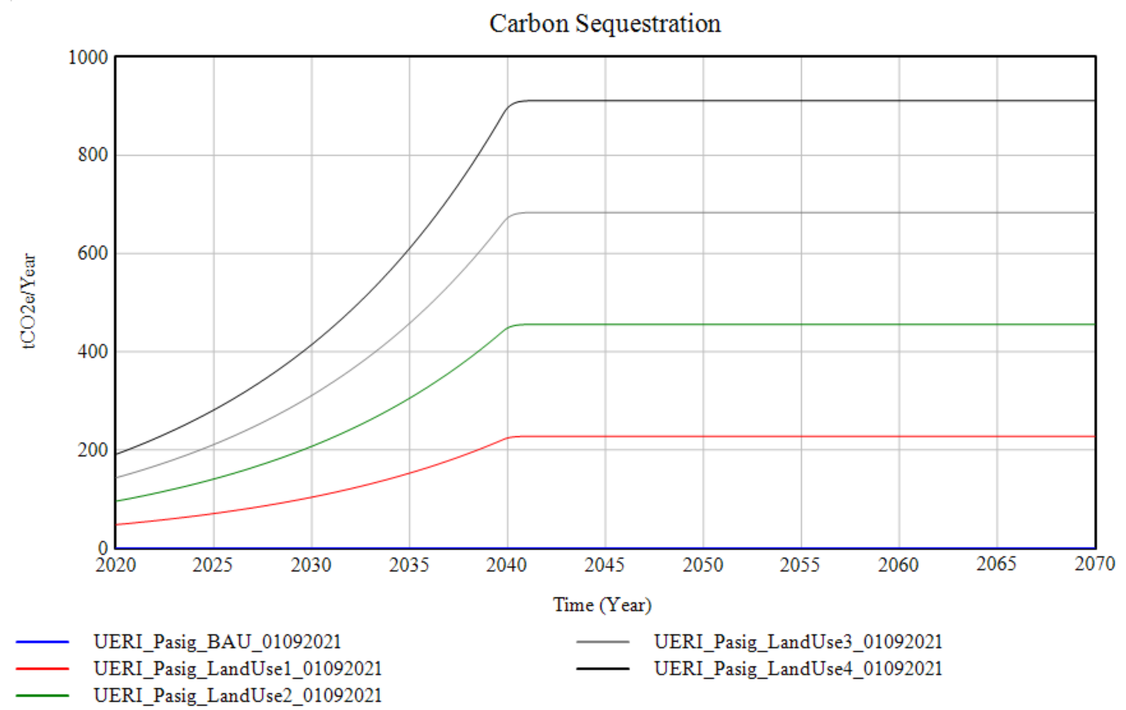


Figure 130. Graph of Carbon Sequestration under Land Use Scenario

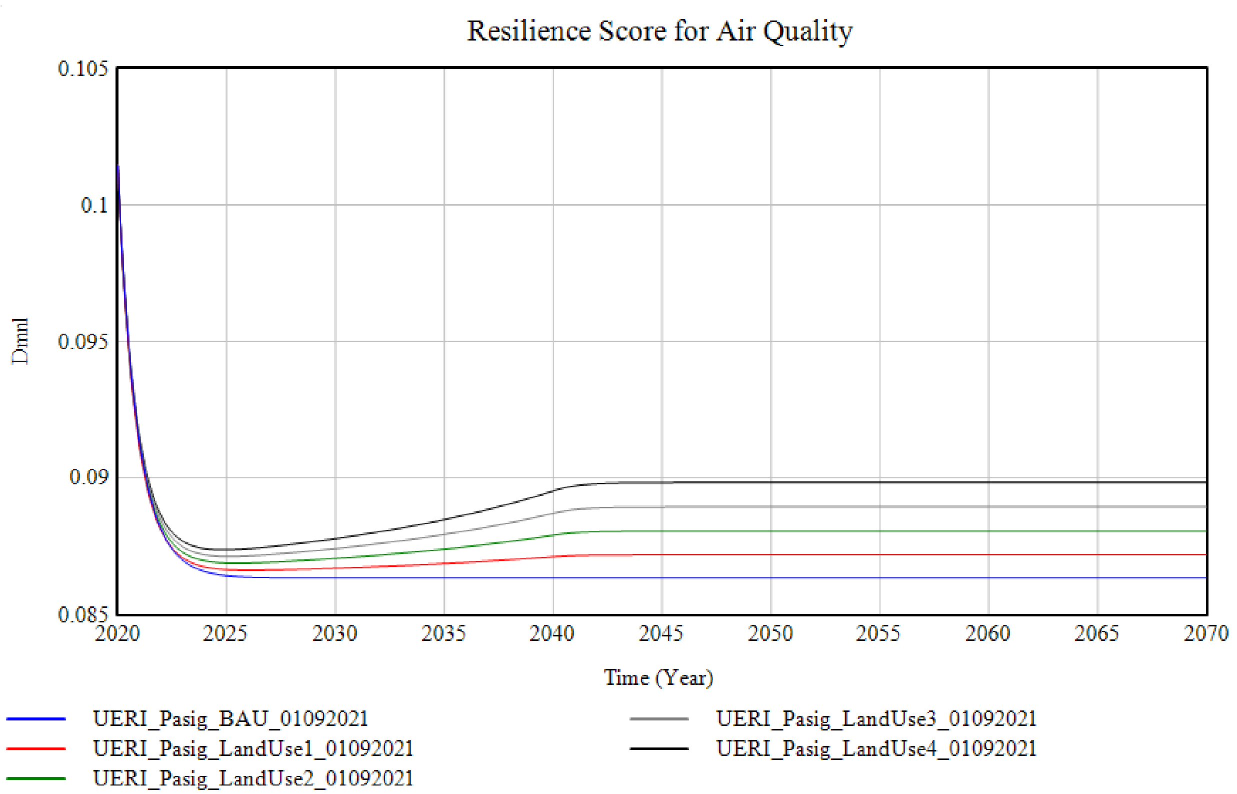


Figure 131. Graph of Resilience Score for Air Quality Under Business-As-Usual and Land Use Scenario for Pasig City

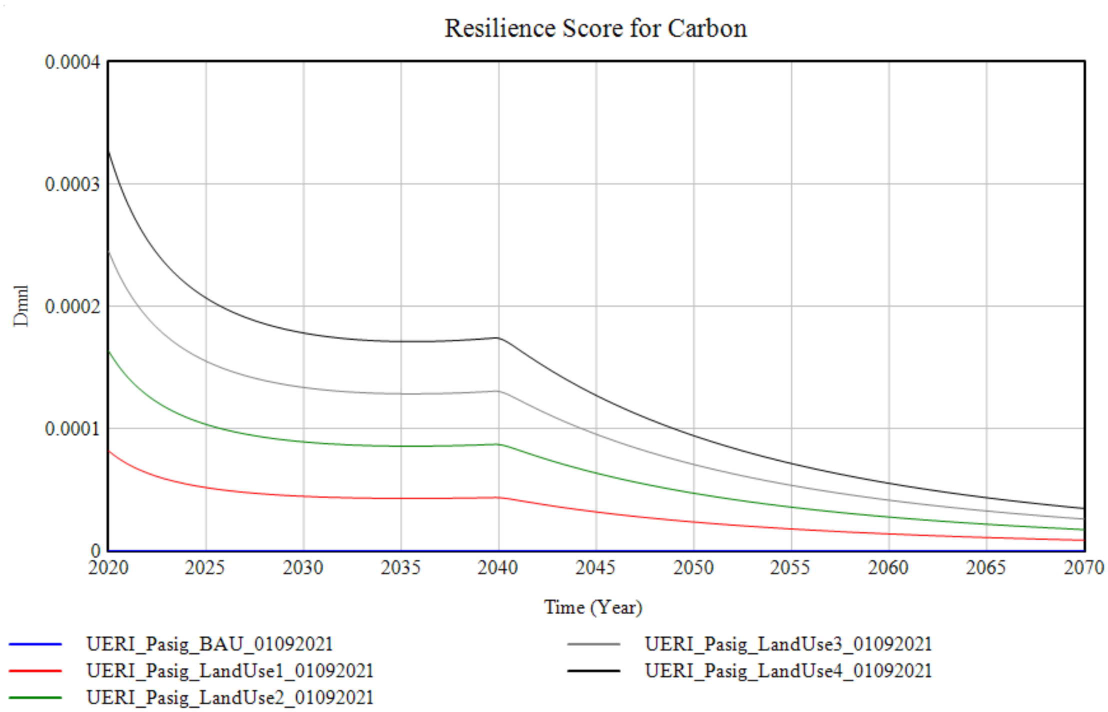


Figure 132. Graph of Resilience Score for Carbon under Business-As-Usual and Land Use Scenario for Pasig City

There were only slight changes to the resilience score observed among Land Use Scenarios. This was indicative that while change in land use contributed to improved resilience, the amount converted was not enough to add any significant difference, as for the case of regulating services. The issue observed was for this was the high accumulated value of emissions given large inflows and minimal outflow values which, despite adjusting, were not effective in reducing the accumulation of emissions. Despite the small land use change, there were significant changes between Land Use Scenarios as observed from the graph of *Pollutant Removal by A&GA*. The same increments of increase were also observed from the *Carbon Sequestration,* but the magnitude of increase was less than the one seen as compared to the regulation of air quality. When the value of carbon sequestration from the Land Use Scenarios is compared to the initial value from the Business-As-Usual, it can be considered significant. Land use change then serves as a leverage point for the components of the regulation services in the city.

4.2.3.2 Cultural Services under Land Use Scenario (Pasig)

The conversion among the different scenarios allowed the *Resilience Score for Recommended Greenspace* to increase by a certain amount based on the fraction of P&RA converted to A&GA. The changing scores were seen in Figure 133. Given this scenario, the corresponding impact to the resilience score would depend on the remaining amount of *Parks and Recreations (P&R)* area that could be modified to allow it to be classified as *Agriculture and Greenspace Area (A&GA)*.

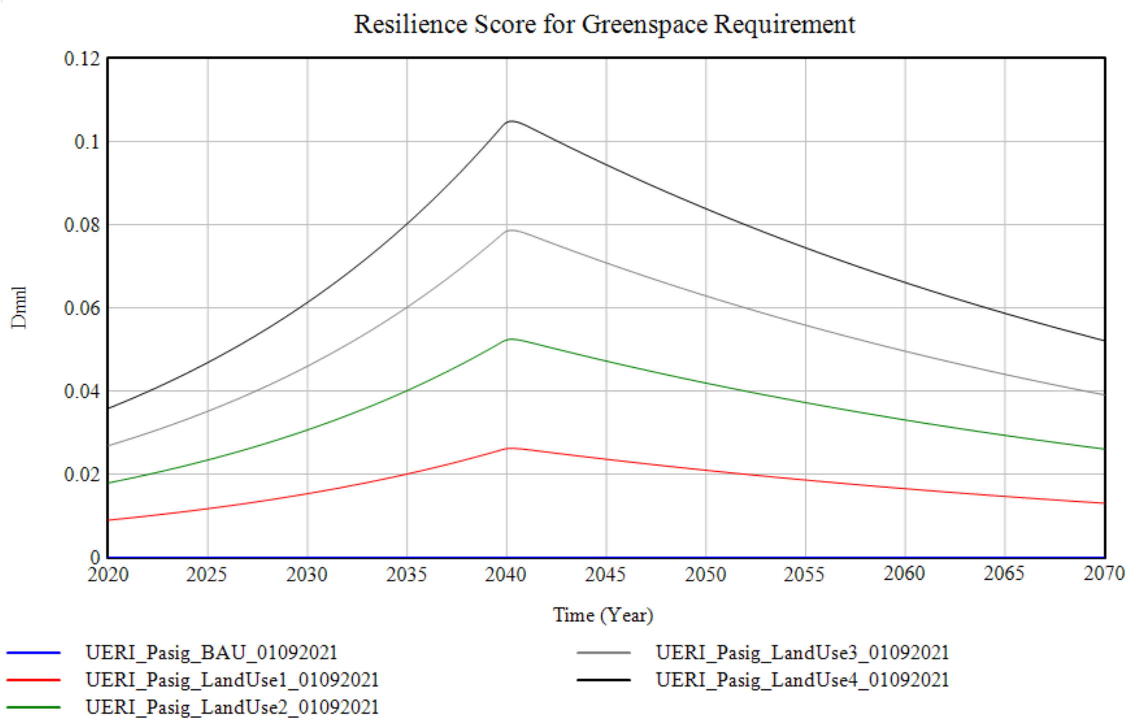


Figure 133. Graph of the Resilience Scores for Greenspace Requirement under Business-As-Usual and Land Use Scenario

The slight increase of the *Resilience Score for Greenspace Requirement* from the Business-As-Usual scenario to the Land Use Scenario implies that there is still a huge gap observed between new amount of greenspace supply and the total recommended greenspace despite the changes from the different scenarios as indicated by the low score.

4.2.3.3 UERI Under the Land Use Scenario (Pasig

The value for UERI under the Land Use Scenario increased from the Business-As-Usual scenario as seen in Figure 134. The increase is a result of the conversion into A&GA from P&R. This highlights the role of the A&GA which can serve dual purposes in terms of its contribution to increase resilience for both for cultural and regulative services. Given the small amount of conversion, the value for UERI increased minimally per scenario. This is reflective of the current development plan of the city which focuses on catering to the socio-economic development needs of the city as compared to the UERI as a whole given that the city does prioritize certain services found in UERI such as provisioning services.

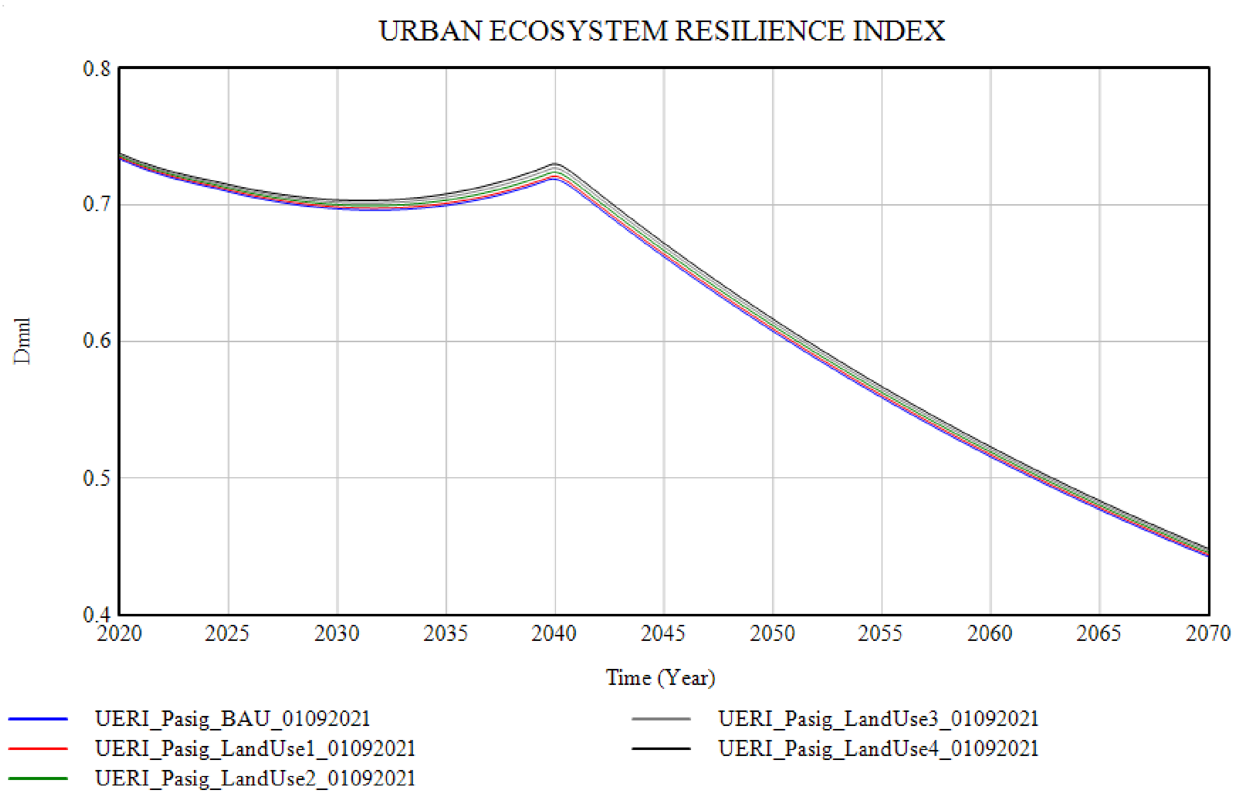


Figure 134. Graph for UERI under Land Use Scenario for Pasig City

4.2.4 UERI Under Land Use and RDF Scenario (Pasig)

Putting together the effects of land use and the RDF scenario resulted into a higher increase in the UERI as seen in Figure 135. There were no observed trade-offs in between services given that land use modifications did not decrease P&R when it was converted to A&GA. What was observed were co-benefits and synergies between services leading to a higher score. This was in the form of the co-benefit between the electricity and the solid waste management service under the RDF scenario. The other was seen in the synergy between the Land Use Scenario which improved multiple services under the regulating and cultural component of UERI.

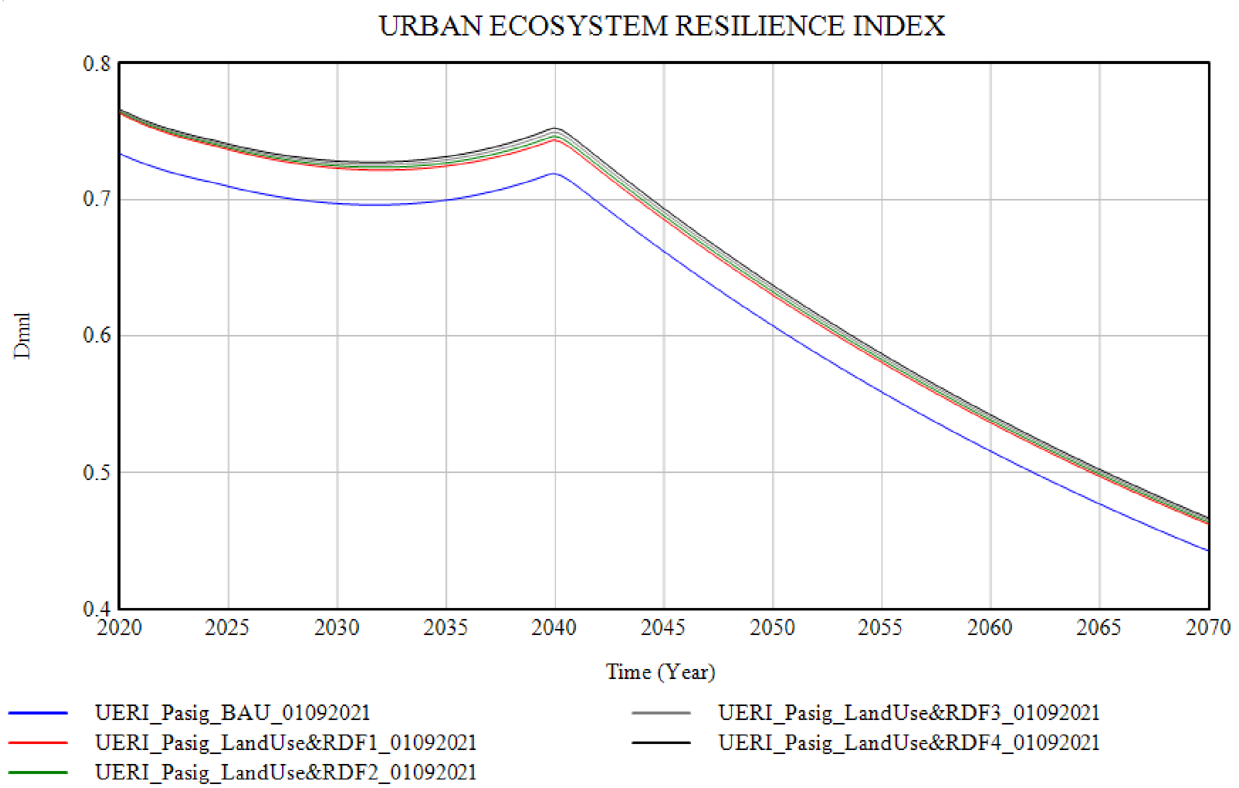


Figure 135. Graph for UERI under the Land Use and RDF Scenario for Pasig City

4.3 Synthesis of Pasig and Valenzuela UERI

The value of the UERI served as an indicator of whether the city, to which the index was applied to, was optimal or sub-optimal in terms of ensuring that services flowed constantly while meeting the requirements set because of demographic growth and city developmental goals. For a city to be resilient, the limits of ecosystem services must first be assessed in terms of adequacy and sustainability in distribution, amidst different development plants, to guide local stakeholders in decision making.

The ecosystems approach helped operationalize urban ecosystem resilience which was translated to the UERI. The comprehensive and holistic approach of the UERI revealed which services were more prioritized in the city and which were less focused on as reflected in the score of the respective urban ecosystem service category. Insights were derived in the form of observed trade-offs between services wherein the increase in the score of one particular urban ecosystem service such as provisioning for example, led to the decrease in the score of another service or in this case, the regulating services.

By classifying the different services found in the city into 4 categories of services (provisioning, regulating, cultural, and supporting), cities could be paralleled to how natural systems work, recontextualizing it to become UES. Framing the model this way depicted which processes all work harmoniously, between biotic and abiotic components of its system. This provided a way to tackle complex systems that are cities which are also composed of biotic and abiotic components in continuous interactions. Categories were scored based on their performance in delivering their respective ecosystem service.

As for the result from the models, Pasig City was observed to have a higher UERI value as compared to Valenzuela City indicating that it is more capable of meeting the demand for services in its own city than Valenzuela city to its own city needs. The scores are indicators of the city's own performance regarding their own delivery of services. The scores obtained for both cities cannot be compared directly given the difference in contexts affecting the model structures. However, despite having different contexts, there were similar patterns observed in both cities that have affected their own scores in the same way, indicating common system behavior for these two cities.

Regarding the difference in overall value, it was assumed that Pasig had a larger capacity for provisioning services, indicated by having higher current maximum supply for water and electricity, as compared to Valenzuela. Differences in model structures include the lack of disaggregated data for Pasig electricity consumption. Given that the maximum electrical supply was based on consumption data, not being able to disaggregate between domestic, industrial, and commercial which led to a lower estimate for recommended electrical supply, therefore improving the resilience score as the gap between maximum and recommended were lower. This improved the performance of Pasig, but to an extent that it was a less dynamic model as compared to Valenzuela electricity given no trends could be observed to add rates of increase for the consumption of different sectors to feed into recommended supply. Should the population grow, Pasig would be able to accommodate more for their respective city needs for provisioning goods as compared to Valenzuela with its own population needs.

What contributed mostly to the behavior of both graphs, indicating similarities in system behavior, was from the land use change as seen from the results obtained for both Pasig and Valenzuela city models. Regulating services derive many benefits from A&GA. Given the difference in prioritization, there was a higher rate of increase for the UERI value, as reflected in the slope of the graph, for Valenzuela in the earlier years because of more conversions towards A&GA. As for Pasig, given that there was no recorded A&GA in the city, what led to a higher overall score as compared to Valenzuela was from having higher regulating capacities not, naturally induced, that are present in cities such as solid waste treatment and wastewater treatment. Additionally, they had a more updated recommended conveyance capacity to account for rainwater as compared to Valenzuela city. Regulating resilience scores would benefit from policies that reduce emissions or improve treatment more than land use change. given the observed improved performance from artificial services.

In terms of the cultural services, Valenzuela had a high score compared to Pasig. The steep increase observed for the cultural resilience score of Valenzuela City implied that the rate of growth was high for certain land types devoted to giving cultural services most especially A&GA for a certain time of development. Pasig, having no recorded A&GA, had a lower overall cultural resilience score given that there were fewer potential benefits to obtain cultural services from as compared to Valenzuela. This difference was framed in the model in terms of the components contributing to the resilience of recommended greenspace in which the one for Pasig had a value of zero given no recorded data. This led to a lower maximum score as reflected in the graph as compared to Valenzuela which was higher overall. The decreasing score observed for both cities after it reached a certain peak were a result of not being able to meet the demand for cultural services that increases with population growth.

The scenarios explored all resulted in an increase in the UERI for both cities, although to different degrees. Both cities included scenarios which explored adjusting the land use in accordance with their respective development goals. The different scenarios for Valenzuela led to a higher increase in the UERI value given that it involved more land conversion towards A&GA which improved both the regulating and the greenspace cultural services as compared to Pasig. Pasig city land use development, being centered on expanding built area, involved only converting portions of P&R to A&GA given no available land could be devoted to A&GA. This would mean that less A&GA was converted in Pasig than Valenzuela resulting in a lower impact for the Land Use Scenario. What hindered the magnitude of growth for Valenzuela city were the services that relied on other land use types such as cultural services for parks, sports, and playgrounds given that less available land as more was allocated to A&GA. From these results, it can be assumed that the impact of any land use change development would depend on the amount of land converted. Given that there were not much existing lands left for these cities, impacts were minimal as reflected in changes to UERI.

Results from both Business-As-Usual and scenario testing revealed certain trade-offs, synergies, and co-benefits among the different services. While not direct, there exists a trade-off between provisioning and regulating service based on their components. As consumption increases, so do the emissions for the respective resource consumed. As the city responds to the growing demand for resources given population growth, they make it so that the provisioning services are often prioritized by local government units including water, food, electricity, and housing given that they want to focus on socio-economic development (Pasig City Government, 2014; Valenzuela City Government, 2014). Doing so results in the increase in wastewater and emissions reflected in the regulating resilience score as seen in the model.

As observed from the models, another visible trade-off in between services were from land use change. Variations of specific fractions allocated per type of land use dictated the amount of land for specific use as well as the extent of the capacity of the regulating services, most especially with regulating air and carbon emissions. This was tested in the long term, in whether configurations made to accommodate socio-economic needs would result in significant decrease in regulation and provisioning services. Additionally, it was clear that by increasing the amount of built-up areas for socio-economic needs, the other sectors needed for food production like agricultural and carbon emission regulation such as carbon emissions also decreased. Other trade-offs, although not direct, were observed as well from the models. This included the trade-off between provisioning and regulating in which an increase in consumption resulted to an increase in emissions as well. While the provisioning resilience goes up given efforts to increase supply, regulating resilience would decrease assuming no changes were made to the treatment capacities for the wastewater.

There were also observed synergies and co-benefits among the 4 UES as observed from both the Pasig and the Valenzuela models. Pasig City's RDF scenario and Valenzuela City's greenspace scenario were examples of this because of the added RDF system and increased greenspace benefitted another service. Specifically, converting more residual waste into RDF meant that Pasig City could utilize that as an alternative source of electricity or fuel while Valenzuela City's increase in greenspace would mean an increase in cultural spaces and agricultural development. While framing the increase of the resilience score as an increase in the capacities of the city to withstand long-term shocks as an adaptive strategy, managing the city's problems from the root problem is also something that should be prioritized.

Lastly, one co-benefit that is not as immediately apparent is that of population and need for services. As population increases, so do the demands for different urban ecosystem services. Without any adjustments to the system to increase supply, this would result in a lower UERI. As seen in the model, managing the population would result in decrease of service demand which would lead to a better UERI for both cities. This is because from a mathematical standpoint, a smaller population would decrease demand therefore, reducing the value of the one of the variables used in the ratio to derive the UERI. Aside from managing population, introducing policies to reduce the value of the consumption per capita and emissions per capita for the different services would also result in a better UERI value while retaining the Business-As-Usual population growth.

4.4 Evaluation of SD Approach to UERI

The main challenge observed in operationalizing resilience in an urban context is the selection of a definition appropriate for the context of the city amidst the many definitions of resilience. This was made difficult given the complexities of city systems which possess underlying and interconnected human-nature systems crucial to understanding the system and how the services are delivered. Framing resilience under the ecosystem services framework—contextualized in an urban setting—allowed for quantifying resilience by measuring the cities' capability to deliver its services.

Because of the difficulty in understanding complex systems, policy formation and development plans are in danger of being crafted in sectoral silos or being merely reactive to immediate needs of the city in response to demographic growth and socio-economic goals. This is both a selective and short-term approach without regard to the dynamics of the system. Processes of complex systems should not be treated in isolation but as a systemic whole. Mapping these processes to understand the different relationships in between services was done through a systems approach. Understanding how these processes are related was done using a causal loop diagram to show the different feedbacks from among and within the categories of ecosystem services. Determining the links among processes could facilitate long-term planning by providing a more holistic measure of UER in the city. The UERI embodies the interrelationship of different ecosystem services and how the different processes in the city lead to their respective resilience scores.

Utilizing the systems thinking approach when applied to UERI had its strengths and limitations. The main strength of applying a systems approach is that the modelers were able to analyze different processes in terms feedbacks, trade-offs, and co-benefits. Another observed strength of the systems approach is that it was able to measure how a system would react over time should certain development plans be implemented. This way, the different feedback identified could be validated and tested as contextualized for the city. This was applied in the UERI via the scenarios for both Pasig and Valenzuela city. Scenarios for land-use change resulted in an increase in overall UER Score, but certain services decreased depending on which land-use type was expanded. Increasing built-up area would cater to the socio-economic needs of a city while A&GA would contribute to improved provisioning, regulating, and cultural services. From these projections, specific components were identified to have contributed more towards improving or decreasing the UER score among services. These include examples such as land use change which had effects across all the services. Other variables specific to the services include supply and demand for provisioning services, capacities for regulation, and land use for cultural services.

These insights obtained from the systems approach can be applied to better planning city development goals. According to the Philippine Development Plan of 2017–2022 (2017), most cities prioritize social welfare through economic growth, even in the context of vulnerability and disaster management. This type of prioritization seen from PDP were also visible in the contexts of Pasig City and Valenzuela City development. When compared to the cities' development goals, the scenarios implemented also brought about more co-benefits. It was observed that certain developments resulted in more synergistic relationships leading to increased co-benefits between services when a certain service is improved. This was in the case of increasing A&GA resulted in an increase in regulating capabilities such as natural pollutant removal, carbon sequestration, and average run-off coefficient value. The results of the different scenarios revealed specific variables which had more effect than others in the resilience score per service. Leverage points were identified across services as variables that, when changed, had a high corresponding change in system's behavior. These include consumption variables, population growth, emissions, treatment variables, and land use change for certain services.

The limitations for systems thinking include the need for reliable and consistent data to formulate a more comprehensive picture of the system in terms of connections and historical trends that potentially affect future directions. This meant to say that the model construction was only as robust as the data collected. Depending on the robustness and stringency, other sources outside of what the LGU provided were required to construct the model. With this caveat being considered, not all feedback mechanisms identified from the causal loop diagrams were included in the model due to said data availability and consistency. In addition, only measurable variables and links that could be translated into the stock-flow structure were considered—it was beyond the scope of this study to attempt to quantify "soft" variables. Despite having identified feedback mechanisms between the four categories in their respective sub-CLDs, not all could be translated to the stock-flow diagrams given the data limitations. These include feedback in between food consumption to increased waste generation. Given the data gaps in the local government units records, certain trade-offs were more developed than the rest. Literature from OECD (2017) also affirmed the challenge of information use and availability. given the difficulty in finding data, policy making often targets tangible and specific aspects of the system instead rather than complex problems given that it requires more resources sufficient data before actions can be rationalized (OECD, 2017). With that, fast-track decision making has become the norm given that it is easier to target issues that can be solved faster than complex issues that require more time and data collection to be understood in-depth.

Another limitation was in terms of the flexibility of models. These models were constructed based on an understanding of how the current system operates, and potential development scenarios are simulated by manipulating the parameters of the existing systems. Therefore, the data and understanding of a particular ecosystem service, which translated into the structure for the Business-As-Usual, was also the structure retained for the scenario development but with slight difference in certain values identified to have effects on the resilience score. Given this, while radical transformations in city systems are possible to model, it will require structural revisions to the model. For this, the LGU stakeholders may not be able to implement the changes themselves with the provided GUI but will need the assistance of someone with an expertise for SD and modelling. This supports the literature of OECD (2017) in terms of the boundaries of systems approach wherein models with abstract designs must be built on existing systems. The challenge proposed by this approach towards modelling would be in how to reform underlying systems while preserving core services.

5. Conclusion & Recommendations

In this study, the definition of Urban Ecosystem Resilience was developed from different resilience concepts which integrate certain components from Urban Resilience while capturing the ecological aspect from Socio-Ecological Resilience. UER was defined as the ability of a city to adapt and transform in face of socio-economic and demographic changes, as well as long-term hazards, in order to sustain delivery of all four types of UES in the long term to achieve sustainable development. This definition was applied to cities given that they complex systems with interconnected and interrelated processes, whose developments are driven by both socio-economic and urbanization drivers.

An ecosystems approach was applied in operationalizing this definition of resilience to form the Urban Ecosystem Resilience Index. The purpose of using an ecosystems approach was to provide a way to understand complex cities. This was done by comparing cities to natural systems given that they are both systems providing their own respective services. As there was a change in context, given that cities are a mix of both built and natural spaces, there was a need to redefine ecosystem services as urban ecosystem services. This allowed for the categorization of the UES based on similarities in dynamics of how these services are measured in a city. Mapping out the interrelation of the processes involved in the delivery of the different UES in a city system involved the use of the systems thinking method. The purpose was to be able to identify certain feedback mechanisms and trade-offs. This visually presented through the creation of the CLD for the different UES and the consolidated one to show interrelation among the different UES categories.

The concept from the CLD was translated into the stock-flow diagrams per urban ecosystem services as well as the respective population growth of both cities. The stock flow diagrams were made to measure whether the UES were optimal or sub-optimal in terms of meeting the city needs as a measure of UER. Therefore, each urban ecosystem service category had a resilience index which was linked to an UERI variable which computed for the overall score for each city and a self-sufficiency index as well.

The resilience and self-sufficiency scores per service were calculated as a ratio of a stock, flow, or an auxiliary variable, depending on which was representative of the scores. For the resilience index, this was normalized as the conditions of the supply and demand or meeting a set standard for a particular service. A score of 1 meaning optimal conditions and a score of below one depicting sub-optimal conditions in terms meeting a set standard or if supply can match the demand. Anything that scored more than 1 indicated a surplus of the delivery of the service. Next, the self-sufficiency index followed the logic of where the city sources it services. A score of 1 depicted that a particular service is all sourced within the city and a score below 1 depicted sourcing the service outside the city.

When applied to each of the 4 UES, the models for the provisioning services measured each index in terms of supply and demand, while the models for the regulating services measured them in terms of performance and capacity. The models for the cultural services measured them in terms of meeting a recommended or set standard, while the supporting services did not have an index due to being framed to ensure the other services are performing as intended. Finalizing all these resulted in the creation of the GUI for usage of relevant stakeholders.

This framework was then applied to the two cities to obtain and analyze the UERI values. Pasig City, under the Business-As-Usual scenario, had a minimum UERI value of 0.42 for the last year and a maximum of 0.3 for the year 2020. The trend was shown to increase until the maximum year and then resulted to a decrease until the last year of projection. As for the value of Valenzuela City UERI, the maximum value observed was 0.61 for the year 2032 while the minimum value was observed to be 0.42 for the year 2020. The trend observed for Valenzuela was similar with Pasig wherein the UERI value increased up until a certain year before decreasing over time. These values obtained for both Pasig and Valenzuela revealed that Pasig was more able to ensure delivery of services to its city as compared to Valenzuela city given that it had a higher value. This was due to the difference in the individual scores of their services which were affected both by the context and the resolution of data given. What led to a higher overall UERI for both cities were their provisioning scores. Similarly, both cities scored low for their regulating services. The cultural services differed in a sense that Valenzuela had more A&GA, while Pasig had more P&R resulting in the difference for their respective scores. However, UERI scores cannot be directly compared given the difference in contexts. Only observations that were common to both cities were mentioned. The difference in the year wherein the value peaked was attributed mostly to the land use change plan of the city. Without any available land to convert, no improvements would be seen in the UERI value under the Business-As-Usual scenario for both cities.

Applying the scenarios improved the overall UERI as they targeted specific services depending on what the cities chose to prioritize. Pasig City displayed an increase in its regulating service and cultural service given the addition of more A&GA as well as the RDF system. The overall impact was higher for the RDF given that it increased solid waste treated as well as improved electricity supply. The new maximum value for UERI under the Land Use and RDF Scenario was observed to be 0.75 at year 2020 while the lowest observed was 0.46 at year 2070. Valenzuela focused on flooding control and land use change to increase A&GA as well. The addition of siltation reduced the flood regulating service to show how much improvement could be derived from dredging activities. As for land use, more A&GA were converted for Valenzuela as compared to Pasig resulting in a higher improvement from the land use scenario for the regulating and cultural service of Valenzuela. Despite this, the changes were minimal when reflected in the UERI for both Land Use Scenarios given the low amount of available land left to convert. The new maximum Value for UERI under the Land Use and Siltation Scenario was observed to be 0.67 for the year 2024 while the new minimum value was observed to be 0.48 for the year 2070.

The results of the model provided insights on trade-offs among services as observed from the Business-As-Usual and the different scenarios. For both cities, the high provisioning score and low regulating score could be explained from the trade-off between consumption and waste. More consumption of services such as water resulted in higher wastes, resulting in a wider gap between emission and treatment for regulating services. Additionally, land-use showed among land use types. Given Pasig's prioritization towards built-up area, less land could be used for P&R and A&GA which improves both regulating and cultural services.

Aside from trade-offs, synergies were also seen such as the case of land use to all the other services given that it was considered a supporting service. Co-benefits were also derived as in the RDF scenario of Pasig City wherein an increase in treatment led to more RDF that could be used for electricity. Lastly, it was observed that population drives most demand for services. Based on the model, managing population growth would improve UERI for both cities, as well as initiatives on reducing consumption and emissions per capita.

Given these insights on the trade-offs and the performances of the UERI from both systems, the following recommendations for the cities were applied separately given difference in context and priorities. In terms of Pasig City, main recommendations would be to target reducing the emissions generated in the city. The city should also improve the capacity of regulating services such as wastewater treatment given that as water provisioning is increased, so do wastewater generated. Given this, the city should be balanced in prioritizing both provisioning and regulating given the observed trade-offs. Exploring new data sets under mobility, flooding, and land use can further enhance current models. These datasets involve indicators transportation capacity, flooding capacities, and records of actual amount of greenspace in the city. Streamlining these datasets would help in future model revisions.

As for Valenzuela City, improving resilience should explore enhancing not just provisioning but also regulating services given identified trade-offs. The city should implement policies in reducing the gap between emissions and the amount treated by regulating services either by targeting the components that lead more emissions or increasing treatment capacity. In the case of flooding which was mentioned to be a main issue in the city, recommendations would be to regulate the inflow of rainwater conveyed to the river given the low capacity allocated in the river to convey this rainwater. introducing flood control infrastructures such as pumping stations, dikes, and levees would help in regulating the inflow. The city could also apply small-scale siltation dredging to increase discharge capacity.

The limits of this approach as well as what could potentially improve the outputs of the obtained models was through improved data availability. While the models were completed given the data sets collected from each LGU and some NGAs, model development and construction revealed that there are some data sets, which, at present, are not mandated for collection by the LGUs, or are collected but not periodically. Therefore, a recommendation on the side of the local government units and national government agencies would be on if it would be feasible to institutionalize, regularize and streamline data collection to allow a faster and a more organized way of collection. Additionally, data sets should be organized and collected on a consistent basis in order to monitor changes more accurately. There also needs to be further coordination with NGAs and the respective LGUs so that the datasets are consistent between both agencies.

As such, specific components that would further refine the model include the following: bulk food supply and demand monitoring, water and electricity distribution and consumption, distribution of trees and grasses, species of trees and grasses, greenhouse gas inventories, indicators for modal shifts, riverside measurements, roadside air quality monitoring, and solid waste and wastewater monitoring mainly for capacities of treatment. Because mobility was framed as an input for emissions rather than as a sub-model itself, there needs to be a more in-depth study of constituent traffic flows, transport capacities and modal switches in order to have its own module.

Overall, this study applied a system dynamics and an ecosystems approach to a city context in order for their respective LGUs to operationalize resilience in terms of providing sustainable services. From the findings and results of the model, the overall strength was being able to operationalize resilience using a system dynamics approach and categorizing the specific goals of the LGUs into the 4 UES. This approach provides an avenue for capacity-building for relevant stakeholders to integrate systems thinking in policy formation for resilience planning in order to achieve development which is more sustainable. After all, a city that is not able to become resilient would result eventual system collapse when faced with demands it cannot meet and challenges it cannot overcome. The models developed can be utilized as decision-support tools for rationalizing investments towards integrative resilience planning that will help LGUs prepare, adapt, and transform amidst long-term hazards.

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Appendix

Appendix A. Indicator Selection

Appendix Table A1. Indicators of Ecosystem Services

Category	Urban Ecosystem Service	Indicator and Unit	Justification	Data Source

Provisioning	Food Supply	Food Security (Escamella, 2008)
		
		1. Household Income and Expenditure (monetary value or quantity of food consumed per capita).
		2. Individual's Dietary intake / Relative dietary supply index - average caloric over dietary energy requirement.
		3. Variability in annual food price
		4. Household Survey Data
		
		Peri-Urban Agriculture (Egoh, 2012)
		
		1. Production of food (t/year)
		    1. Crop Yield
		    2. Land Cover and Vegetation Maps
			Indicators were chosen for components of food security such as availability, accessibility, and utilization	NFA, FNRI, LGU

		CRI Indicators 1. Percentage of malnourished children under five 2. Proportion of population below minimum level of dietary energy consumption 3. Percentage of consumer spending on food at home as a proportion of income, of the poorest 20% of the population 4. Proportion of households with income below the food threshold (CBMS, F11) 5. Proportion of households that experienced food shortage (CBMS, F12) 6. Percentage of population which could be served by food reserves for 72 hours		
	Water	UN Indicators for Sustainable Development (Kettner et al., 2012). 1. Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water 2. BOD in Water Bodies Concentration of Faecal Coliform in Freshwater Water Availability (Babel, 2011): 1. Per capita water use for industrial, commercial, residential, and agricultural. 2. Number of people using improved water sources	Water supply is divided into two main parts mainly quantity and quality. The Indicators for Sustainable development assesses both aspects (Kettner et al., 2012). Indicators under water productions are used to compute for water demand (Trifunovic, 2002). Additionally, similar to food, water security is particularly focused on availability and accessibility as such indicators were chosen to show these components.	MWSS, MMDA, LGU, EMB

	3. Investment in water supply facilities
	4. Number of customers/Number of employees in water utility
	5. Types, Service Area (Public tap). How many is covered and supply and quality (Tap / Indoor).
	6. Total water consumption /City population
	7. Alternative water sources in the city such as greywater and rainwater.
	
	Water Production (Trifunovic, 2002)
	
	1. Common unit - for Water Consumption, Leakage, Production, and Demand: Cubic meters per hour (m^3/h) or liters per second (l/s)
	    1. Water use in various sectors
	    2. Domestic consumption
	    3. Non-domestic consumption
	    4. Commercial
	    5. Residential
	
	CRI Indicators
	
	1. Number of days that city fuel supplies could maintain essential household functions
	2. Proportion of households with access to potable water supply
	3. Average percentage of household income spent on potable water by the poorest 20 percent of the population
	4. Distance of household to water source		

	5. Percentage of population which can be supplied water by alternative methods for 72 hours during disruption		
Energy	Energy Sustainability (Kettner et al., 2012) 1. Gross inland energy consumption, by fuel 2. Electricity generated from renewable sources 3. Share of biofuels in fuel consumption of transport 4. Combined heat and power generation 5. Implicit tax rate on energy Renewable Energy 1. Increasing Share of Renewable Energy 2. Global Standards for Consumption 3. Frequency of Blackouts Electricity Consumption (Kettner et al., 2012) 1. Final energy consumption, by sector mainly industrial, commercial, and residential. 2. Motorisation rate Consumption and Energy Use (Kettner et al., 2012) 1. Annual Energy Consumption per Capita	Indicators were chosen based on consumption and sustainability of electricity (Kettner et al., 2012). Consumption and energy use serve as possible indicators for energy flows of the city ecosystem (Kettner et al., 2012). Similar to food and water, electrical provisioning indicators were chosen to show availability and accessibility of electricity within the city.	DOE, LGU,

		2. Share of Consumption of Renewable Energy Resources 3. Intensity of Energy CRI Indicators 1. Percentage of households spending more than 10% of their income on electricity 2. Number of days per year that households do not have electricity for the poorest 20 percent of the population 3. The average number of electrical interruptions per customer per year 4. Percentage of the population with electricity/ formally connected to the power grid 5. Number of days that city fuel supplies could maintain essential household functions		
	Housing (Habitat Provisioning)	**UN Indicators for Sustainable Development (Ketter et al., 2018).** 1. Number of Houses 2. Population 3. Floor Area per Person Housing Measures and Related Variables (Westfall, de Villa, 2001). 1. Dwelling type 2. Tenure type 3. House prices and rents, available area 4. Financing of house purchase	Indicators selected are used in studies to determine housing per individual and the factors that determine availability of these for people (Ketter et al., 2018; Westfall, de Villa, 2001). Similar to the other components of provisioning, indicators were chosen to show availability and accessibility of housing within the city.	CBMS, AIP, HLURB

		5. The production of new housing 6. Treatment of squatter settlements 7. Government expenditure 8. Informal Settlements CBMS 1. Proportion of households living in makeshift housing 2. Proportion of households who are squatters 3. Construction materials of walls & roof CRI Indicators 1. Percentage of houses which adhere to the national building code 2. Percentage of household income spent on housing 3. Percentage of household income spent on housing Provision of safe hazard shelter vs. perceived public demand		

Regulating	Climate Regulation	Carbon Data (Gómez -Baggethun and Barton, 2013):
		
		1. Carbon Storage/Sequestration Rate
		   1. tonnes/year
		   2. t C/ha*y
		2. Emission of GHGs per year/GHG Inventory per sector
		3. Vegetation Cover Rate of Change per Year
			Carbon Data and Adaptation help in determining regulation paired with air quality regulation. Urban Infrastructure and Anthropogenic disturbances increase vulnerability to climate-related hazards which is why indicators for adaptation are important to regulate	PAG-ASA, UHI, CMO, LCCAP, LGU

		Climate data 1. Historical Temperature 2. Historical Rainfall Climate Change Adaptation 1. Adaptive Capacity Measures of Green Space 2. Adaptive measures via infrastructure	climate-related events (Gómez -Baggethun and Barton, 2013).	
	Water Quality Regulation	Water Sewage 1. Amount of wastewater safely treated. 2. Amount of wastewater produced per capita 3. Amount of wastewater generated per sector. 4. Amount of wastewater Treatment Facilities 5. Pollution Retention Rate Related to Sanitation (PSA, nd) 1. Household with access to sanitary toilets 2. Type of toilet facility (unimproved sanitation includes toilets that do not flush to septic tanks or sewage system) 3. Percentage of population which can be served by alternative methods of sanitation during disruption	Infrastructure in coastal cities obstruct natural waterways. Quantification of water regulation using wastewater quality coupled with amount of waste from the supporting ES determine water quality for water provisioning and buffers for climate change-related risks such as floods (Bolund and Hunhammar, 1999). Water waste management facilitates water quality in lieu of natural ecosystems which can filter our pollution and retain nutrients. These indicators are selected to see the treatment rates in correlation with water regulation to see if treatment rates and if solid waste	CLUP, MWSS, LGU, LLDA

	4. Number of years since the city's wastewater contingency plan was updated Sponge City Concept for Water Flow 1. Rainwater Treatment Facilities 2. Green roofs 3. Greywater Treatment Facilities. 4. Dikes and Levees in City 5. Natural impermeable surfaces 6. Land Cover Maps for Flood Obstruction	production rates outweigh water flow (Bolund and Hunhammar, 1999)	
Air Quality Regulation	Natural Air Regulation 1. Vegetation Cover Rate of Change per Year 2. Urban Cooling Rate (Amount of cooling units per household) Other Useful Indicators 3. Traffic Data (such as traffic time, time spent on road,	Indicators used depict regulation of air quality in terms of filtration through vegetation from possible urban sources (UNEP, 2010; Gómez -Baggethun and Barton, 2013, 2012).	

	Solid Waste Management	Waste Management (EPA/UN) 1. Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities 2. National recycling rate, tons of material recycled, and sold. 3. Service Coverage 4. Number of MWF in the city and amount of trash treated. 5. Generation of Industrial and Municipal Solid Waste (segregated into types and sources) 6. Proximity of city to landfill	Waste Management facilitates water quality in lieu of natural ecosystems which can filter our pollution and retain nutrients. These indicators are selected to see the treatment rates in correlation with water regulation to see if treatment rates and if solid waste production rates outweigh water flow (Bolund and Hunhammar, 1999) Solid Waste management indicators were chosen similar to water in order to measure waste produced and recycling rate per city. These were chosen based on availability of data (ADB, 2010).	CBMS, CLUP, MMDA

Cultural	Stress Levels and Mental Health	Recreation (Gómez-Baggethun and Barton, 2013; La Rosa, 2015) 1. Average time spent on recreational activities 2. Number Recreational facilities	Indicators are divided into two based on different studies: recreation and physical health (Gómez-Baggethun and Barton, 2013; Ketter et al., 2012; La Rosa, 2015). Recreational indicators were chosen to be common among many cultural services literature (La Rosa, 2015). Selection of sustainable development indicators is used to assess health conditions in a city (Ketter et al., 2012). Hospital network system was used as an indicator in a study done by ADB as a proxy to assessing health conditions (Westfall, de Villa, 2001).	PHILHEALTH, AIP, CLUP, LGU, DOH

Supporting	Available Land	UN Indicators for Sustainable Development (Kettner, 2012) 1. Area of Urban Formal and Informal Settlements (as a percentage of city area) Land Resource Indicators (Hasse, Lathrop, 2003) 1. Urban Density in Residential, Industrial, and Commercial (From Density Index - Percent Population Change) 2. Area of Greenspace 3. Impervious Surface (Surface area changes over time) CRI Indicators: 1. Jobs/housing ratio 2. Green area (hectares) per 100,000 population	Land Resource Impact was used to determine indicators associated with Urban Sprawl which is a prominent driver of Land use change. (Hasse, Lathrop, 2003).	CBMS, CLUP, CDP, AIP

	Mobility	Sustainable Indicators for Travel (Tafidis, et al., 2017) 1. Traffic Congestion 2. Road Density 3. Daily or annual passenger-km by private vehicles 4. Private Car Ownership 5. Transportation Expenditure 6. Capacity of Transportation Facilities	Sustainable indicators for mobility include indicators that have available data from city governments (Tafidis, et al., 2017). Long term observations for indicators that are related to population and land use change were chosen using this criteria as well.	LGU, MMDA, PSA, PAG-ASA

	Alternative Water Sources	UN Indicators for Sustainable Development (Kettner et al., 2012) and Water Availability.
		1. Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water
		2. Precipitation Collection Infrastructure
		3. Investment in water treatment facilities
		4. Total water consumption /City population
		5. Alternative water sources in the city such as greywater and rainwater.
		
		Water Production (Trifunovic, 2002)
		6. Common unit - for Water Consumption, Leakage, Production, and Demand: Cubic meters per hour (m^3/h) or liters per second (l/s)
		    1. Water use in various sectors
		    2. Domestic consumption
		    3. Non-domestic consumption
		    4. Commercial
		    5. Residential
			Water supply is divided into two main parts mainly quantity and quality. The Indicators for Sustainable development assesses both aspects (Kettner et al., 2012). Indicators under water productions are used to compute for water demand (Trifunovic, 2002). Additionally, alternative water sources aim to provide additional water provisioning aside from the regular means of the city to provide water to its citizens.	NWRB, MWSS, Water Management Office

Appendix B. NGAs and LGUs Consulted

Appendix Table B1. List of Valenzuela Offices Consulted

Office	Key Informant	Document Received	Data Sets	Questions Asked for Key Informant
City Planning and Development Office (CPDO)	Ms. Josefina Acurentes	1. Comprehensive Land Use Plan. 2. Comprehensive Development Plan. 3. Socio-Ecological Profile.	1. Fractions of Land Use in Hectares. 2. Conversion Rates of each Land Use Type. 3. Annual Consumption Electricity per Sector.	1. Why did you remove the Agriculture and Greenspace Category in the second CLUP? 2. What development will you focus on for the following years? 3. How is flooding addressed in the city? 4. What are the main issues towards resilience? 5. How is resilience defined by the city?
Solid Waste Management Office (SWMO)	Ms. Marietta Antonio	1. 10-Year Solid Waste Management Plan 2. Environmental Compliance Audit (ECA) 2016 – 2020	1. EWG per Capita 2. Collection Efficiency 3. Fraction of Residuals, Compostables, Recyclables 4. Amount of Treated Compostables and Recyclables 5. Amount Recycled 6. Amount Compostables 7. Target Diversion	1. How many functional MRSs and MRFs are there in the city? 2. Where are the MRFs located? Do you have a map? 3. How much do garbage trucks collect? Do they collect everday? 4. What is the narrative pathway of waste for the city? 5. How much from the waste collected are compostables, recyclables, residuals, or other wastes? 6. How much of those segregated actually get composted, recycled, and dumped in the landfills?

				7. Is the target diversion retained through the years? 8. Are there any landfills in the city that are operational?
Flood Management Division (FMD)	Engr. Joselito Cantilon	1. Master Drainage Plan	1. Discharge capacity of flood control infrastructure.	1. Are there existing flood control mechanisms in the city? 2. What agencies help with flood control in the city? 3. Does the city monitor the effects of siltation and trash in the flow of the rivers? 4. Are there any plans to improve flood regulation? If so, how are these reflected in the development plans?
Agriculture and Veterinary	Dr. Basil Sison	1. Excerpts from the Socio-Ecological Profile.	1. Average Yield of Rice, Fruits, and Vegetables. 2. Distribution of agricultural produce for the overall agricultural land.	1. What are the major agricultural produce in the city? 2. Any set requirements for allocation on land for urban farming? 3. Does the city promote livestock? 4. What is the major type of farming in the city? 5. Are there plans to improve urban farming in the future?
Cultural Affairs and Tourism Development Office (CATDO)	Mr. King Utiera	1. Development Plans for Existing Recreational Areas	1. Total Hectarage of Recreational Area for Parks, Sports, and Playgrounds.	1. Does the city plan to add more recreational spaces in the future? 2. Are there any existing tourism development plans in the city? 3. What potential spaces will be converted towards recreational sites?

				4. Any existing measures of cultural benefits in the city?
City Environmental & Natural Resource Office	Engr. Rommel Pondevida	1. Urban Greening Plan	1. Total Hectarage for Greenspace in the city.	1. What are the major species of trees in the city? 2. Are there equipment to measure air and carbon emissions in the city? 3. What standards are used to compare observed air and carbon emissions? 4. What is the frequency of monitoring for emissions and effluents in the city? 5. What are the future plans to improve and reduce both emissions and effluents in the city?
City Health Office	Dr. Jaime Exconde Jr.	1. Project TIMBANG results.	1. Annual number of underweight and super underweight before and after feeding program.	1. How does the city address issues of malnutrition and food loss? 2. Are there any other programs that target issues on caloric and nutritional deficiency? 3. What is the frequency of feeding programs in the city?

Appendix Table B2. List of Pasig Offices Consulted

Office	Key Informant	Document Received	Data Sets	Questions Asked for Key Informant
City Planning and Development Office (CPDO)	Engr. Romelo Palermo	1. Comprehensive Land Use Plan. 2. Comprehensive Development Plan.	1. Fractions of Land Use in Hectares. 2. Conversion Rates of each Land Use Type.	1. What development will you focus on for the following years? 2. How is flooding addressed in the city? 3. What are the main issues towards resilience? 4. How is resilience defined by the city? 5. Are there plans to introduce more greenspace in the city? 6. Are there plans for urban farming in the city?
Cultural Affairs and Tourism Office (CATO)	Ms. Malou Gonzales	1. Development Plans for Existing Recreational Areas	1. Total Hectarage of Recreational Area for Parks, Sports, and Playgrounds.	1. Does the city plan to add more recreational spaces in the future? 2. Are there any existing tourism development plans in the city? 3. What potential spaces will be converted towards recreational sites? 4. Any existing measures of cultural benefits in the city?

City Environmental & Natural Resource Office (CENRO)	Mr. Allendri B. Angeles	1. Solid Waste Management Plan 2. Greenhouse Gas Inventory 3. Environmental Compliance Audit (ECA) 2020	1. Total Hectarage for Greenspace in the city. 2. Annual Electrical Consumption 3. EWG per Capita 4. Collection Efficiency 5. Fraction of Residuals, Compostables, Recyclables 6. Amount of Treated Compostables and Recyclables 7. Amount Recycled 8. Amount Compostables 9. Target Diversion	1. What are the major species of trees in the city? 2. Are there equipment to measure air and carbon emissions in the city? 3. What standards are used to compare observed air and carbon emissions? 4. What is the frequency of monitoring for emissions and effluents in the city? 5. What are the future plans to improve and reduce both emissions and effluents in the city? 6. Is there any way to measure GHG or has there been a study conducted on how to calculate it? 7. How many functional MRFs are there in the city? 8. How much do garbage trucks collect? Do they collect everyday? 9. What is the narrative pathway of waste for the city? 10. How much from the waste collected are compostables, recyclables, residuals, or other wastes?

				11. How much of those segregated actually get composted, recycled, and dumped in the landfills? 12. Is the target diversion retained through the years? 13. Are there any landfills in the city that are operational? 14. Are you planning to do anything with the residual waste?
City Health Office	Dr. Georgina Galutera	1. Project TIMBANG results.	1. Annual number of underweight and super underweight before and after feeding program.	1. How does the city address issues of malnutrition and food loss? 2. Are there any other programs that target issues on caloric and nutritional deficiency? 3. What is the frequency of feeding programs in the city?

Appendix Table B3. List of NGAs Consulted

Office	Key Informant	Document Received	Data Sets	Questions Asked for Key Informant
Manila Water Company, Inc.	Sir. David Co and Sir. John Von Dela Cruz	1. Water Reports	1. Annual Consumption of Water disaggregated per Sector. 2. Annual Supply of Water. 3. Annual volume of treated sewage and septage. 4. Annual sewage connections in the city. 5. Frequency of desludging. 6. Number and capacity of treatment plants.	1. Where does Pasig source there water from? 2. What are the main determinants of water loss in the city? 3. Are there plans to address the growing water shortages? 4. What is the capacity of sewage connections? How much volume is treated per year? 5. What is the frequency of desludging in the city? How much volume is treated per year? 6. What is the acceptance rate for desludging in the city? 7. Are there plans for constructing new sewage treatment plants in the city? Will this increase the number of sewage connections as well?

Maynilad Water Services Inc.	Engr. Erwin Batalla and Sir. Jefferson Garza	1. Water Reports	1. Annual consumption of water disaggregated per sector. 2. Annual supply of water. 3. Annual volume of treated sewage and septage. 4. Annual sewage connections in the city. 5. Frequency of desludging. 6. Number and capacity of treatment plants.	1. Where does Valenzuela source there water from? 2. What are the main determinants of water loss in the city? 3. Are there plans to address the growing water shortages? 4. What is the capacity of sewage connections? How much volume is treated per year? 5. What is the frequency of desludging in the city? How much volume is treated per year? 6. What is the acceptance rate for desludging in the city? 7. Are there plans for constructing new sewage treatment plants in the city? Will this increase the number of sewage connections as well?

Flood Control & Sabo Engineering Center (FCSEC – DPWH).	Sir. Harold Uyap	1. Master Plan for Flood Management in Metro Manila and Surrounding Areas. 2. Flood maps of Pasig and Valenzuela River Bodies.	1. Design discharge capacity 2. Existing drainage capacity 3. Rainfall Intensity Distribution Frequency 4. Datasets to compute for the Manning's coefficient. 5. Slope of the area.	1. How is urban flooding framed and measured in cities? 2. What flood control infrastructures are being built to address flooding in the city? 3. What are the main determinants of urban flooding? 4. What are the main determinants of dampened river flow?
Metropolitan Manila Development Authority Effective Flood Control Operation System (EFCOS)	Engr. Capistrano	1. Flood Maps 2. Water Level Data	1. Rainfall Intensity Distribution Frequency 2. Map of Flood Control Mechanisms 3. Diversion Capacity of Flood Control Mechanisms.	1. How is urban flooding framed and measured in cities? 2. What flood control infrastructures are being built to address flooding in the city? 3. What are the main determinants of urban flooding? 4. What are the main determinants of dampened river flow? 5. When does the city divert floodwater?

Appendix C. Valenzuela City Sub-Model Variables

Appendix Table C1. Valenzuela Population Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Source
Population	Total number of populations	Stock	Population Growths Initial: 568928	People	PSA Census, 2000; 2015 (PSA, 2013)
Population Growth	Number of people added to population	Flow	Population*Population Growth Rate	People/Year	Computed
Population Growth Rate	Rate of population growth	Constant	Exponential Growth Formula	1/Year	PSA Census 2000; 2015 (PSA, 2013)

Appendix Table C2. Valenzuela Water Sub-Model Variables

Variable	Description	Type	Value	Unit	Data Source	Notes
Total Recommended Supply for Water	Total of recorded domestic consumption and maximum recorded industrial and commercial consumption to derive recommended supply	Auxiliary	Maximum Industrial and Commercial Consumption+Recommended Domestic Consumption	m3/Year	Computed	
Maximum Industrial and Commercial Consumption	Maximum recorded industrial and commercia consumption (not disaggregated)	Constant	2.10007e+06	m3/Year	Maynilad Report (Batalla, 2020)	Recorded maximum from year 2019. No disaggregated data available.
Resilience Score for Recommended Water Supply	Ratio between current maximum supply and recommended water supply.	Auxiliary	Current Maximum Water Supply/Total Recommended Supply for Water	Dmnl	Computed	

Recommended Domestic Consumption	Total recommended water consumption	Auxiliary	Recommended Water Consumption per Capita*Population	m3/Year	Computed	
Current Maximum Supply	Recorded maximum supply	Constant	3.50012e+07	m3/Year	Maynilad Report (Batalla, 2020)	
Recommended Water Consumption per Capita	Water subsistence level per year.	Constant	51.1	m3/(People*Year)	Basic Household Water Requirements (Inocencio, 1999)	
Non-Residential Consumption Growth Rate	Computed non-residential consumption growth rate.	Constant	0	1/Year	Computed	Assumed to be 0 at BAU; Slider for LGU to use
Annual Average Water Bill for Commercial and Industrial Establishment	Average industrial and commercial water consumption volume.	Flow	Averaged Billed Industrial and Commercial+("Non-Residential Consumption Growth Rate"*Averaged Billed Industrial and Commercial)	m3	Computed	
Average Billed Industrial and Commercial	Recorded average recorded billed industrial and commercial volume.	Auxiliary	1.87649e+06	m3/Year	Maynilad Report (Batalla, 2020)	

Total Billed Domestic Consumption	Computed total billed domestic consumption.	Auxiliar y	Population*Recorded Consumption per Capita	m3/Year	Computed	
Average Domestic Water Consumption	Average domestic water consumption in the city.	Flow	Total Billed Domestic Consumption	m3/Year	Computed	
Water Supplied to Valenzuela City	Total water supplied to Valenzuela city.	Flow	Average Water Supply-"Average Non-Revenue Water"	m3/Year	Computed	
Average Water Supply	Recorded average water supply.	Constan t	5.14262e+07	m3/Year	Maynilad Report (Batalla, 2020)	Yearly average used.
Average Non-Revenue Water	Non-revenue observed.	Constan t	2.34656e+07	m3/Year	Maynilad Report (Batalla, 2020)	Average based on 2017 – 2019 data.
Recorded Consumption per Capita	Recorded consumption per capita.	Auxiliar y	48.9477	m3/People/Year	Maynilad Report (Batalla, 2020)	Based on 2017 – 2019 data.
Valenzuela Water Reserves	Total Valenzuela water for consumption.	Stock	Water Supplied to Valenzuela City-Average Domestic Water Consumption-Average Industrial and Commercial Water Consumption Initial: 0	m3	Computed	

Appendix Table C3. Valenzuela Electricity Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Current Maximum Electricity Supply	Recorded current maximum electricity supply of the city.	Constant	1.08e+09	kwh/(People*Month)	Socio-Ecological Profile (Acurentes, 2018)	From the recorded consumption of 2016.
Resilience Score for Recommended Electrical Supply	Ratio between current maximum electrical supply and total recommended supply for electricity.	Auxiliary	Current Maximum Electricity Supply/Total Recommended Electrical Supply	Dmnl	Computed	
Total Recommended Electrical Supply	Total recommended electrical supply of the city.	Auxiliary	Commercial Electrical Consumption+Industrial Electrical Consumption+Recommended Domestic Electrical Consumption+Streetlight Electrical Consumption	kwh/Year	Computed	
Recommended Domestic Electrical Consumption	Total recommended domestic electrical consumption of the city.	Auxiliary	Recommended Electrical Consumption per Capita*Population	kwh/Year	Computed	

Recommended Electrical Consumption per Capita	Recommended electrical consumption per capita.	Constant	600	kwh/(People*Year)	Worldbank Study (Kojima et al., 2016)	Month value multiplied by 12 to obtain yearly per capita.
Industrial Electrical Consumption	Total industrial electrical consumption of the city.	Flow	Maximum Industrial Electrical Consumption+(Maximum Industrial Electrical Consumption*Growth Rate for IEC)	kwh/Year	Computed	
Growth Rate for IEC	Growth rate of industrial electrical consumption.	Constant	0.3986	1/Year	Socio-Ecological Profile (Acurentes, 2018)	Based on the trend of historical data between 2008 - 2016.
Maximum Industrial Electrical Consumption	Recorded maximum industrial electrical consumption in the city.	Constant	9.83909e+08	kwh	Socio-Ecological Profile (Acurentes, 2018)	Maximum value used from year 2016.
Commercial Electrical Consumption	Total commercial electrical consumption in the city.	Flow	Maximum Commercial Consumption + (Maximum Commercial Consumption*Growth Rate for CEC)	kwh/Year	Computed	
Maximum Commercial Consumption	Recorded maximum commercial consumption in the city.	Constant	1.8612e+08	kwh	Socio-Ecological Profile (Acurentes, 2018)	Maximum value used from year 2016.

Growth Rate for CEC	Growth rate for commercial electrical consumption.	Constant	0.44068	1/Year	Socio-Ecological Profile (Acurentes, 2018)	Based on the trend of historical data between 2008 - 2016.
Growth Rate for SC	Growth rate for streetlight consumption	Constant	0.46212	1/Year	Socio-Ecological Profile (Acurentes, 2018)	Based on the trend of historical data between 2008 - 2016.
Maximum Streetlight Consumption	Maximum observed streetlight consumption among the years	Constant	4.51824e+06	kwh	Socio-Ecological Profile (Acurentes, 2018)	Maximum value used from year 2016.
Streetlight Electrician Consumption	Total electrical consumption for streetlight	Flow	Maximum Streetlight Consumption+(Maximum Streetlight Consumption*Growth rate for SC)	kwh	Computed	

Appendix Table C4. Valenzuela Food Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Source	Notes
Remaining Agricultural Area	Total land area of agricultural purposes	Stock	Equation: -Fruit Production Growths-Rice Production Growth-Vegetable Production Growths Initial: 133.4	Ha	Computed	
Area for Fruit Production	Total land area for agricultural purposes, mainly fruit	Stock	Equation: Fruit Production Growths Initial: Total Agricultural Area of 2015*Fraction of Area for Fruit Production Initial: 8.12	Ha	Computed	
Area for Rice Production	Total land area for agricultural purposes, mainly rice	Stock	Equation: Rice Production Growth Initial: Total Agricultural Area of 2015*Fraction of Area for Rice Production Initial: 10.9	Ha	Computed	
Area for Vegetable Production	Total land area of agricultural purposes, mainly vegetable	Stock	Equation: Vegetable Production Growths Initial: Total Agricultural Area of 2015*Fraction of Vegetable Area Initial: 6.9	Ha	Computed	

Vegetable Production Growths	Area for vegetable production	Auxiliary	MIN (Remaining Agricultural Area*Function Unit Converter, Area for Vegetable Production*Vegetable Production Growth Rates)	MT/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	Based on land conversion and reported land use data from 2015-2018.
Fruit Production Growths	Area for fruit production	Auxiliary	MIN (Remaining Agricultural Area*Function Unit Converter, Area for Fruit Production*Fruit Production Growth Rates)	MT/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	Based on land conversion and reported land use data from 2015 – 2018.
Rice Production Growths	Area for rice production	Auxiliary	MIN(Remaining Agricultural Area*Function Unit Converter, Rice Production Growth Rate*Area for Rice Production)	MT/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	Based on land conversion and reported land use data from 2015 – 2018.
Productivity per Hectare for Vegetable and Fruit Production per Mos	Based on Estimates from Ecological Profile	Constant	2	MT/(Month*Ha)	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017)	

Mos-Year Converter	Month to year converter.	Constant	12	Month/Year	Conversion Unit	
Total Yield for Fruit MT per Year	Total yield for fruits per year	Auxiliary	Area for Fruit Production*"Mos-Year Converter"*Productivity per Hectare for Vegetable and Fruit Production per Mos	MT/Year	Computed	
Total Yield for Vegetable MT per Year	Total yield for vegetables per year	Auxiliary	Area for Vegetable Production*"Mos-Year Converter"*Productivity per Hectar for Vegetable and Fruit Production per Mos	MT/Year	Computed	
Self Sufficiency Score for Fruits and Vegetables	Ratio between total fruit and vegetables requirement and total yield for fruit per year.	Auxiliary	(Total Yield for Fruit MT per Year+Total Yield for Vegetable MT per Year)/Total Fruits and Vegetables Requirement	Dmnl	Computed	
Total Fruits and Vegetable Requirement	Sum of total requirements needed for the whole population per year	Auxiliary	Population*Recommended Fruits and Vegetables per Capita per Day*Day to Year Converter	MT/Year	Computed	
Day to Year Converter	Coverts day to years.	Constant	365	Day/Year	Conversion Unit	
Recommended Fruits and Vegetables per Capita per Day	Standard for fruit and vegetable consumption	Constant	0.0004	MT/People/Day	Global Strategy on Diet (WHO, 2003)	

Rice Production Growth Rate	Growth rate of agricultural land for rice	Constant	-0.0719	1/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	
Fruit Production Growth Rate	Growth rate of agricultural land for fruits	Constant	0.0676	1/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	
Vegetable Production Growth Rates	Growth rate of agricultural land for vegetables	Constant	0.0621	1/Year	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	
Fraction of Vegetable Area	Multiplier to total land to derive land area devoted for vegetables	Constant	0.195978	Dmnl	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	
Fraction of Area for Fruit Production	Multiplier to total land to derive land area devoted for fruits	Constant	0.23	Dmnl	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	Based on land conversion and reported land use data from 2015.

Fraction of Area for Rice Production	Multiplier to total land to derive land area devoted for rice	Constant	0.31	Dmnl	Socio-Ecological Profile (Acurentes, 2018; Sison, 2017).	Based on land conversion and reported land use data from 2015.
Rice Productivity per Hectare for Rice per Mos	Productivity of rice per hectare.	Constant	5.68	MT/(Ha*Month)	Precision Agriculture (Tallada, 2019)	Productivity per month.
Total Yield for Rice MT per Year	Total rice production per year	Auxiliary	Productivity per Hectar for Rice per Mos*Area for Rice Production*"Mos-Year Converter"	MT/Year	Computed	
Self Sufficiency Score for Rice	Ratio between total recommended rice and total rice yield.	Auxiliary	Total Yield for Rice MT per Year/Total Rice Requirements	Dmnl	Computed	
Total Rice Requirements	Total rice required for whole population per year	Auxiliary	Population*Rice Consumption per Capita per Year	MT/Year	Computed	
Rice Consumption per Capita per Year	Rice consumption per capita.	Constant	0.119	MT/(People*Year)	Precision Agriculture (Tallada, 2019)	Factors in the yearly time step.

Resilience Score for Caloric Intake	Ratio of total population and population categorized as normal.	Auxiliary	(Population-UW and SUW)/Population	Dmnl	Computed	
Fraction of UW and SUW	Fraction of total population categorized as UW & SUW.	Constant	$1.64*10^{-3}$	Dmnl	City Health Office Summary Report for Operation Timbang, 2015 - 2018	
Prevalence Rate	Prevalence rate of UW and SUW	Constant	0.139845	1/Year	City Health Office Summary Report for Operation Timbang, 2015 - 2018	
UV and SUW	Total number of UW and SUW in Valenzuela city.	Stock	"UW & SUW Growths"-After Feeding Programs Initial: 0	People	Computed	
UV and SUW Growths	UW AND SUW from total population.	Flow	Fraction of UW and SUW*Population*Prevalence Rate	People/Year	Computed	

After Feeding Programs	UW & SUW becoming normal.	Flow	"Average Fraction of UW & SUW to Normal"*UW and SUW	People/Year	Computed	
Average Fraction of UW & SUW to Normal	Fraction of the population categorized as UW & SUW that become normal category after feeding program.	Constant	0.8	1/Year	City Health Office Summary Report for Operation Timbang, 2015 - 2018	

Appendix Table C5. Valenzuela Solid Waste Management Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Sources	Notes
Amount of Uncollected Waste	Total uncollected waste.	Stock	Uncollected Waste Initial: 0	kg	Computed	No account for uncollected.
Uncollected Waste	Waste categorized as uncollected waste.	Flow	Generated Waste*(1-Collection Efficiency)	kg/Year	Computed	
Collection Efficiency	Collection efficiency for waste in Valenzuela city.	Constant	0.9	Dmnl	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	
Collection from Generated	Total collected waste.	Flow	Collection Efficiency*Generated Waste	kg/Year	Computed;	
Generated Waste	Total generated waste.	Auxiliary	Day to Year Converter*EWG per Year*Population	kg/Year	Computed; 10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	

EWG per Year	Estimated waste generated per capita per year.	Constant	0.35	kg/People/Day	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	
Self – Sufficiency for SWM	Ratio between total amount of waste diverted and generated waste.	Auxiliary	(Composting+Waste Recycling)/Generated Waste	Dmnl	Computed	
Target Diversion	Target diversion of the city.	Constant	0.55	Dmnl	Summarized WACS Report (MMDA, 2019)	Percentage of generated waste that should be diverted.
Resilience Score for SWM	Ratio between total amount of waste diverted and actual diverted waste.	Auxiliary	(Composting+Waste Recycling)/(Generated Waste*Target Diversion)	Dmnl	Computed	
Recyclable Fraction	Fraction of collected	Constant	0.38	1/Year	10-Year Solid Waste Management	Based on the Environmental Compliance

	waste that are recyclable.				Plan (Antonio M. , Solid Waste Management Plan, 2009)	Audit of each barangay.
Segregating Recyclables	Amount of recyclables segregated.	Flow	Collected Waste*Recyclable Fraction	kg/Year	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	
Collected Waste	Total amount of collected waste.	Stock	Collection from Generated-" Segregating Biodegradable & Compostable"-Recyclable Segregating Recyclables-Segregating Residuals Initial: 6.54125e+07	kg	Computed	
Segregating Residuals	Amount of residuals segregated.	Flow	Collected Waste*Residual Fraction	kg/Year	Computed	
Residual Fraction	Fraction of collected waste that are residual.	Auxiliary	0.16	1/Year	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste	Based on the Environmental Compliance Audit of each barangay.

					Management Plan, 2009)	
Amount of Residuals	Total amount of residual.	Stock	Segregating Residuals Initial: 0	kg	Computed	
Amount of Recyclables	Total amount of recyclables.	Stock	Segregating Recyclabes-Waste Recycling Initial: : 2.48568e+07	kg	Computed	
Recycled Wastes	Total amount of recycled waste.	Stock	Waste Recycling Initial: 0	kg	Computed	
MRF Operation Hours	Operating hours of MRF.	Constant	1	1/Year	Computed	Assumed to operate all the time based on the solid waste management office.
Waste Recycling	Amount of waste recycled.	Flow	MIN (Amount of Recyclables*MRF Operating Hours, Amount Recycled per Year)	kg/Year	Computed	
Amount Recycled per Year	Capacity for recycling of the city.	Constant	4.4927e+06	kg/Year	Waste ECA (Antonio M. , 2020)	
Bio & Compost Fraction	Fraction of generated waste are biodegradable	Constant	0.46	1/Year	10-Year Solid Waste Management Plan (Antonio M. , Solid	Based on the Environmental Compliance Audit of each barangay.

	and compostable.				Waste Management Plan, 2009)	
Segregating Compostables	Amount of biodegradable and compostable segregated.	Flow	Collected Waste*"Bio & Compost. Fraction"	kg/Year	Computed	
Amount of Compostable	Total amount of compostable.	Stock	"Biodegradable & Compostable Segragation"-Composting Initial: 3.00898e+07	kg	Computed	
Composting	Amount composted.	Auxiliary	MIN (MRF Operating Hours*Amount of Compostables, Amount Composted per Year)	kg/Year	Computed	
Amount Composted per Year	Capacity for composting in the city.	Constant	44679	kg/Year	Waste ECA (Antonio M. , 2020)	
Composted Waste for Fertilizer	Total amount of composted waste.	Stock	Composting Initial: 0	kg	Computed	Used as fertilizer.

Appendix Table C6. Valenzuela Wastewater Sub-Model

Variable	Definition	Type	Method of Analysis	Unit	Data Sources	Notes

Household Connection Growth Rate	Rate of new households connected per year	Constant	0.014	1/Year	Maynilad Water Report (Garza, 2020)	
Households Connections	Households connected per year.	Flow	MIN (Household Connection Growth Rate*Households Connected to Sewerage, Population Growth Rate*Households Connected to Sewerage)	House/Year	Computed	
Households Connected to Sewerage	Total households connected to sewerage.	Stock	Household Connections Initial: 0	House	Computed	No recorded connections for sewerage lines.
Average People per Household	Observed average number of people per household.	Constant	5	People	CLUP (Valenzuela City Government, 2018)	
Population Connected to Sewerage Lines	Total population connected to sewerage lines.	Auxiliary	Average Number per Household*Households Connected to Sewerage	People	Computed	

Population Not Connected to Sewerage Lines (PNCSL)	Total population not connected to sewerage lines.	Auxiliary	Population-Population Connected to Sewerage Lines	People	Computed	
Water consumed by PNCSL	Total wastewater produced from population not connected to sewerage lines.	Auxiliary	"Population Not Connected to Sewerage Lines (PNCSL)"*Residential Water Consumption per Capita per Year	m3/Year	Computed	Residential water consumption based on water provisioning service.
Water consumed by PCSL	Total wastewater produced from population connected to sewerage lines.	Auxiliary	Population Connected to Sewerage Lines*Residential Water Consumption per Capita per Year	m3/Year	Computed	Residential water consumption based on water provisioning service.
Infiltration Rate	Infiltration rate of wastewater.	Constant	1.15	Dmnl	Maynilad Water Report (Garza, 2020)	Part of the empirical equation used in computing for wastewater.

WW as Septage	Wastewater categorized as septage.	Auxiliary	Infiltration Rate*WW Consumed by PNCSL*WW Generation Coefficient	m3/Year	Computed	
WW Generation Coefficient	Percentage of wastewater from water consumed.	Constant	0.8	Dmnl	Maynilad Water Report (Garza, 2020)	Part of the empirical equation used in computing for wastewater.
WW as Sewage	Wastewater categorized as sewage.	Auxiliary	Infiltration Rate*WW Consumed by PNCSL*WW Generation Coefficient	m3/Year	Computed	
Untreated WW Septage	Total untreated wastewater for septage.	Auxiliary	WW as Septage-"Treated (Desludged) Septage"	m3/Year	Computed	
Treated (Desludged) Septage	Total treated wastewater as septage.	Auxiliary	Acceptance Rate for Desludging*Frequency of Desludging*WW as Septage	m3/Year	Computed	
Frequency of Desludging	Frequency of desludging done in the city.	Constant	1/5	Year	Maynilad Water Report (Garza, 2020)	
Treated Sewage	Total treated wastewater as sewage.	Auxiliary	WW as Sewage	m3/Year	Computed	

Acceptance Rate for Desludging	Acceptance rate of desludging services in the city.	Constant	0.6	1/Year	Maynilad Water Report (Garza, 2020)	
Resilience Score for WW	Ratio between treated wastewater and generated wastewater.	Auxiliary	("Treated (Desludged) Septage"+Treated Sewage)/Total WW Generated	Dmnl	Computed	
Total WW Generated	Total wastewater generated by the city.	Auxiliary	WW as Septage+WW as Sewage	m3/Year	Computed	
Self-Sufficiency for WW	Ratio between total generated wastewater and treated sewage.	Auxiliary	Treated Sewage/Total WW Generated	Dmnl	Computed	

Appendix Table C7. Valenzuela Air Quality Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Ug to g converter	Microgram to gram converter.	Constant	1e-06	g/ug	Conversion Unit	
Average Roadside Air Quality Concentration	Computed average roadside air quality concentration.	Constant	55	ug/m3	National Air Quality Status Report 2008 – 2015 (DENR-EMB, 2015)	
Average PM2.5 Road Emissions	Observed average PM2.5 roadside emissions.	Auxiliary	Average Roadside Air Quality Concentration*Volume of Valenzuela City*ug to g converter	g	Computed	Standard observed for Metro Manila.
PM2.5 Emissions Dispersed per Year	Natural PM2.5 emissions removed per year.	Auxiliary	"PM2.5 in McArthur Highway"-"Average PM2.5 Roadside Emissions"	g	Computed	
Volume of Valenzuela City Air Shed	Total volume of Valenzuela City.	Auxiliary	Area of Valenzuela*km3 to m3 Converter*Mixing Height of Metro Manila	m3	Computed	Computed using box model.
Km3 to m3 Converter	Cubic kilometer to cubic meter converter.	Constant	1e+09	m3/(km2*km)	Unit converter	
Area of Valenzuela	Total land area of Valenzuela city.	Constant	47.02	km2	CLUP (Valenzuela City Government, 2018)	

Mixing Height of Metro Manila	Observed mixing height of Metro Manila.	Constant	1.635	km	Tubal et al., 2002	Applies to Valenzuela city. Characterized as summertime, midday height.
g to ug converter	Grams to micrograms converter.	Constant	1e+06	ug/g	Conversion Unit	
Concentration of PM2.5	Total PM2.5 concentration in the city.	Auxiliary	("PM2.5 in McArthur Highway"*g to ug converter)/Volume of Valenzuela City	ug/m3	Computed	
Resilience Score for Air Quality	Ratio between concentration of PM2.5 and air quality standard,	Auxiliary	Air Quality Standard/"Concentration of PM2.5"	Dmnl	Computed	
Air Quality Standard	Standard for PM2.5 concentration in an area.	Constant	35	ug/m3	DAO No. 2013 – 13 (DENR EMB, 2013)	
Natural Dispersion Rate	Natural PM2.5 removal rate.	Constant	1	1/Year	Computed	Assumed to happen all the time; Accounts for seasonal and natural dispersion and dry and

						wet deposition.
Kilometer Travelled for McArthur Highway	Total KM travelled for McArthur Highway.	Constant	6.7	km/cars	Google Earth	
Average Car per day for McArthur Highway	Average number of cars in McArthur highway.	Constant	33812	Cars/Day	Metropolitan Manila AADT (MMDA, 2018)	
Total Annual VKT of Cars in McArthur Highway	VKT from KM and number of cars.	Auxiliary	Average Car per Day for McArthur Highway*Day to Year Converter*Kilometers Travelled for McArthur Highway	km/Year	Computed	
Emission Factor for McArthur Highway	Emission factor for McArthur Highway.	Constant	0.0965424	g/km	Computed	Applied to all. Uses fleet data in the empirical formula derived from the vehicle composition of the selected road.

Fugitive Dust from Cars	Total fugitive dust from cars.	Flow	Emission Factor for McArthur Highway*VKT of Cars in McArthur Highway	g/Year	Computed	
Fugitive Dust from PUB	Total fugitive dust from PUB.	Flow	Emission Factor for McArthur Highway*VKT for PUB in McArthur Highway	g/Year	Computed	
Fugitive Dust from PUJ	Total fugitive dust from PUJ.	Flow	Emission Factor for McArthur Highway*VKT for PUJ in McArthur Highway	g/Year	Computed	
Total Annual VKT for PUJ in McArthur Highway	VKT from KM and number of PUJ.	Auxiliary	Average PUJ per Day for McArthur Highway*Day to Year Converter*Kilometers Travelled for McArthur Highway	km/Year	Computed	
Average PUJ per Day for McArthur Highway	Average number of PUJ in McArthur highway.	Constant	9568	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT for PUB in McArthur Highway	VKT from KM and number of PUB.	Auxiliary	Average PUB per Day for McArthur Highway*Day to Year Converter*Kilometers Travelled for McArthur Highway	km/Year	Computed	

Average PUB per Day for McArthur Highway	Average number of PUB for McArthur highway.	Constant	2233	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
PM2.5 in McArthur Highway	Total PM2.5 emissions in McArthur highway.	Stock	Fugitive Dust from Cars+Fugitive Dust from PUB+Fugitive Dust from PUJ-"Natural PM2.5 Removal"-Pollutant Removal Initial: 1.093e+07	g	Computed	Partial assessment as it only considers three main vehicle types.
Pollutant Removal by A&GA	Total PM2.5 emission removed by agriculture and greenspace area.	Flow	MIN(Agricultural and Greenspace Area in m2*"Removal Rate of PM2.5","PM2.5 in McArthur Highway"*Function Unit Converter)	g/Year	Computed	
Natural PM2.5 Removal	Total PM2.5 emissions removed naturally.	Flow	MIN("PM2.5 Emissions Removed per Year"*Rate Naturally Removed per Year,"PM2.5 in McArthur Highway"*Function Unit Converter)	g/Year	Computed	
Agricultural and Greenspace Area in m2	Total land area of A&GA in square meters.	Auxiliary	"Agricultural and Greenspace Area (A&GA)"*Ha to m2 Converter	m2	Computed	

Ha to m2 Converter	Hectare to square meters converter.	Constant	10000	m2/Ha	Unit converter	
Removal Rate for PM2.5	Removal rate per hectare of A&GA.	Constant	1.79	g/m2/Year	Urban Forestry & Urban Greening (Selmi, 2016)	

Appendix Table C8. Valenzuela Carbon Emission Regulation Sub-Model Variables

Variable	Description	Type	Values	Unit	Data Source	Notes
Emission Factor for BOD River Discharge	Emission factor for river discharge.	Constant	0.06	kg/kgBOD	GHG Inventory (Pasig City Government, 2014)	
River Discharge CH4 Emissions	Total CH_4 from river discharge.	Auxiliary	Emissions Factor BOD River Discharge*Untreated WW Septage*BOD per WW Generated	kg/Year	Computed	
WW Generated per Year	Total wastewater generated per year.	Auxiliary	Infiltration Rate*Residential Water Consumption per Capita per Year*WW Generation Coefficient	m3/(People*Year)	Computed	
BOD per WW Generated	Conversion between volume to BOD.	Auxiliary	Per Capita BOD Generation per Year/WW Generated per Capita per Year	kgBOD/m3	Computed	Derived from multiple literature.
Septic Tank CH4 Emissions	Total CH_4 emissions for septic tank.	Auxiliary	Emissions Factor BOD Septic*WW as Septage*BOD per WW Generated	kg/Year	Computed	

Emission Factor BOD Septic	Emission factor for septic tank wastewater.	Constant	0.3	kg/kgBOD	GHG Inventory (Pasig City Government, 2014)	
Per Capita BOD Generation per Year	BOD generated per capita per year	Constant	14.6	kgBOD/(People*Year)	GHG Inventory (Pasig City Government, 2014)	
Emission Factor BOD Sewage	Emission factor for sewage waste.	Constant	0.6	kg/kgBOD	Maynilad Water Report (Garza, 2020)	
Sewage CH4 Emissions	Total CH_4 emissions for sewage.	Auxiliary	Emission Factor BOD Sewerage*WW as Sewage*BOD per WW Generated	kg/Year	Computed	
Septic Tank CH4 Emissions	Total CH_4 emissions from septic tank wastewater.	Auxiliary	Emissions Factor BOD Septic*WW as Septage*BOD per WW Generated	kg/Year	Computed	
CH4 Emissions (WW)	Total CH_4 for all wastewater.	Auxiliary	(River Discharge CH4 Emissions+Septic Tank CH4 Emissions+Seweage CH4 Emissions)*kg to MT Converter	tCH4/Year	Computed	Only considers septic tank wastewater, sewage, and river discharged wastewater.

Kg to MT Converter	Kilogram to metric ton converter.	Constant	1/1000	tCH4/kg	Conversion Unit	
CH4 Generated	Total CH_4 generated from all sources.	Auxiliary	"CH4 Emissions (SWM)"+"CH4 Emissions (WW)"	tCH4/Year	Computed	
DOC Yard Waste	DOC factor for yard waste.	Constant	0.43	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Total DOC of Yard Waste	Total DOC from yard waste.	Auxiliary	DOC Yard Waste*Fraction of Yard Waste	GgC/Gg	Computed; GHG Inventory (Pasig City Government, 2014)	
Fraction of Yard Waste	Fraction of compostable that are yard waste.	Constant	0.142857	Dmnl	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	
Fraction of Food Waste	Fraction of compostable that are food waste.	Constant	0.5	Dmnl	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste	

					Managemen t Plan, 2009)	
Total DOC of Food Waste	Total DOC from food waste.	Auxiliary	DOC of Food Waste*Fraction of Food Waste	GgC/Gg	Computed; GHG Inventory (Pasig City Government, 2014)	
DOC of Food Waste	DOC factor of food waste.	Constan t	0.16	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Fraction of Clothes and Textiles	Fraction of compostable that are clothes and textiles.	Constan t	0.214286	Dmnl	10-Year Solid Waste Managemen t Plan (Antonio M. , Solid Waste Managemen t Plan, 2009)	
DOC of Clothes and Textiles	DOC factor for clothes and textiles.	Constan t	0.4	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Total DOC of Clothes and Textiles	Total DOC from clothes and textiles.	Auxiliary	DOC of Clothes and Textiles*Fraction of Clothes and Textiles	GgC/Gg	Computed	

Total DOC of Rubber and Leather	Total DOC from rubber and leather.	Auxiliary	DOC of Rubber and Leather*Fraction of Rubber and Leather	GgC/Gg	Computed	
Fraction of Rubber and Leather	Fraction of compostable that are rubber and leather.	Constan t	0.142857	Dmnl	10-Year Solid Waste Managemen t Plan (Antonio M. , Solid Waste Managemen t Plan, 2009)	
DOC of Rubber and Leather	Total DOC from rubber and leather.	Constan t	0	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Degradable Organic Carbon (DOC)	Total generated DOC from all compostable waste.	Auxiliary	Total DOC of Clothes and Textiles+Total DOC of Food Waste+Total DOC of Rubber and Leather+Total DOC of Yard Waste	GgC/Gg	Computed; GHG Inventory (Pasig City Government, 2014)	
kg to Gg Converter	kg to Gg converter.	Constan t	1e-06	Gg/kg	Conversion Unit	
Fraction of Degraded Organic Carbon Dissimilated (DOCf)	Fraction of DOCf	Constan t	0.77	Dmnl	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	Standard provided for developing countries from IPCC.

Fraction of CH4 in Landfill (F)	Fraction of CH_4 in selected landfill.	Constant	0.5	Dmnl	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	Standard provided for developing countries from IPCC.
Methane Correction Factor	Methane correction factor used in empirical equation.	Constant	0.4	GgCH4/GgC	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	Standard provided for developing countries from IPCC.
Methane Generation Potential	Total potential methane generated.	Auxiliary	("Degradable Organic Carbon (DOC)"*"Fraction of Degraded Organic Carbon Dissimilated (DOCf)"*"Fraction of CH4 in Landfill (F)"*Methane Correction Factor)*(16/12)	GgCH4/Gg	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	
Recovered CH4	Recovered CH_4 from landfill if any.	Constant	0	GgCH4/Year	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, &	None for the chosen landfill.

					Pipatti, 2016)	
Oxidation Factor	Oxidation factor if open landfill.	Constant	0	Dmnl	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	Landfill is sanitary and maintained.
Fraction Disposed to SWDS (MSWf)	Fraction of all compostable waste disposed to landfill.	Constant	1	1/Year	10-Year Solid Waste Management Plan (Antonio M. , Solid Waste Management Plan, 2009)	
CH4 Emissions (SWM)	Total CH_4 emissions from SWM.	Auxiliary	(("Compostables in Gg (MSWt)"*"Fraction Disposed to SWDS (MSWf)"*Methane Generation Potential)-Recovered CH4)*(1-Oxidation Factor)*Gg to MT Converter	tCH4/Year	Computed	
Gg to MT Converter	Gigagrams to metric tons converter.	Constant	1000	tCH4/GgCH4	Conversion Unit	
CH4 Emissions from SWM and WW	Total CH_4 emissions from SWM and WW.	Stock	CH4 Generated-"Methane Decay (WW)" Initial: 0	tCH4	Computed	

Methane Decay	Total Methane decay.	Flow	"CH4 Emissions from SWM & WW"*Decay Rate	tCH4/Year	Computed	
Decay Rate	Decay rate of Methane.	Constan t	0.07701	1/Year	Tubal et al., 2002	
Emissions from Waste	Converter of Methane into $tCO2_e$	Auxiliary	("CH4 Emissions from SWM & WW")*CH4 GWP per Year	tCO2e/Year	Computed	
CH4 GWP	Global warming potential of CH_4	Constan t	25	tCO2e/tCH4/Year	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	
Resilience Score for Carbon	Ratio between total $tCO2_e$ emissions and Carbon sequestration.	Auxiliary	Carbon Sequestration/CO2e Emission	Dmnl	Computed	
Sequestratio n Rate per Ha per Year of Grassland	Sequestration based on hectarage per year.	Constan t	8	tCO2e/(Year*Ha)	Urban Forestry & Urban Greening (Selmi et al., 2016)	
CO2e Emission	Total $tCO2_e$ emissions generated	Flow	Electrical tCO2e+Mobility tCO2e+tCO2e from WW and SWM	tCO2e/Year	Computed	

Carbon Emissions for Valenzuela	Total $tCO2_e$ emissions in Valenzuela city.	Stock	CO2e Emission-Carbon Sequestration Initial: 0	tCO2e	Computed	
Carbon Sequestration	Total amount of $tCO2_e$ sequestered.	Flow	"Agricultural and Greenspace Area (A&GA)"*Sequestration per Year	tCO2e/Year	Computed	
tCO2e for PUB	Total $tCO2_e$ emissions from PUB.	Auxiliary	Carbon Emission Factor For PUB*(VKT for PUB in Marcos Highway+"VKT for PUB (Shaw)"+"VKT for PUB in C-5"+VKT for PUB in Ortigas)	g/Year	Computed	
Carbon Emission Factor for PUB	Emission factor for PUB.	Constant	12.4	g/km	GHG Inventory (Pasig City Government, 2014)	
tCO2e for PUJ	Total $tCO2_e$ emissions for PUJ.	Auxiliary	Carbon Emission Factor for PUJ*(VKT for PUJ in Marcos Highway+"VKT for PUJ in C-5"+"VKT for PUJ (Shaw)"+VKT for PUJ in Ortigas)	g/Year	Computed	
Carbon Emission Factor for PUJ	Emission factor for PUJ.	Constant	2.5	g/km	GHG Inventory (Pasig City Government, 2014)	

tCO2e for Cars	Total $tCO2_e$ emissions for cars.	Auxiliary	Carbon Emission Factor for Cars*(VKT of Cars in Marcos Highway+"VKT of Cars in C-5"+VKT of Cars in Ortigas+VKT of Cars in Shaw Blvd)	g/Year	Computed	
Carbon Emission Factor for Cars	Emissions factor for Cars.	Constan t	49.5	g/km	GHG Inventory (Pasig City Government, 2014)	
Emissions from Transport	Total emissions from automobiles.	Auxiliary	(tCO2e for PUB+tCO2e for Cars+tCO2e for PUJ)*g to tons converter	tCO2e/Year	Computed	Only considered three main vehicle types mainly PUB, PUJ, and private cars.
g to tons converter	Grams to tons converter.	Constan t	1e-06	tCO2e/g	Conversion Unit	
Emissions from Electricity	Total emissions from electricity consumption.	Auxiliary	"Average Aggregate Consumption per Year (kWh)"*Electrical Consumption Emission Factor*"kWh - MWh Conversion"	tCO2e/Year	Computed	

Electrical Consumption Emission Factor	Electrical consumption emission factor.	Constant	0.5192	tCO2e/mwh	GHG Inventory (Pasig City Government, 2014)	
kWh to mWh Conversion	Kilowatts per hours to megawatts per house conversion.	Constant	1/1000	mwh/kwh	Conversion Unit	

Appendix Table C9. Valenzuela River Rainwater Conveyance Sub-Model Variables

Variable	Description	Type	Value	Units	Data Source	Notes
Resilience Score for River Rainwater Conveyance	Ratio between Additional Rainwater Conveyed and Surface Run-Off.	Auxiliary	Additional Rainwater Conveyed/"Surface Run-Off"	Dmnl	Computed	Does not consider natural discharge, only surface run-off conveyed.
Surface Run-Off	Total surface run-off.	Auxiliary	("Average Run-Off Coefficient"*RIDF* Valenzuela Land Area)/Flood Equation Constant	(m*m*m)/Year	Computed	
Flood Equation Constant	Based on Empirical Formula used to convert values.	Constant	3.6	Dmnl	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	
Valenzuela Land Area	Total land area of Valenzuela city.	Constant	47.02	m*m	CLUP (Valenzuela City Government, 2018)	
RIDF	Rainfall data for 50-year return period	Constant	107.233	m/Year	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	Based on typhoon Ondoy level event
Valenzuela Land Area in Ha	Converted land area	Auxiliary	km2 to Ha*Valenzuela Land Area	Ha		

Km2 to Ha	Square kilometer to hectare converter.	Auxiliary	100	Ha/(m*m)	Unit converter	
Annual Sediment Yield	Total sediment yield per year	Auxiliary	Estimated Annual Sediment Suspension Load*Valenzuela Land Area in Ha	MT/Year	Computed	
Estimated Annual Suspension Load	Annual sediment suspension load per hectares	Constant	0.48	MT/Ha/Year	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	
Sediment-Conveyance Conversion	Conversion to MT for sediment	Auxiliary	0.47/8774.4	Year/MT	Computed (Rate of Sediment Yield (Tukur & Olofin, 2013))	Converted based on literature from the effects of MT to discharge capacity.
Fraction Silted	Fraction of discharge capacity silted	Auxiliary	Annual Sediment Yield*"Sediment-Conveyance Conversion"	Dmnl	Computed	
Additional Rainwater Conveyed	Capacity to discharge rainfall surface run-off	Auxiliary	(Design Discharge Capacity-Normal Discharge Capcity)*(1-Fraction Silted)	(m*m*m)/Year	Computed	

Design Discharge Capacity	Designated discharge to account for rainfall induced surface run-off	Constant	520	m*m*m/Year	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	
Normal Discharge Capacity	Natural discharge capacity of the river	Constant	400	m*m*m/Year	Computed	Computed outside model using Manning's Equation from JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)

Appendix Table C10. Valenzuela Land Use Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Source	Notes
Total Land Area	Total Land Area for Pasig	Constant	4459.41	Ha	CLUP (Valenzuela City Government, 2018)	
Available Land (AL)	Total Available Land / Convertible Land	Stock	Total Land Area*Fraction of AL Initial: 919.3	Ha	CLUP (Valenzuela City Government, 2018)	
Parks and Recreations (P&R)	Total Parks and Recreations Area	Stock	Total Land Area*"Fraction of P&R" Initial: 13.34	Ha	CLUP (Valenzuela City Government, 2018)	
Roads (R)	Total Roads	Stock	Total Land Area*Fraction of R Initial: 295	Ha	CLUP (Valenzuela City Government, 2018)	
Built – up Area (BuA)	Total Built-up Area	Stock	Total Land Area*Fraction of BUA Initial: 2673.8	Ha	CLUP (Valenzuela City Government, 2018)	
Agricultural and Greenspace Area (A&GA)	Total Agriculture and Greenspace Area	Stock	Total Land Area*"Fraction of A&GA" Initial: 557.9	Ha	CLUP (Valenzuela City Government, 2018)	
Conversion of AL to R	Available land converted to R	Flow	MIN("Roads (R)"*Conversion Rate of AL to R,"Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	

Conversion of AL to A&GA	Available land converted to A&GA	Flow	MIN("Conversion Rate of AL to A&GA"*"Agricultural and Greenspace Area (A&GA)","Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion of AL to BUA	Available land converted to BUA	Flow	MIN("Built-up Area (BUA)"*Conversion Rate of AL to BUA,"Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion of AL to P&R	Available land converted to P&R	Flow	MIN("Parks and Recreations (P&R)"*"Conversion Rate of AL to P&R","Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion Rate of AL to R	Actual conversion rate observed from AL to R	Constant	0.0626799	1/Year	CLUP (Valenzuela City Government, 2018)	Based on 2009 to 2018 land conversion.
Conversion Rate of AL to P&R	Actual conversion rate observed from AL to P&R	Constant	-0.0122262	1/Year	CLUP (Valenzuela City Government, 2018)	Based on 2009 to 2018 land conversion.
Conversion Rate of AL to BUA	Actual conversion rate observed	Constant	-0.00737976	1/Year	CLUP (Valenzuela City Government, 2018)	Based on 2009 to

	from AL to BUA					2018 land conversion.
Conversion Rate of AL to A&GA	Actual conversion rate observed from AL to A&GA	Constant	0.36491	1/Year	CLUP (Valenzuela City Government, 2018)	Based on 2009 to 2018 land conversion.
Fraction of A&GA	Fraction of initial total land area as A&GA	Constant	0.00512	Dmnl	CLUP (Valenzuela City Government, 2018)	Based on 2009 land use plan.
Fraction of P&R	Fraction of initial total land area as P&R	Constant	0.00299143	Dmnl	CLUP (Valenzuela City Government, 2018)	Based on 2009 land use plan.
Fraction of BUA	Fraction of initial total land area as BUA	Constant	0.599591	Dmnl	CLUP (Valenzuela City Government, 2018)	Based on 2009 land use plan.
Fraction of AL	Fraction of initial total land area as AL	Constant	0.326151	Dmnl	CLUP (Valenzuela City Government, 2018)	Based on 2009 land use plan.
Fraction of R	Fraction of initial total land area as R	Constant	0.0661522	Dmnl	CLUP (Valenzuela City Government, 2018)	Based on 2009 land use plan.
C constant for AL	Surface run-off Coefficient for AL	Constant	0.25	Dmnl	Manual of Flood Control Planning, 2003	

C value for AL	C value for land use type	Auxiliary	("Available Land (AL)"/Total Land Area*100)*C constant for AL	Dmnl	Computed	
C constant for BUA	Surface Run-off Coefficient for BUA	Constant	0.55	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for BUA	C value for land use type	Auxiliary	("Built-up Area (BUA)"/Total Land Area*100)*C constant for BUA	Dmnl	Computed	
C constant for A&GA	Surface Run-off Coefficient for A&GA	Constant	0.2	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for A&GA	C value for land use type	Auxiliary	("Agricultural and Greenspace Area (A&GA)"/Total Land Area*100)*"C constant for A&GA"	Dmnl	Computed	
C constant for P&R	Surface Run-off Coefficient for P&R	Constant	0.25	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for P&R	C value for land use type	Auxiliary	("Parks and Recreations (P&R)"/Total Land Area*100)*"C constant for P&R"	Dmnl	Computed	

C constant for R	Surface Run-off Coefficient for R	Constant	0.75	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for R	C value for land use type	Auxiliary	("Roads (R)"/Total Land Area*100)*C constant for R	Dmnl	Computed	
Average Run-off Coefficient	Average of all C values for different land use type	Auxiliary	("C value for A&GA"+C value for BUA+C value for AL+"C value for P&R"+C value for R)/100	Dmnl	Computed	Computed using the whole land area of Valenzuela city.
Actual Agricultural Area	Disaggregated land from A&GA	Auxiliary	Agricultral to Greenspace Area Ratio*"Agricultural and Greenspace Area (A&GA)"	Dmnl	CLUP (Valenzuela City Government, 2018)	
Agricultural to Greenspace Area Ratio	Actual ratio between agricultural and greenspace land area.	Constant	0.239181	Dmnl	CLUP (Valenzuela City Government, 2018)	Derived from Land Area for Greenspace and Land Area for Agricultural Use
Function Unit Converter	Unit Converter	Constant	1	1/Year	Conversion Unit	

Appendix Table C11. Valenzuela Cultural Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Source	Notes
Resilience Score for Recommended Greenspace	Ratio between current and recommended greenspace in Valenzuela city.	Auxiliary	"Agricultural and Greenspace Area (A&GA)"/Recommended Greenspace Supply	Dmnl	Computed	
Recommended Greenspace Supply	Total greenspace required for population per year	Auxiliary	Population*Recommended Greenspace per Capita	Ha	Computed	
Recommended Greenspace per Capita	Recommended greenspace per capita value.	Constant	0.00095	Ha/People	WHO-UN, 2020	
Recommended Recreational Spaces Supply (Only for Sports and Playgrounds)	Total recreational space required for sports and playgrounds	Auxiliary	(Population*"Population per 1,000 Converter")*"Recommended Recreational Spaces (Only for Sports and Playgrounds)"	Ha	Computed	
Recommended Recreational Spaces (Only for Sports and Playgrounds)	Recommended recreational space per capita for sports and playgrounds.	Constant	0.5	Ha/People	CLUP (Valenzuela City Government, 2018), Guidebook Volume 2 for Designing Resilience	

Recommended Recreational Spaces Supply (Only for Parks)	Total recreational space required for parks	Auxiliary	(Population*"Population per 1,000 Converter")*"Recommended Recreational Spaces (Only for Parks)"	Ha	Computed	
Recommended Recreational Spaces (Only for Parks)	Recommended recreational space per capita for parks.	Constant	0.05	Ha/People	CLUP (Valenzuela City Government, 2018), Guidebook Volume 2 for Designing Resilience	
Resilience Score for Recommended Sports and Playgrounds.	Ratio between current and recommended sports and playgrounds in the city.	Auxiliary	"Parks and Recreations (P&R)"/"Recommended Recreational Spaces Supply (Only for Sports and Playgrounds)"	Dmnl	Computed	
Resilience Score for Recommended Parks	Ratio between current and recommended parks in the city.	Auxiliary	"Parks and Recreations (P&R)"/"Recommended Recreational Spaces Supply (Only for Parks)"	Dmnl	Computed	
Population per 1,000 Converter	Population converter	Constant	1/1000	Dmnl	Conversion Unit	

Appendix D. Pasig City Sub-Model Variables

Appendix Table D1. Pasig Population Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Population	Total number of populations	Stock	Population Growths Initial: 701054	People	PSA Census 2000; 2015 (PSA, 2013)	
Population Growth	Number of people added to population	Flow	Population*Population Growth Rate	People/Year	Computed	
Population Growth Rate	Rate of population growth	Constant	Exponential Growth Formula	1/Year	PSA Census 2000; 2015 (PSA, 2013)	

Appendix Table D2. Pasig Waster Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Pasig City Water Reserves	Total water supply per year	Stock	Water Supplied to Pasig-Total Commercial Consumption-Total Domestic Consumption-Total Industrial Consumption Initial: 0	m3	Computed	
Total Commercial Consumption	Total commercial consumption volume.	Flow	Average Billed Commercial+(Average Billed Commercial*Commercial Growth Rate)	m3/Year	Computed	
Annual Average Water Bill for Commercial Establishments	Recorded average billed commercial consumption volume.	Constant	9.54619e+06	m3	Manila Water Report (Co, 2020)	
Commercial Growth Rate	Observed consumption growth rate.	Constant	0	1/Year	Computed	Derived from 2007 – 2018 data sets.
Total Industrial Consumption	Disaggregated consumption per sector per year	Flow	Average Billed Industrial	m3/Year	Computed	
Annual Average Water	Recorded average billed industrial	Auxiliary	3.00187e+06	m3	Co, 2020	

Bill for Billed Establishments	consumption volume.					
Industrial Consumption Growth Rate	Observed industrial consumption growth rate.	Constant	0	1/Year	Computed	Derived from 2007 – 2018 data sets.
Total Domestic Consumption	Disaggregated consumption per sector per year	Flow	Total Water Consumed	m3/Year	Computed	
NRW Fraction	Observed non-revenue water from net supply.	Constant	0.0786	Dmnl	Manila Water Report (Co, 2020)	
Water Supplied to Pasig	Volume of water supplied to Pasig city.	Flow	"Average Total Water Supplied (2019 Data)"*(1-NRW Fraction)	m3/Year	Computed	
Average Total Water Supplied (2019 Data)	Recorded average water supplied per year.	Auxiliary	2.39255e+07	m3/Year	Manila Water Report (Co, 2020)	
Resilience Score for Recommended Water Supply	Ratio between current maximum water supply and total recommended water supply.	Auxiliary	Current Maximum Water Supply/Total Recommended Supply for Water	Dmnl	Computed	

Recommended Water Consumption per Capita	Recommended water consumption per capita.	Constant	51.1	m3/People/Year	Basic Household Water Requirements (Inocencio, 1999)	
Recommended Water Consumption	Total recommended water consumption.	Auxiliary	Recommended Water Consumption per Capita*Population	m3/Year	Computed	
Maximum Industrial Consumption	Maximum recorded industrial consumption.	Constant	3.71646e+06	m3/Year	Manila Water Report (Co, 2020)	Obtained from year 2018 consumption data set.
Maximum Commercial Consumption	Maximum recorded commercial consumption.	Constant	1.03323e+07	m3/Year	Manila Water Report (Co, 2020)	Obtained from year 2018 consumption data set.
Current Maximum Water Supply	Maximum recorded water supplied to Pasig.	Constant	5.22512e+07	m3/Year	Manila Water Report (Co, 2020)	Obtained from year 2018 consumption data set.

Appendix Table D3. Pasig Electricity Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Total Recommended Supply for Electricity	Total recommended electrical supply of the city.	Auxiliary	Recommended Electrical Consumption per Capita*Population	kwh/Year	Computed	
Recommended Electrical Consumption per Capita	Recommended electrical consumption per capita.	Constant	600	kwh/People/Year	Worldbank Study (Kojima et al., 2016)	
Current Maximum Electricity Supply	Recorded current maximum electricity supply of the city	Constant	1.08e+09	kwh/Year	GHG Inventory for Pasig City (2012)	Obtained from 2012 data set.
Resilience Score for Recommended Electricity Supply	Ratio between current maximum electrical supply and total recommended supply for electricity.	Auxiliary	Current Maximum Electricity Supply/(Total Recommended Supply for Electricity-Energy Derived from RDF)	Dmnl	Computed	
Energy Derived from RDF	Total energy produced from RDF.	Auxiliary	"MWH per RDF (in MT)"*MWH to kWH*RDF Consumables Produced	kwh/Year	Computed	0 in BAU scenario

MWh per RDF (in MT)	Energy derived from RDF.	Constant	4	mwh/MT	RDF to Electricity (Thirugnanam & Pragasam, 2013)	
MWh to kWh	Megawatts per house to kilowatts per house converter.	Constant	1000	kwh/mwh	Conversion unit	
RDF Consumables Produced	Total number of RDF produced.	Auxiliary	kg to MT*RDF for Electrical Usage	MT/Year	Computed	
kg to MT	Kilogram to metric tons converter.	Constant	1/1000	MT/kg	Conversion Unit	

Appendix Table D4. Food Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Fraction of Population with UW and SUW	Fraction from total population categorized as UW & SUW.	Constant	Fraction of Population with UW and SUW*Population	People	City Health Office Summary Report for Operation Timbang, 2015 - 2018	Earliest date was 2015.
Population Categorized as UW or SUW	Number of People UW and SUW.	Auxiliary	0.0137	People	Computed	
Resilience Score for Caloric Intake	Ratio between total population and population categorized as normal.	Auxiliary	(Population-Population Categorized as UW or SUW)/Population	Dmnl	Computed	

Appendix Table D5. Pasig Solid Waste Management Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Sources	Notes
Amount of Uncollected Waste	Total uncollected waste.	Stock	Uncollected Waste Initial: 0	kg	Computed	
Uncollected Waste	Waste categorized as uncollected waste.	Flow	Generated Waste*(1-Collection Efficiency)	kg/Year	Computed	
Collection Efficiency	Collection efficiency for waste in Pasig city.	Constant	0.9	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
Collection from Generated	Total collected waste.	Flow	Collection Efficiency*Generated Waste	kg/Year	Computed	
Generated Waste	Total generated waste.	Auxiliary	Day to Year Converter*EWG per Year*Population	kg/Year	Computed	
EWG per Year	Estimated waste generated per capita per year.	Constant	0.5	kg/People/Day	10-Year Solid Waste Management Plan (Angeles, 2012)	
Self – Sufficiency for SWM	Ratio between total amount of waste diverted and generated waste.	Auxiliary	Total Amount Diverted/Generated Waste	Dmnl	Computed	

Total Amount Diverted		Auxiliary	Composting+Waste Recycling+Residuals	kg/Year	Computed	
Target Diversion	Target diversion of the city.	Constant	0.55	Dmnl	Solid Waste Management Plan (Angeles, 2012)	Percentage of generated waste that should be diverted.
Target Diversion from Generated Waste		Auxiliary	Generated Waste*Target Diversion Fraction		Computed	
Resilience Score for SWM	Ratio between total amount of waste diverted and actual diverted waste.	Auxiliary	Total Amount Diverted/Target Diversion from Generated Waste	Dmnl	Computed	
Recyclable Fraction	Fraction of collected waste that are recyclable.	Constant	0.4267	1/Year	Solid Waste Management Plan (Angeles, 2012)	Based on the Environmental Compliance Audit of each barangay.
Segregating Recyclables	Amount of recyclables segregated.	Flow	Collected Waste*Recyclable Fraction	kg/Year	Computed	

Collected Waste	Total amount of collected waste.	Stock	Collection from Generated-Segregating Compostables-Segregating Recyclables -Segregating Residuals Initial: 1.15148e+08	kg	Computed	
Segregating Residuals	Amount of residuals segregated.	Flow	Collected Waste*Residual Fraction	kg/Year	Computed	
Residual Fraction	Fraction of collected waste that are residual.	Constant	0.1382	1/Year	Solid Waste Management Plan (Gonzales, 2012)	Based on the Environmental Compliance Audit of each barangay.
Amount of Residuals	Total amount of residual.	Stock	Segregating Residuals-Residuals Initial: 1.59135e+07	kg	Computed	
Residuals	Residuals for RDF.	Flow	MIN (Maximum Capacity of RDF Facility per Year, Amount of Residuals*Function Unit Converter)	kg/Year	Computed	
Waste for RDF	Total residuals collected for RDF.	Stock	Residuals-Shredding Initial: 0	kg	Computed	

Shredding	Treated residuals.	Flow	RDF Fraction*Waste for RDF*Function Unit Converter	kg/Year	Computed	
RDF Produced	Total amount of RDF produced.	Stock	Shredding Initial: 0	kg	Computed	
RDF For Electrical Usage	RDF to be used for electricity provisioning.	Auxiliary	RDF Fraction*Residuals	kg/Year	Computed	
Residual Fraction	Fraction of residuals from collected waste.	Constant	0.3	Dmnl	Pasig City Government, 2015	
Maximum Capacity of RDF Facility per Year	Maximum capacity of RDF facility.	Constant	0	kg/Year	Pasig City Government, 2015	0 for the BAU Scenario
Amount of Recyclables	Total amount of recyclables.	Stock	Segregating Recyclables-Waste Recycling Initial: 4.91337e+07	kg	Computed	
Recycled Wastes	Total amount of recycled wastes.	Stock	Waste Recycling Initial: 0	kg	Computed	
MRF Operating Hours	Operating hours of MRF.	Constant	1	1/Year	Pasig City Government, 2020	Assumed to be operating all year if when not given a time frame

Waste Recycling	Amount of waste recycled.	Flow	MIN (Amount of Recyclables*MRF Operating Hours, Amount Recycled per Year)	kg/Year	Computed	
Amount Recycled per Year	Capacity of the city for recycling.	Constant	1.3e+07*4	kg/Year	Waste ECA (Angeles, 2020)	
Compostables Fraction	Fraction of compostable from generated waste.	Constant	0.4351	1/Year	Solid Waste Management Plan (Gonzales, 2012)	Based on the Environmental Compliance Audit of each barangay.
Segregating Compostables	Amount of segregated compostable.	Flow	Collected Waste*"Bio & Compost. Fraction"	kg/Year	Computed	
Amount of Compostables	Total amount of compostable segregated.	Stock	"Biodegradable & Compostable Segragation"-Composting Initial: 5.01009e+07	kg	Computed	
Composting	Amount of treated compostable.	Flow	MIN (MRF Operating Hours*Amount of Compostables, Amount Composted per Year)	kg/Year	Computed	
Amount Composted per Year	Maximum capacity of the city to treat compost.	Constant	9e+06*4	kg/Year	Waste ECA (Angeles, 2020)	

Composted Waste for Fertilizer	Total amount of compost.	Stock	Composting Initial: 0	kg	Computed	Used as fertilizer.

Appendix Table D6. Pasig Wastewater Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Sources	Notes
Household Connection Growth Rate	Rate of new households connected per year	Constant	0.020676	1/Year	Manila Water Report (Dela Cruz, 2020)	
Households Connections	Households connected per year.	Flow	MIN(Households Connected to Sewerage Lines*Household Connection Growth Rate, Population Growth Rate*Households Connected to Sewerage Lines)	House/Year	Computed	
Households Connected to Sewerage Lines	Total households connected to sewerage.	Stock	Household Connections Initial: 8086 (Co, 2020)	House	Computed	
Average People per Household	Observed average number of people per household.	Constant	5	People	PSA Survey (PSA, 2013)	
Population Connected to Sewerage Lines (PCSL)	Total population connected to sewerage lines.	Auxiliary	Average Number per Household*Households Connected to Sewerage Lines	People	Computed	

Population Not Connected to Sewerage Lines (PNCSL)	Total population not connected to sewerage lines.	Auxiliary	Population-"Population Connected to Sewerage Lines (PCSL)"	People	Computed	
WW Consumed by PNCSL	Total wastewater produced from population not connected to sewerage lines.	Auxiliary	"Population Not Connected to Sewerage Lines (PNCSL)"*Recorded Water Consumption per Capita	m3/Year	Computed	Residential water consumption based on water provisioning service.
WW Consumed by PCSL	Total wastewater produced from population connected to sewerage lines.	Auxiliary	"Population Connected to Sewerage Lines (PCSL)"*Recorded Water Consumption per Capita	m3/Year	Computed	Residential water consumption based on water provisioning service.
Infiltration Rate	Infiltration rate of wastewater.	Constant	1.15	Dmnl	Manila Water Report (Dela Cruz, 2020)	Part of the empirical equation used in computing for wastewater.

WW as Septage	Wastewater categorized as septage.	Auxiliary	Water Consumed by PNCSL*Infiltration Rate*WW Generation Coefficient	m3/Year	Computed	
WW Generation Coefficient	Percentage of wastewater from water consumed.	Constant	0.8	Dmnl	Manila Water Report (Dela Cruz, 2020)	Part of the empirical equation used in computing for wastewater.
WW as Sewage	Wastewater categorized as sewage.	Auxiliary	Infiltration Rate*Water Consumed by PCSL*WW Generation Coefficient	m3/Year	Computed	
Untreated WW Septage	Total untreated wastewater for septage.	Auxiliary	WW as Septage-"Treated (Desludged) Septage"	m3/Year	Computed	
Treated (Desludged) Septage	Total treated wastewater as septage.	Auxiliary	Acceptance Rate for Desludging*Frequency of Desludging*WW as Septage	m3/Year	Computed	
Frequency of Desludging	Frequency of desludging done in the city.	Constant	1/5	Year	Manila Water Report (Dela Cruz, 2020)	
Treated Sewage	Total treated wastewater as sewage.	Auxiliary	WW as Sewage	m3/Year	Computed	

Acceptance Rate for Desludging	Acceptance rate of desludging services in the city.	Constant	0.6	1/Year	Manila Water Report (Dela Cruz, 2020)	
Resilience Score for WW	Ratio between treated wastewater and generated wastewater.	Auxiliary	("Treated (Desludged) Septage"+Treated Sewage)/Total WW Generated	Dmnl	Computed	
Total WW Generated	Total wastewater generated by the city.	Auxiliary	WW as Septage+WW as Sewage	m3/Year	Computed	
Self-Sufficiency for WW	Ratio between total generated wastewater and treated sewage.	Auxiliary	Treated Sewage/Total WW Generated	Dmnl	Computed	

Appendix Table D7. Pasig Air Quality Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Day to Year Converter	Day to year converter.	Constant	1	1/Year	Conversion Unit	
Kilometers Travelled for Marcos Highway	Total kilometers travelled for Marcos Highway.	Constant	2.4	km/cars	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Average Cars per Day for Marcos Highway	Recorded average cars for Marcos highway.	Constant	101845	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT of Cars in Marcos Highway	Computed VKT from km and cars.	Auxiliary	Average Cars per Day for Marcos Highway*Day To Year Converter*Kilometers Travelled for Marcos Highway	km/Year	Computed	
Kilometers Travelled for C-5	Total kilometers travelled for C-5.	Constant	3.8	km/cars	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	

Average Cars per Day in C-5	Recorded average cars for C-5.	Constant	134214	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Kilometers Travelled for Shaw Blvd	Total kilometers travelled for Shaw Blvd.	Constant	2.5	km/cars	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Average Cars per Day in Shaw Blvd	Recorded average cars for Shaw Blvd.	Constant	57056	VKT/Cars	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT of Cars in Shaw Blvd	Computed VKT of cars in Shaw Blvd.	Auxiliary	Average Cars per Day in Shaw Blvd*Day To Year Converter*Kilometers Travelled for Shaw Blvd	km/Year	Computed	
Emission Factor for CP Garcia	Emission factor for CP Garcia road.	Constant	0.0692307	g/km	Computed	Applied to all. Uses fleet data in the empirical formula derived from the
Emission Factor for Marcos Highway	Emission factor for Marcos Highway road.	Constant	0.0782605	g/km	Computed	

Emission Factor for Shaw Blvd	Emission Factor for Shaw Blvd Road.	Constant	0.0757087	g/km	Computed	vehicle composition of the selected road.
Emission Factor for Ortigas	Emission Factor for Ortigas road.	Constant	0.115743	g/km	Computed	
Kilometers Travelled for Ortigas	Total kilometers travelled for Ortigas.	Constant	5.15	VKT/Cars	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Average Cars per Day in Ortigas	Recorded average cars ins Ortigas.	Constant	74080	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT for Cars in Ortigas	Computed VKT of cars in Ortigas.	Auxiliary	Average Cars per Day in Ortigas*Day To Year Converter*Kilometers Travelled for Ortigas	km/Year	Computed	
Fugitive Dust from Cars (MH)	Fugitive dust emissions from cars in MH.	Flow	Emission Factor for Marcos Highway*VKT of Cars in Marcos Highway	g/Year	Computed	
Fugitive Dust from Cars (C-5)	Fugitive dust emissions from cars C-5.	Flow	Emission Factor for CP Garcia*"VKT of Cars in C-5"	g/Year	Computed	

Fugitive Dust from Cars (Shaw)	Fugitive dust emissions from cars in Shaw.	Flow	Emission Factor for Shaw Blvd*VKT of Cars in Shaw Blvd	g/Year	Computed	
Fugitive Dust from Cars (Ortigas)	Fugitive dust emissions from cars in Ortigas.	Flow	Emission Factor for Ortigas*VKT of Cars in Ortigas	g/Year	Computed	
Total Annual VKT for PUJ in Marcos Highway	Computed VKT for PUJ in MH.	Auxiliary	Average PUJ per Day for Marcos Highway*Day To Year Converter*Kilometers Travelled for Marcos Highway	km/Year	Computed	
Average PUJ per Day for Marcos Highway	Recorded average PUJ in MH.	Constant	15421.7	Cars/Day	Metropolita n Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT for PUJ in C-5	Computed VKT for PUJ in C-5.	Auxiliary	"Average PUJ per Day in C-5"*Day To Year Converter*"Kilometers Travelled for C-5"	km/Year	Computed	
Average PUJ per Day in C-5	Recorded average PUJ in C-5.	Constant	1370	Cars/Day	Metropolita n Manila AADT (MMDA, 2012 - 2018)	
Average PUJ per Day in Shaw Blvd	Recorded average PUJ in Shaw Blvd.	Constant	18466	Cars/Day	Metropolita n Manila AADT (MMDA,	

					2012 - 2018)	
Total Annual VKT for PUJ in Ortigas	Computed VKT for PUJ in Ortigas.	Auxiliary	Average PUJ per Day in Ortigas*Day To Year Converter*Kilometers Travelled for Ortigas	km/Year	Computed	
Average PUJ per Day in Ortigas	Recorded average PUJ in Ortigas.	Constant	12259	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Fugitive Dust from PUJ (MH)	Fugitive dust emissions from PUJ in MH.	Flow	Emission Factor for Marcos Highway*VKT for PUJ in Marcos Highway	g/Year	Computed	
Fugitive Dust from PUJ (C-5)	Fugitive dust emissions from PUJ in C-5.	Flow	"VKT for PUJ in C-5"*Emission Factor for CP Garcia	g/Year	Computed	
Fugitive Dust from PUJ (Shaw)	Fugitive dust emissions from PUJ in Shaw.	Flow	Emission Factor for Shaw Blvd*"VKT for PUJ (Shaw)"	g/Year	Computed	
Fugitive Dust from PUJ (Ortigas)	Fugitive dust emissions from PUJ in Ortigas.	Flow	Emission Factor for Ortigas*VKT for PUJ in Ortigas	g/Year	Computed	
Total Annual VKT For PUB in Ortigas	Computed VKT for PUB in Ortigas.	Auxiliary	Average PUB per Day in Ortigas*Day To Year Converter*Kilometers Travelled for Ortigas	km/Year	Computed	

Average PUB per Day in Ortigas	Recorded average PUB in Ortigas.	Constant	957	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT for PUB (Shaw)	Computed VKT for PUB in Shaw.	Auxiliary	Average PUB per Day in Shaw Blvd*Day To Year Converter*Kilometers Travelled for Shaw Blvd	km/Year	Computed	
Average PUB per Day in Shaw Blvd	Recorded average PUB in Shaw Blvd.	Constant	66	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Total Annual VKT for PUB in C-5	Computed VKT for PUB in C-5.	Auxiliary	"Average PUB per Day in C-5"*Day To Year Converter*"Kilometers Travelled for C-5"	km/Year	Computed	
Average PUB per day in C-5	Recorded average PUB in C-5.	Auxiliary	349	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	
Average PUB per Day for Marcos Highway	Recorded average PUB in Marcos Highway.	Constant	1039.43	Cars/Day	Metropolitan Manila AADT (MMDA, 2012 - 2018)	

Total Annual VKT for PUB in Marcos Highway	Computed VKT for PUB in MH.	Auxiliary	Average PUB per Day for Marcos Highway*Day To Year Converter*Kilometers Travelled for Marcos Highway	km/Year	Computed	
Fugitive Dust from PUB (MH)	Fugitive dust emissions from PUB in MH.	Flow	Emission Factor for Marcos Highway*VKT for PUB in Marcos Highway	g/Year	Computed	
Fugitive Dust from PUB (C-5)	Fugitive dust emissions from PUB in C-5.	Flow	Emission Factor for CP Garcia*"VKT for PUB in C-5"	g/Year	Computed	
Fugitive Dust from PUB (Shaw)	Fugitive dust emissions from PUB in Shaw Blvd.	Flow	Emission Factor for Shaw Blvd*"VKT for PUB (Shaw)"	g/Year	Computed	
Fugitive Dust from PUB (Ortigas)	Fugitive dust emissions from PUB in Ortigas.	Flow	Emission Factor for Ortigas*VKT for PUB in Ortigas	g/Year	Computed	
Natural PM2.5 Dispersion	Natural PM2.5 removal rate.	Flow	"PM2.5 Emissions Dispersed per Year"*Natural Dispersion Rate	g/Year	Computed	
PM2.5 Emissions Dispersed per Year	Natural PM2.5 emissions removed per year.	Auxiliary	("PM2.5 in Major Roads of Pasig"-"Average PM2.5 Emissions per Year")	g	Computed	

Natural Dispersal Rate	Natural PM2.5 removal rate.	Constant	1	1/Year	Computed	Assumed to happen all the time; Accounts for seasonal and natural dispersion and dry and wet deposition.
Pollutant Removal by A&GA	Total PM2.5 emission removed by agriculture and greenspace area.	Flow	Agricultural and Greenspace Area in m2*"Removal Rate of PM2.5"	g/Year	Computed	
Agricultural and Greenspace Area in m2	Total land area of A&GA in square meters.	Auxiliary	"Agricultural and Greenspace Area (A&GA)"*Ha to m2 to Converter	m2	Computed	
Removal Rate of PM2.5	Removal rate per hectare of A&GA.	Constant	1.79	g/m2/Year	Urban Forestry & Urban Greening (Selmi, 2016)	
Ha to m3 Converter	Hectare to square meters converter.	Constant	10000	m2/Ha	Conversio n Unit	

Ug to g Converter	Microgram to gram converter.	Constant	1e-06	g/ug	Conversion Unit	
Average PM2.5 Emissions per Year	Observed average PM2.5 roadside emissions.	Auxiliary	"Average Observed PM2.5 Concentration per Year"*ug to g Converter*Volume of Pasig City	g	Conversion Unit	
Average Observed PM2.5 Concentration per Year	Computed average roadside air quality concentration.	Constant	55	ug/m3	National Air Quality Status Report 2008 – 2015 (DENR-EMB, 2015)	
Volume of Pasig City Air Shed	Total Volume of Pasig city.	Auxiliary	(Area of Pasig*Mixing Height of Metro Manila)*km3 to m3 Converter	m3	Computed	
Mixing Height of Metro Manila	Observed mixing height of Metro Manila.	Constant	1.635	km	Tubal et al., 2002	
Area of Pasig	Total land area of Pasig city.	Constant	79.2158	km2	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015	

Km3 to m3 converter	Cubic kilometer to cubic meter converter.	Constant	1e+09	m3/(km2*km)	Conversion Unit	
g to ug Converter	Microgram to gram converter.	Constant	1e+06	ug/g	Conversion Unit	
Concentration of PM2.5	Total PM2.5 concentration in the city.	Auxiliary	(("PM2.5 in Major Roads of Pasig")*g to ug Converter)/Volume of Pasig City	ug/m3	Computed	
Resilience Score for Air Quality	Ratio between concentration of PM2.5 and air quality standard,	Auxiliary	Standard for Air Quality/"Concentration of PM2.5"	Dmnl	Computed	
Standard for Air Quality	Standard for PM2.5 concentration in an area.	Constant	35	ug/m3	DAO No. 2013 – 13 (DENR EMB, 2013)	

PM2.5 in Major Roads of Pasig	Total PM2.5 emissions from all major roads.	Stock	"Fugitive Dust from Cars (C-5)"+"Fugitive Dust from Cars (MH)"+"Fugitive Dust from Cars (Ortigas)"+"Fugitive Dust from Cars (Shaw)"+"Fugitive Dust from PUB (C-5)"+"Fugitive Dust from PUB (MH)"+"Fugitive Dust from PUB (Ortigas)"+"Fugitive Dust from PUB (Shaw)"+"Fugitive Dust from PUJ (C-5)"+"Fugitive Dust from PUJ (MH)"+"Fugitive Dust from PUJ (Ortigas)"+"Fugitive Dust from PUJ (Shaw)"-"Natural PM2.5 Removal"-Pollutant Removal Initial: 44687790	g	Computed	

Appendix Table D8. Pasig Carbon Emission Regulation Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Emission Factor for BOD River Discharge	Emission factor for river discharge.	Constant	0.06	kg/kgBOD	GHG Inventory (Pasig City Government, 2014)	
River Discharge CH4 Emissions	Total CH_4 from river discharge.	Auxiliary	Emissions Factor BOD River Discharge*Untreated WW Septage*BOD per WW Generated	kg/Year	Computed	
WW Generated per Capita per Year	Total wastewater generated per year.	Auxiliary	Infiltration Rate*WW Generation Coefficient*Recorded Water Consumption per Capita	m3/People /Year	Computed	
BOD per WW Generated	Conversion between volume to BOD.	Auxiliary	Per Capita BOD Generation per Year/WW Generated per Capita per Year	kgBOD/m3	Computed	
Septic Tank CH4 Emissions	Total CH_4 emissions for septic tank.	Auxiliary	Emissions Factor BOD Septic*WW as Septage*BOD per WW Generated	kg/Year	Computed	
Emission Factor BOD Septic	Emission factor for septic tank wastewater.	Constant	0.3	kg/kgBOD	GHG Inventory (Pasig City Government, 2014)	
Per Capita BOD Generation per Year	BOD generated per capita per year	Constant	14.6	kgBOD/(People*Year)	GHG Inventory (Pasig City Government, 2014)	

Emission Factor BOD Sewage	Emission factor for sewage waste.	Constant	0.6	kg/kgBOD	GHG Inventory (Pasig City Government, 2014)	
Sewage CH4 Emissions	Total CH_4 emissions for sewage.	Auxiliary	Emission Factor BOD Sewerage*WW as Sewage*BOD per WW Generated	kg/Year	Computed	
Septic Tank CH4 Emissions	Total CH_4 emissions from septic tank wastewater.	Auxiliary	Emissions Factor BOD Septic*WW as Septage*BOD per WW Generated	kg/Year	Computed	
CH4 Emissions (WW)	Total CH_4 for all wastewater.	Auxiliary	(Septic Tank CH4 Emissions+River Discharge CH4 Emissions+Sewerage CH4 Emissions)*kg to MT Converter	tCH4/Year	Computed	
Kg to MT Converter	Kilogram to metric ton converter.	Constant	1/1000	tCH4/kg	Conversion Unit	
CH4 Generated	Total CH_4 generated from all sources.	Auxiliary	"CH4 Emissions (SWM)"+"CH4 Emissions (WW)"	tCH4/Year	Computed	
DOC Yard Waste	DOC factor for yard waste.	Constant	0.43	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Total DOC of Yard Waste	Total DOC from yard waste.	Auxiliary	DOC Yard Waste*Fraction of Yard Waste	GgC/Gg	Computed	

Fraction of Yard Waste	Fraction of compostable that are yard waste.	Constant	3/70	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
Fraction of Food Waste	Fraction of compostable that are food waste.	Constant	20/23	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
Total DOC of Food Waste	Total DOC from food waste.	Auxiliary	DOC of Food Waste*Fraction of Food Waste	GgC/Gg	Computed	
DOC of Food Waste	DOC factor of food waste.	Constant	0.16	GgC/Gg	GHG Inventory (ICLEI, 2014)	
Fraction of Clothes and Textiles	Fraction of compostable that are clothes and textiles.	Constant	7/93	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
DOC of Clothes and Textiles	DOC factor for clothes and textiles.	Constant	0.4	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Total DOC of Clothes and Textiles	Total DOC from clothes and textiles.	Auxiliary	DOC of Clothes and Textiles*Fraction of Clothes and Textiles	GgC/Gg	Computed	
Total DOC of Rubber and Leather	Total DOC from rubber and leather.	Auxiliary	DOC of Rubber and Leather*Fraction of Rubber and Leather	GgC/Gg	Computed	

Fraction of Rubber and Leather	Fraction of compostable that are rubber and leather.	Constant	1/83	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
DOC of Rubber and Leather	Total DOC from rubber and leather.	Constant	0	GgC/Gg	GHG Inventory (Pasig City Government, 2014)	
Degradable Organic Carbon (DOC)	Total generated DOC from all compostable waste.	Auxiliary	Total DOC of Clothes and Textiles+Total DOC of Food Waste+Total DOC of Rubber and Leather+Total DOC of Yard Waste	GgC/Gg	Computed	
kg to Gg Converter	Kilogram to Gigagram converter.	Constant	1e-06	Gg/kg	Conversion Unit	
Fraction of Degraded Organic Carbon Dissimilated (DOCf)	Fraction of DOCf	Constant	0.77	Dmnl	10-Year Solid Waste Management Plan (Angeles, 2012)	
Fraction of CH4 in Landfill (F)	Fraction of CH_4 in selected landfill.	Constant	0.5	Dmnl	GHG Inventory (Pasig City Government, 2014)	
Methane Correction Factor	Methane correction factor used in empirical equation.	Constant	0.4	GgCH4/Gg C	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	

Methane Generation Potential	Total potential methane generated.	Auxiliary	("Degradable Organic Carbon (DOC)"*"Fraction of Degraded Organic Carbon Dissimilated (DOCf)"*"Fraction of CH4 in Landfill (F)"*Methane Correction Factor)*(16/12)	GgCH4/Gg	Computed	
Recovered CH4	Recovered CH_4 from landfill if any.	Constant	0	GgCH4/Year	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	
Oxidation Factor	Oxidation factor if open landfill.	Constant	0	Dmnl	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	
Fraction Disposed to SWDS (MSWf)	Fraction of all compostable waste disposed to landfill.	Constant	1	1/Year	Computed	Assumed to happen all year round
CH4 Emissions (SWM)	Total CH_4 emissions from SWM.	Auxiliary	(("Compostables in Gg (MSWt)"*"Fraction Disposed to SWDS (MSWf)"*Methane Generation Potential)-Recovered CH4)*(1-Oxidation Factor)*Gg to MT Converter	tCH4/Year	Computed	

Gg to MT Converter	Gigagrams to metric tons converter.	Constant	1000	tCH4/GgCH4	Conversion Unit	
CH4 Generated	Total CH_4 emissions from SWM and WW.	Flow	"CH4 Emissions (SWM)"+"CH4 Emissions (WW)"	tCH4/Year	Computed	
CH4 Emissions from SWM and WW	Total CH_4 emissions from SWM and WW.	Stock	CH4 Generated-"Methane Decay (WW)" Initial: 0	tCH4	Computed	
Methane Decay	Total Methane decay.	Flow	"CH4 Emissions from SWM & WW"*Decay Rate	tCH4/Year	Computed	
Decay Rate	Decay rate of Methane.	Constant	0.07701	1/Year	Tubal et al., 2002	
Emissions from Waste	Converter of Methane into $tCO2_e$	Auxiliary	("CH4 Emissions from SWM & WW")*CH4 GWP per Year	tCO2e/Year	Computed	
CH4 GWP per Year	Global warming potential of CH_4	Constant	25	tCO2e/tCH4/Year	IPCC Waste Emissions (Hiraishi, Nyenzi, Jensen, & Pipatti, 2016)	
Resilience Score for Carbon	Ratio between total $tCO2_e$ emissions and Carbon sequestration.	Auxiliary	Carbon Sequestration/CO2e Emission	Dmnl	Computed	

Sequestration per Year	Sequestration based on hectarage per year.	Constant	8	tCO2e/(Year*Ha)	Urban Forestry & Urban Greening (Selmi et al., 2016)	
CO2e Emission	Total $tCO2_e$ emissions generated.	Flow	Electrical tCO2e+Mobility tCO2e+tCO2e from WW and SWM	tCO2e/Year	Computed	
Carbon Emissions for Pasig	Total $tCO2_e$ emissions in Pasig city.	Stock	CO2e Emission-Carbon Sequestration Initial: 0	tCO2e	Computed	
Carbon Sequestration	Total amount of $tCO2_e$ sequestered.	Flow	"Agricultural and Greenspace Area (A&GA)"*Sequestration per Year	tCO2e/Year	Computed	
tCO2e for PUB	Total $tCO2_e$ emissions from PUB.	Auxiliary	Carbon Emission Factor For PUB*(VKT for PUB in Marcos Highway+"VKT for PUB (Shaw)"+"VKT for PUB in C-5"+VKT for PUB in Ortigas)	g/Year	Computed	
Carbon Emission Factor for PUB	Emission factor for PUB.	Constant	12.4	g/km	GHG Inventory (Pasig City Government, 2014)	

tCO2e for PUJ	Total $tCO2_e$ emissions for PUJ.	Auxiliary	Carbon Emission Factor for PUJ*(VKT for PUJ in Marcos Highway+"VKT for PUJ in C-5"+"VKT for PUJ (Shaw)"+VKT for PUJ in Ortigas)	g/Year	Computed	
Carbon Emission Factor for PUJ	Emission factor for PUJ.	Constant	2.5	g/km	GHG Inventory (Pasig City Government, 2014)	
tCO2e for Cars	Total $tCO2_e$ emissions for cars.	Auxiliary	Carbon Emission Factor for Cars*(VKT of Cars in Marcos Highway+"VKT of Cars in C-5"+VKT of Cars in Ortigas+VKT of Cars in Shaw Blvd)	g/Year	Computed	
Carbon Emission Factor for Cars	Emissions factor for Cars.	Constant	49.5	g/km	GHG Inventory (Pasig City Government, 2014)	
Emissions from Transport	Total emissions from automobiles.	Auxiliary	(tCO2e for PUB+tCO2e for Cars+tCO2e for PUJ)*g to tons converter	tCO2e/Yea r	Computed	
g to tons converter	Grams to tons converter.	Constant	1e-06	tCO2e/g	Conversion Unit	
Emissions from Electricity	Total emissions from electricity consumption.	Auxiliary	"Current Maximum Electricity Supply per Year (kWh)"*Electrical Consumption Emission Factor*"kWh - MWh Conversion"	tCO2e/Yea r	Computed	

Electrical Consumption Emission Factor	Electrical consumption emission factor.	Constant	0.5192	tCO2e/mwh	GHG Inventory (Pasig City Government, 2014)	
kWh to MWh Conversion	Kilowatts per hours to megawatts per house conversion.	Constant	1/1000	mwh/kwh	Conversion Unit	

Appendix Table D9. Pasig River Rainwater Conveyance Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Flood Equation Constant	Based on Empirical Formula used to convert values.	Constant	3.6	Dmnl	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	
Surface Run-Off	Total surface run-off.	Auxiliary	(Average C*RIDF*Pasig Land Area)/Converter	m*m*m/Year	Computed	
Pasig Land Area	Pasic city total land area.	Flow	48.45	m*m	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
RIDF	Rainfall data for 50-year return period	Auxiliary	127.625	m/Year	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	
Rainwater Conveyance Resilience	Ratio between Additional Rainwater Conveyed and Surface Run-Off.	Auxiliary	Rainwater Conveyance Capacity/"Surface Run-Off"	Dmnl	Computed	

Rainwater Conveyance Capacity	Capacity to discharge rainfall surface run-off	Flow	(Design Discharge Capacity-Normal Discharge Capacity)*(1-Fraction Silted)	m*m*m/Year	Computed	
Design Discharge Capacity	Designated discharge to account for rainfall induced surface run-off	Constant	900	m*m*m/Year	Urban Flood Loss & Mitigation (UN, 1990)	
Normal Discharge Capacity	Natural discharge capacity of the river	Constant	527.633	m*m*m/Year	Computed	Computed outside model using Manning's Equation from JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)
Fraction Silted	Fraction of discharge capacity silted	Auxiliary	Annual Sediment Yield*Estimated Sediment Yield	Dmnl	Computed	

Estimated Sediment Yield	Conversion to MT for sediment.	Constant	0.47/8774.4	Year/MT	Computed (Rate of Sediment Yield (Tukur & Olofin, 2013))	Converted based on literature from the effects of MT to discharge capacity
Annual Sediment Yield	Total sediment yield per year.	Auxiliary	Estimated Annual Sediment Suspension Load*Pasig Land Area in Ha	MT/Year	Computed	
Estimated Annual Sediment Suspension Load	Annual sediment suspension load per hectares.	Constant	0	MT/Ha/Year	JICA Report (The Study on Flood Control and Drainage Project in MM, 1990)	

Appendix Table D10. Pasig Land Use Sub-Model Variables

Variable	Definition	Type	Method of Analysis	Unit	Data Source	Notes
Total Land Area	Total Land Area for Pasig	Constant	4459.41	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Available Land (AL)	Total Available Land / Convertible Land	Stock	Total Land Area*Fraction of AL Initial: 408.9	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Parks and Recreations (P&R)	Total Parks and Recreations Area	Stock	Total Land Area*"Fraction of P&R" Initial: 23.9	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Roads (R)	Total Roads	Stock	Total Land Area*Fraction of R Initial: 384.6	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Built-Up Area (BuA)	Total Built-up Area	Stock	Total Land Area*Fraction of BUA Initial: 2614.6	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	

Agricultural and Greenspace Area (A&GA)	Total Agriculture and Greenspace Area	Stock	Total Land Area*"Fraction of A&GA" Initial: 0	Ha	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Conversion of AL to R	Available land converted to R	Flow	MIN("Roads (R)"*Conversion Rate of AL to R,"Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion of AL to A&GA	Available land converted to A&GA	Flow	MIN("Conversion Rate of AL to A&GA"*"Agricultural and Greenspace Area (A&GA)","Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion of AL to BuA	Available land converted to BuA	Flow	MIN("Built-up Area (BUA)"*Conversion Rate of AL to BUA,"Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	
Conversion of AL to P&R	Available land converted to P&R	Flow	MIN("Parks and Recreations (P&R)"*"Conversion Rate of AL to P&R","Available Land (AL)"*Function Unit Converter)	Ha/Year	Computed	

Conversion Rate of AL to R	Actual conversion rate observed from AL to R	Constant	0.0021027	1/Year	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Conversion Rate of AL to P&R	Actual conversion rate observed from AL to P&R	Constant	0.077887	1/Year	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Conversion Rate of AL to BuA	Actual conversion rate observed from AL to BUA	Constant	0.0054829	1/Year	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Conversion Rate of AL to A&GA	Actual conversion rate observed from AL to A&GA	Constant	0	1/Year	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Fraction of A&GA	Fraction of initial total land area as A&GA	Constant	0	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	

Fraction of P&R	Fraction of initial total land area as P&R	Constant	0.00695513	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Fraction of BuA	Fraction of initial total land area as BuA	Constant	0.761841	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Fraction of AL	Fraction of initial total land area as AL	Constant	0.119138	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
Fraction of R	Fraction of initial total land area as R	Constant	0.112066	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
C constant for AL	Surface run-off Coefficient for AL	Constant	0.25	Dmnl	Comprehensive Land Use Plan 2009 – 2018 (Pasig City Government, 2015)	
C value for AL	C value for land use type	Auxiliary	("Available Land (AL)"/Total Land Area*100)*C constant for AL	Dmnl	Computed	

C constant for BUA	Surface Run-off Coefficient for BUA	Constant	0.55	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for BUA	C value for land use type	Auxiliary	("Built-up Area (BUA)"/Total Land Area*100)*C constant for BUA	Dmnl	Computed	
C constant for A&GA	Surface Run-off Coefficient for A&GA	Constant	0.2	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for A&GA	C value for land use type	Auxiliary	("Agricultural and Greenspace Area (A&GA)"/Total Land Area*100)*"C constant for A&GA"	Dmnl	Computed	
C constant for P&R	Surface Run-off Coefficient for P&R	Constant	0.25	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for P&R	C value for land use type	Auxiliary	("Parks and Recreations (P&R)"/Total Land Area*100)*"C constant for P&R"	Dmnl	Computed	
C constant for R	Surface Run-off Coefficient for R	Constant	0.75	Dmnl	Manual of Flood Control Planning (JICA, 2003)	
C value for R	C value for land use type	Auxiliary	("Roads (R)"/Total Land Area*100)*C constant for R	Dmnl	Computed	

Average Run-off Coefficient	Average of all C values for different land use type	Auxiliary	("C value for A&GA"+C value for BUA+C value for AL+"C value for P&R"+C value for R)/100	Dmnl	Computed	
Function Unit Converter	Unit Converter for No Errors	Constant	1	1/Year	Vensim function	

Appendix Table D11. Pasig Cultural Sub-Model Variables

Variable	Description	Type	Method of Analysis	Unit	Data Source	Notes
Resilience Score for Greenspace Requirement	Ratio between existing and recommended greenspace in Pasig city.	Auxiliary	"Agricultural and Greenspace Area (A&GA)"/Recommended Greenspace Supply	Dmnl	Computed	
Recommended Greenspace Supply	Total greenspace required for population per year	Auxiliary	Population*Recommended Greenspace per Capita	Ha	Computed	
Recommended Greenspace per Capita	Recommended greenspace per capita value.	Constant	0.00095	Ha/People	WHO-UN, 2020	
Recommended Recreational Spaces Supply (Only for Sports and Playgrounds)	Total recreational space required for sports and playgrounds	Auxiliary	(Population*"Population per 1,000 Converter")*"Recommended Recreational Spaces (Only for Sports and Playgrounds)"	Ha	Computed	
Recommended Recreational Spaces (Only for Sports and Playgrounds)	Recommended recreational space per capita for sports and playgrounds.	Constant	0.5	Ha/People	CLUP Guidebook Volume 2 for Designing Resilience	

Recommended Recreational Spaces Supply (Only for Parks)	Total recreational space required for parks	Auxiliary	(Population*"Population per 1,000 Converter")*"Recommended Recreational Spaces (Only for Parks)"	Ha	Computed	
Recommended Recreational Spaces (Only for Parks)	Recommended recreational space per capita for parks.	Constant	0.05	Ha/People	CLUP Guidebook Volume 2 for Designing Resilience	
Resilience Score for Recommended Sports and Playgrounds	Ratio between existing and recommended sports and playgrounds in the city.	Auxiliary	"Parks and Recreations (P&R)"/"Recommended Recreational Spaces Supply (Only for Sports and Playgrounds)"	Dmnl	Computed	
Resilience Score for Parks	Ratio between existing and recommended parks in the city.	Auxiliary	"Parks and Recreations (P&R)"/"Recommended Recreational Spaces Supply (Only for Parks)"	Dmnl	Computed	
Population per 1,000 Converter	Population Converter	Constant	1/1000	Dmnl	Conversion Unit	
Fraction of Parks as A&GA	Scenario Slider	Constant	0	Dmnl	Computed	0 at the for BAU