THE BENEFITS OF INCORPORATING SHIPPING CONTAINERS INTO THE CLIMATE CHANGE ADAPTATION PLANS AT NASA WALLOPS FLIGHT FACILITY

By

Carl Kenneth Gonzaga Hamilton

A MASTER RESEARCH PROJECT (MRP) PRESENTED
TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL
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To my wife, children, mother, late father, siblings, and friends.

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By
Carl “Cleo” Hamilton
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Chair: William Tilson
Co-chair: Kathryn Frank, PhD
Major: Architecture

The National Aeronautics and Space Administration has several centers and facilities located near the coast that are undoubtedly susceptible to climate change. One of those facilities is Wallops Flight Facility on the Eastern Shore of Virginia which is separated into three areas: Main Base, Mainland, and the Island. Wallops Island has numerous buildings and assets that are vulnerable to flood inundation, intense storms, and storm surge. The shoreline of Wallops Island is prone to beach erosion and is slated for another beach replenishment project in 2019. In addition, current climate projections for NASA’s centers and facilities, conducted by the Climate Adaptation Science Investigators, warn of inevitable increases in annual temperature, precipitation, sea level rise, and extreme events such as heatwaves. The aforementioned vulnerabilities Wallops Island faces in addition to the projections of future climate change reveal an urgency for NASA to adjust how new buildings at its centers and

facilities near the coast are built to adapt to the inevitable effects of climate change. Although the agency has made strides to mitigate the effects of climate change by incorporating L.E.E.D. into new buildings that produce less greenhouse gas, the strides for the agency to institute clear climate adaptation policies for the buildings at its centers and facilities near the coast seem to lag behind.

As NASA continues to formulate formidable climate change adaptation plans for its centers and facilities, an architectural trend that should be examined for its potential to replace several old buildings at Wallops Island is shipping containers buildings. Shipping containers or Intermodal Steel Building Units offer an array of benefits such as strength, durability, versatility, modular, and since they can be upcycled, they are also eco-friendly. Some disadvantages of shipping containers are they contain harmful chemicals, insulation must be added, fossil fuels must be used to transport them to the site, and multiple ISBU's are needed. Ultimately, this Masters Research Project will focus on how the benefits of shipping containers can be incorporated into the climate change adaptation plans at Wallops Island and will make recommendations for NASA climate change policies and facility design guidelines.

CHAPTER 1:

INTRODUCTION

Coastal Flooding at NASA Centers and Facilities

The relentless pumping of CO2 emissions into the atmosphere by human beings continues to exasperate global warming (National Research Council of the National Academies, 2011). A direct product of global warming is sea level rise (SLR), which is an unsustainable phenomenon that has put many coastal towns, cities and various properties in jeopardy of having increases in coastal flooding that will impact daily operations, including the National Aeronautics and Space Administration centers located on the coast (Rozensweig & et.al, 2014). Thus, putting a tremendous risk on their respective assets. One of those locations is NASA Goddard Space Flight Center's Wallops Flight Facility (WFF) nestled on Virginia's Eastern Shore as expressed on NASA's Climate Resilience Workshop Report:

"Because of its coastal location, WFF faces an increasing risk of impacts from sea level rise (SLR), storm surge, snow events, and other climate-related stresses, including threats to human health. Vulnerabilities of WFF to risks associated with climate change are multi-faceted and are worsened by its subjection to extreme weather events like hurricanes and Nor'easters...WFF currently encounters yearly damage due to hurricanes and Nor'easters with storm surge and wind acting as the two biggest contributing factors to infrastructure damage on Wallops Island." (Moisan, Turner, Mitchell, & Bonsteel, 2013)

Aside from rocket launches, supply missions to the International Space Station, collecting beautifully detailed photos of the cosmos through the Hubble Telescope, and preparing to send humans to Mars, NASA is also a giant in climate science by leading the monitoring of our precious Earth's "Vital Signs" by way of observing SLR, global temperatures, carbon dioxide levels, and arctic ice melts to name a few (NASA, 2017). Since two-thirds of NASA's assets are within 16 feet (or 5 meters) of sea level

(Rozensweig & et.al, 2014), those vital signs are pivotal in determining what federal agencies like NASA, as well as cities near the coast, will have to prepare for if SLR predictions come into fruition and disrupt daily operations by impeding on infrastructures such as transportation, electrical, storm water management, and communications. Perhaps the shipping container building trend can serve as a viable solution to address the flood inundation issues due to predicted increases in heavy precipitation events and storm surge from storms at The Island section of Wallops Flight Facility.

Overview of Wallops Flight Facility

In 1945, the National Advisory Committee for Aeronautics (NACA), the precursor to NASA, established WFF as a center for aeronautic research (NASA WFF, 2015). The facility is currently owned and operated by NASA Goddard Space Flight Center (NASA GSFC, 2012). Located on the on the Eastern Shore of Virginia in Accomack County (Figure 2-1), WFF is an ideal location for rocket launches because the trajectory of the rockets travel directly over the Atlantic Ocean and away from any population centers. In addition, WFF is NASA's principal facility for management and implementation of suborbital research programs (NASA WFF, 2015) and home to a team of approximately 1,100 full time employees including 281 civil servants (NASA, 2016) and has constructed assets of approximately $900 million or 2.8% of NASA's agency wide total of constructed assets of $32 billion (Rozensweig & et.al, 2014).

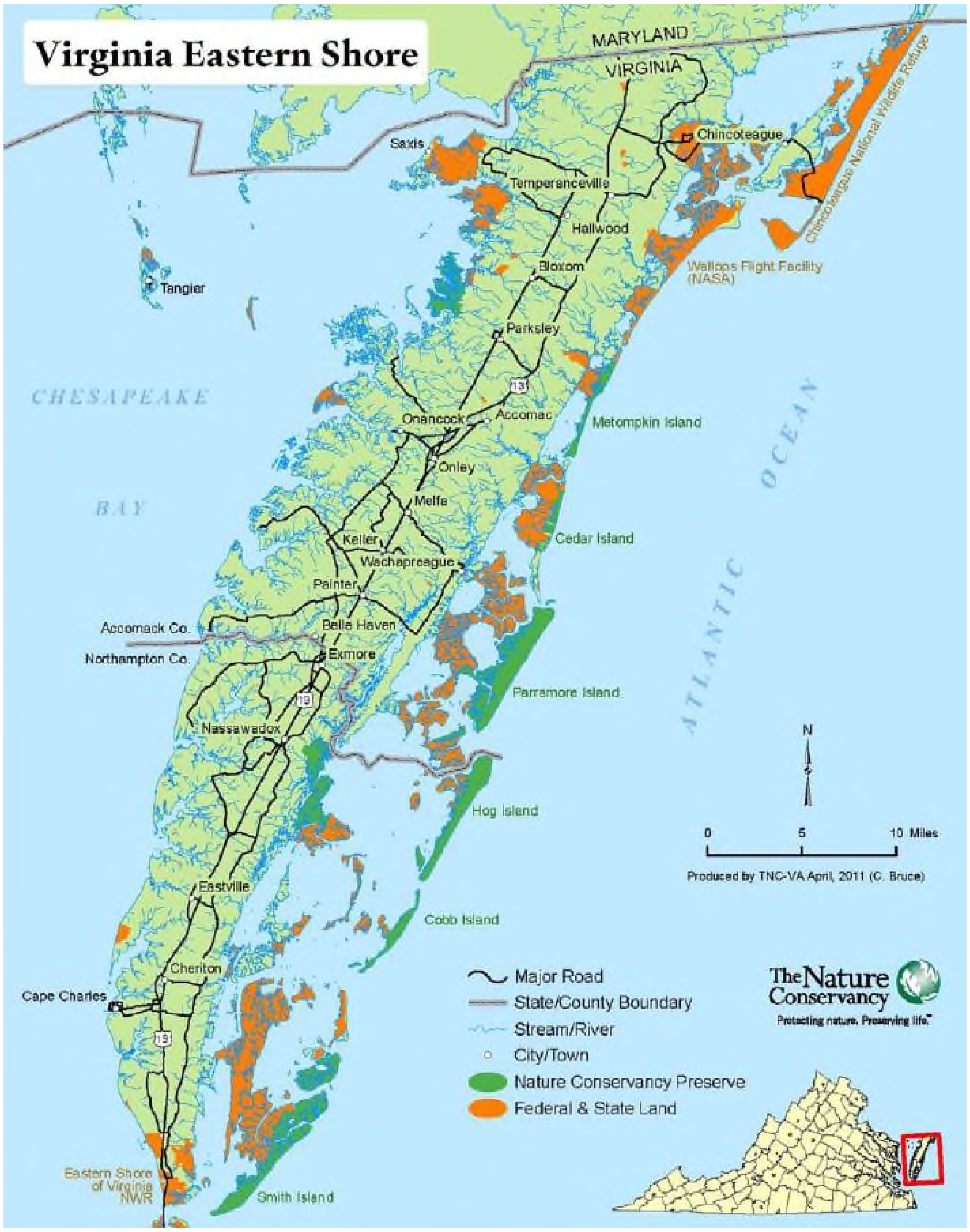

Figure 1- 1: Map of the Virginia Eastern Shore. (The Nature Conservancy, 2011)

The facility has a partnership with the Mid-Atlantic Regional Spaceport (M.A.R.S.) to support the launch of orbital vehicles such as the Antares rocket that brings the Cygnus cargo capsule into orbit where Cygnus makes it trek to deliver supplies and science experiments to the crew of the International Space Station (Virginia Space, n.d.). The WFF mission Plan includes the following objectives (Moisan, Turner, Mitchell, & Bonsteel, 2013):

1. To help achieve NASA's strategic objectives for scientific and educational excellence through cost efficient integration, launch, and operations of suborbital and small orbital payloads.
2. To enable scientific, educational, and economic advancement by providing the facilities and expertise to enable frequent flight opportunities for a diverse customer base.
3. To serve as a key facility for operational test, integration, and certification of NASA and commercial next-generation, low-cost orbital launch technologies.
4. To pioneer productive and innovative government, industry, and academic partnerships.

Three Areas of Wallops Flight Facility

WFF is divided into three areas: the Main Base, Mainland, and the Island (Figure 1-2) (NASA GSFC, 2012) and has various assets located there as shown on Table 1-1. The Island, better known as Wallops Island, is the WFF focus area for this MRP. Locations of facilities and assets at Wallops are shown on Figure 1-3.

Figure 1- 2: Map of the three areas of Wallops Island. (NASA GSFC, 2012)

AREA	SIZE	ASSETS
Main Base	1,800 acres (720 hectares)	• Offices • Laboratories • Maintenance • NASA owned airport • Air traffic control facilities • Hangers • Runways • Aircraft maintenance • Ground support buildings • Water & sewage treatment plants
Mainland	100 acres (40.5 hectares)	• Long-range radar • Communications • Optical tracking installations
Island (see Figure 2-3)	4,600 acres (1,680 hectares)	• Launch and testing facilities • Rocket storage facilities • Assembly shops • Unmanned aerial vehicle (UAV) runway • Other related support structures

Table 1- 1: Three areas of Wallops Flight Facility and Assets.

Figure 1- 3: Map of Facilities at Wallops Island. (NASA GSFC WFF, 2013)

Research Direction

On October 5th, 2009, President Barak Obama signed Executive Order (EO) 13514 into law for “Leadership in Environmental, Energy, and Economic Performance” requiring U.S. agencies such as the National Aeronautics and Space Administration (NASA) “to establish an integrated strategy towards sustainability in the Federal Government and to make reduction of greenhouse gas emissions (GHS) a priority of Federal agencies.” (C.F.R., 2009). Thus, ushering in a new era for U.S. federal agencies to counter climate change with adaptation and mitigation policies. Since then, EO 13514 has evolved into the EO 13693 “Planning for Federal Sustainability in the Next Decade” which was signed by President Barak Obama on March 19th, 2015 (C.F.R., 2015).

A trend that should be explored for its viability in climate change adaptation plans for NASA WFF are shipping container buildings. Shipping containers are made to withstand harsh winds and storms aboard huge cargo ships. These structures are known for their durability, versatility, and flexible configurability and could provide an alternative means for WFF to prepare for more frequent high precipitation events, storm surge, and SLR due to climate change. There are several examples of climate adaptation plans NASA, other federal agencies, and cities have considered or implemented, making it relevant for further investigation in this MRP. The author of this MPR aims to distinguish between mitigation and adaptation efforts at NASA WFF Island through the analysis of various policies and plans of NASA as an agency analysis of research conducted by the NASA Engineering Constructions Innovations Committee (ECIC) Climate Change Sub-Committee. Furthermore, NASA’S Kennedy Space Center is presented by the author of this MRP due to some of its respective assets location near the coast and similar topography. In addition, the author plans to investigate the shipping container building trend to answer the following questions:

1. **What are the benefits of incorporating shipping containers into the climate adaptation plans for the Island at NASA Wallops Flight Facility?**
2. **What recommendations in NASA's policies/guidelines should be considered if shipping containers are utilized at NASA Wallops Flight Facility to protect its assets?**

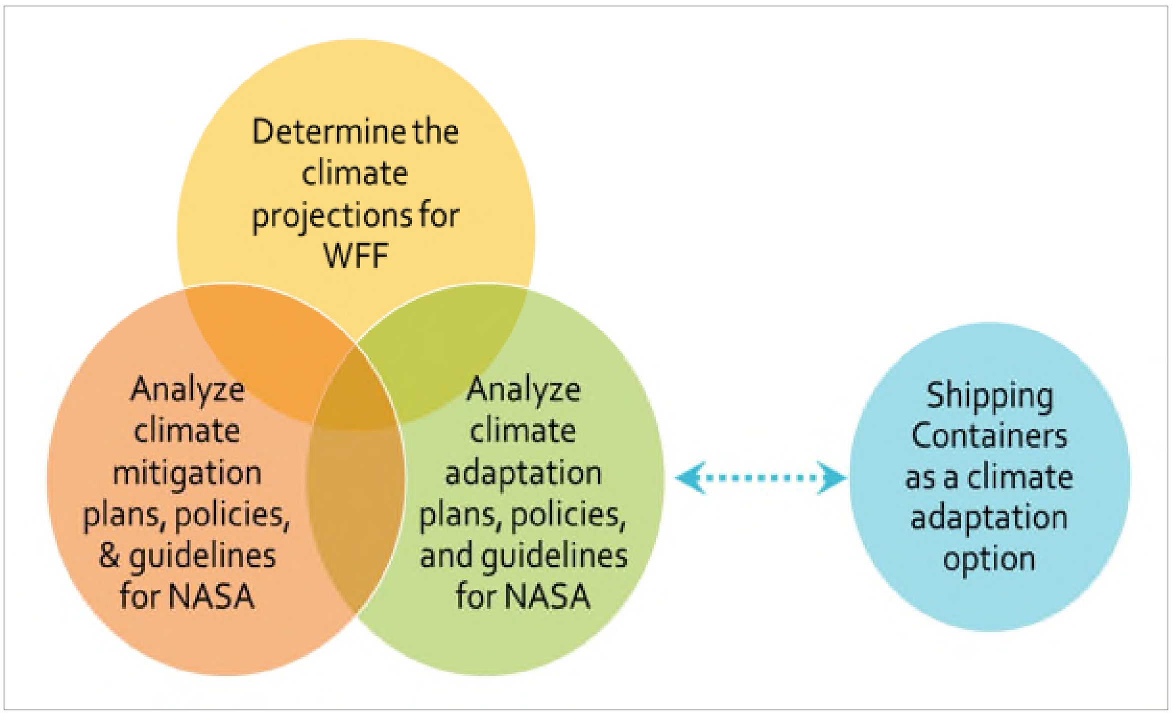

Figure 1- 4: Research direction diagram.

CHAPTER 2:

LITERATURE REVIEW

Climate Adaptation and Resiliency

"Adaptation is a process through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate ***adjustments*** *and changes. There are many options and opportunities to adapt. These range from technological options such as increased sea defenses or flood-proof houses on stilts, to behaviour change at the individual level, such as reducing water use in times of drought and using insecticide-sprayed mosquito nets. Other strategies include early warning systems for extreme events, better water management, improved risk management, various insurance options and biodiversity conservation."* (United Nations Framework Convention on Climate Change, 2007, p. 12)

NASA describes climate adaptation as, "adapting to life in a changing planet that involves **adjusting** to actual or expected climate change." (NASA, 2017). Essentially, we must prepare and adjust to the anticipated changes predicted to occur to the climate of our planet. Climate adaptation shares an interconnected relationship with climate risk as mentioned in NASA'S 2015 Strategic Sustainability Performance Plan:

"Recognizing climate risks as a potential impediment to a sustainable NASA and the importance of "walking the talk" to drive culture ***change****, science and institutional leaders have made adapting to climate risks a focus, participating actively in workshops, advocating for applicable research, and advancing relevant policies."* (NASA , 2015)

The keywords in the descriptions above are adjust and change which is essential in preparing for the effects of climate change. A 2009 report by the Government Accountability Office critique of the federal governments emerging adaption activities stated them as "…*being carried out in an ad hoc manner and were not well coordinated across federal agencies, let alone with state and local governments."* (United States GAO, 2009). That statement suggests the federal agencies need a cohesive climate change adaptation document for strategies that cover all geographical types, locations, assets, etc. for better direction.

According to the NASA Facilities Design Guide, published in 2012, In order to achieve the climate resiliency described above, it is recommended that the following activities be carried out for design and planning projects (NASA, 2012):

- Identify current and future climate hazards (such as sea level rise, salt water intrusion, coastal flooding, overall increased temperature, increased number of high temperature days, precipitation changes, fire, wind, and air quality);
- Characterize risk of climate change on systems and assets (to result in a low, medium, high risk rating through a vulnerability and risk assessment) to identify facilities and locations at most risk;
- Develop potential adaptation strategies, such as:

  a) Raising critical infrastructure which sits in basements or on ground floors;

  b) Increasing cleaning of drains and gutters to reduce flooding;

  c) Integrating green infrastructure to help reducing flood impacts;

  d) Planting more heat and drought/flood tolerant trees, shrubs, and grasses to replace less

  e) tolerant species as the latter deteriorate;

  f) Installing or increasing height of flood barriers such as revetments, levees and sea walls;

  g) Using construction materials resilient to increased temperatures, wind and fire risk or

  h) periodic inundation;

i) Maintaining wildlife corridors; and

j) Zoning changes

- Identify implementation approaches and funding for the adaptation strategies;
- Identify opportunities for partnership and coordination, particularly for sea level rise impacts which can sometimes be more effectively dealt with at a sub-regional level; Integrate into management and planning; and
- Monitor and reassess

Thus, the facilities design guide has recognized that formulating climate change adaptation plans is key in protecting the various infrastructures and buildings at NASA's centers and facilities. Implementation of these plans, however, is not as well-defined as the recommendations and taking the next step in climate adaptation implementation could entail a similar approach as the following from the United Nations:

"Implementing adaptation plans and strategies is a vital next step for developing countries. As highlighted in this chapter, many plans and strategies have been made and a number of capacity-building projects have been undertaken. Now, it is important to bridge the gap between adaption assessment and planning and adaption implementation, and to build on knowledge from capacity building projects. Adaptation options need to be matched to priority needs both in the context of community-based action and in national and sectoral planning as well as disaster risk reduction. Adaptation plans must be integrated into top-down and bottom up approaches for planning to enable sustainable development and the efficient use of resources for adaptation." (United Nations Framework Convention on Climate Change, 2007)

Mitigation

Climate mitigation, according to NASA, is an effort to **reduce** the amount of heat trapping **greenhouse gases** that are released into the atmosphere in hopes of stabilizing humans influence on the climate (NASA, 2017) and is reiterated in the following statement, "Mitigation is a human intervention to **reduce** the sources or enhance the sinks of **greenhouse gases**." (University of Cambridge, 2014). The key term of the two definitions is reduce greenhouse gases. Thus, mitigation in the context of climate change is focused on overall reducing the gases produced by humans that, as mentioned in chapter 1, exasperate global warming.

Shipping Containers

Shipping containers are typically used to transport goods internationally and in building application, shipping containers are referred to as Intermodal Steel Building Units (ISBU's) which are manufactured in various sizes (Home Tune Up, 2014). The typical size for shipping containers are the 20' and 40' varieties that are 8'-6" in height and 8'-0" wide (Figure 2-1 and Figure 2-2). A taller version, called the high-cube, is a foot taller as listed on Table 2-1.

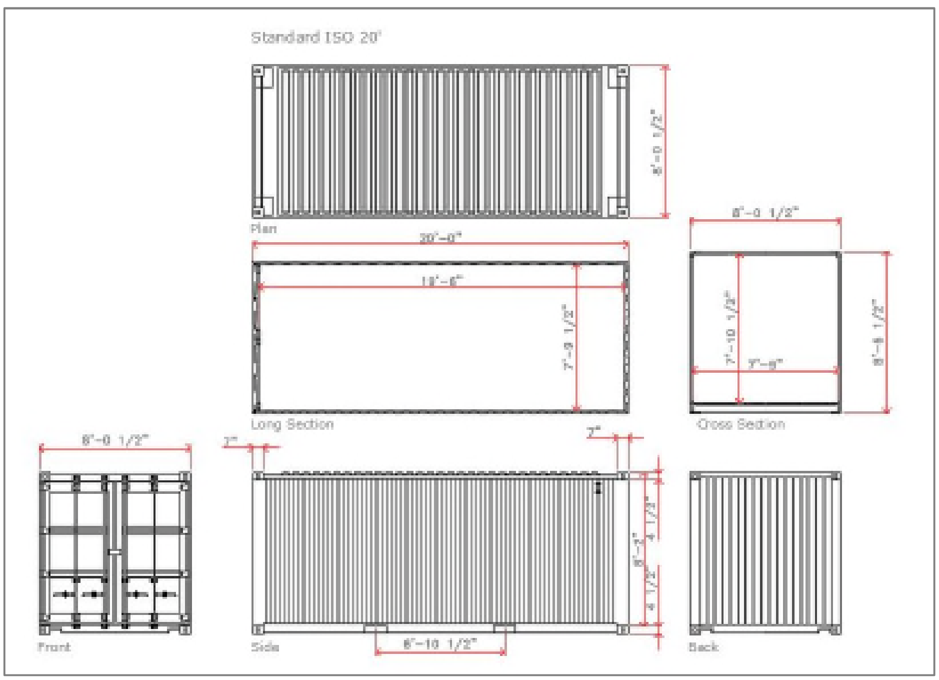

Figure 2- 1: Standard 20' shipping container. (Residential Shipping Container Primer, 2017)

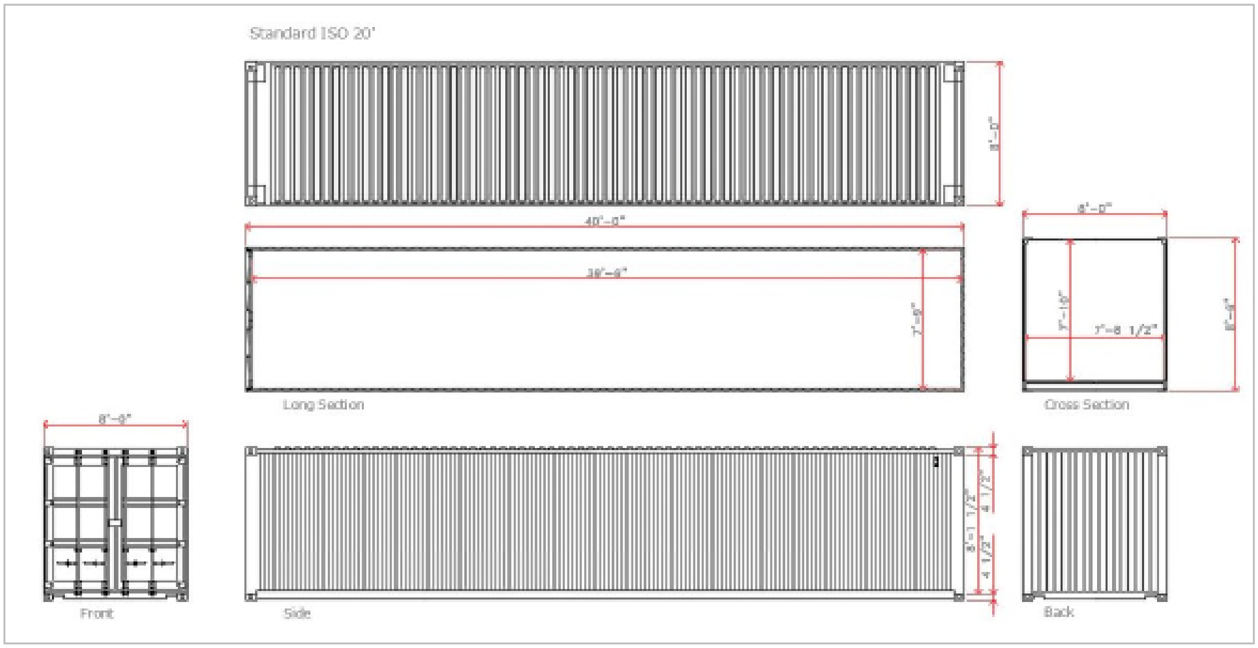

Figure 2- 2: Standard 40' shipping container. (Residential Shipping Container Primer, 2017)

SPECS **Shipping Containers**	**Exterior**			**Internal**			**Door Openings**		**Weight**
	L	W	H	L	W	H	W	H	Empty
20ft.	19′10½″	8′	8′6″	19′3″	7′8″	7′9⅞″	7′8″	7′5″	5050 lb
40ft.	40′	8′	8′6″	39′5″	7′8″	7′9⅞″	7′8″	7′5″	8000 lb
40ft. HC	40′	8′	9′6″	39′5″	7′8″	8′10″	7′8″	8′5½″	8775 lb
45ft. HC	45′	8′	9′6″	44′5″	7′8″	8′10″	7′8″	8′5½″	9810 lb
20ft. Refrigerated	19′10½″	8′	8′6″	17′11″	7′6″	7′6″	7′5″	7′3″	6503 lb
40ft. Refrigerated	40′	8′	8′6″	37′11″	7′6″	7′6″	7′6″	7′6″	9750 lb
40ft. HC Refrigerated	40′	8′	9′6″	37′11″	7′6″	8′4″	7′6″	8′4″	9590 lb

Table 2- 1: Typical shipping containers specs. (Pouraghabagher, 2017)

Primary Structural Components of a Shipping Container

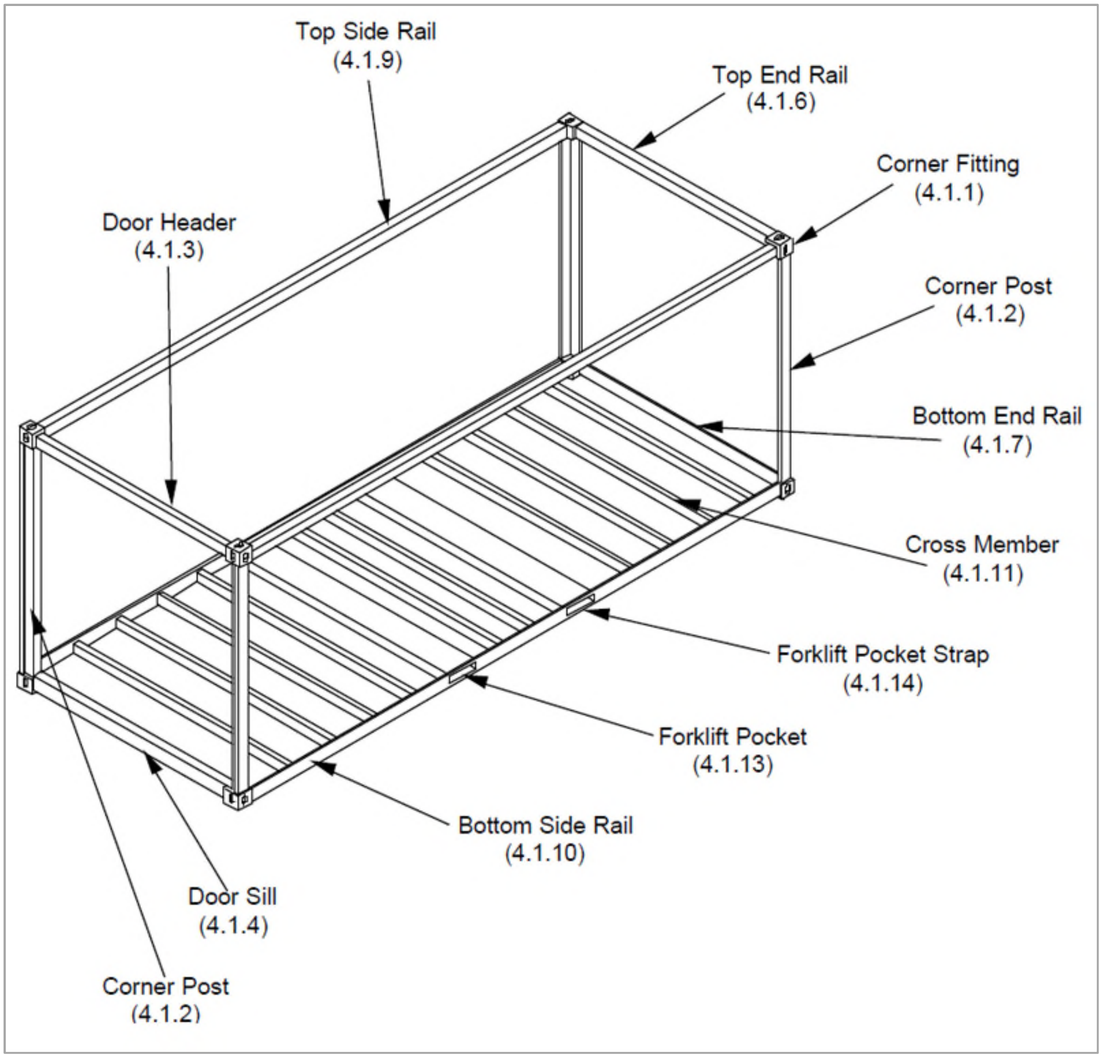

Figure 2- 3: Diagram of shipping container components. (Residential Shipping Container Primer, 2017)

Secondary Structural Components of a Shipping Container

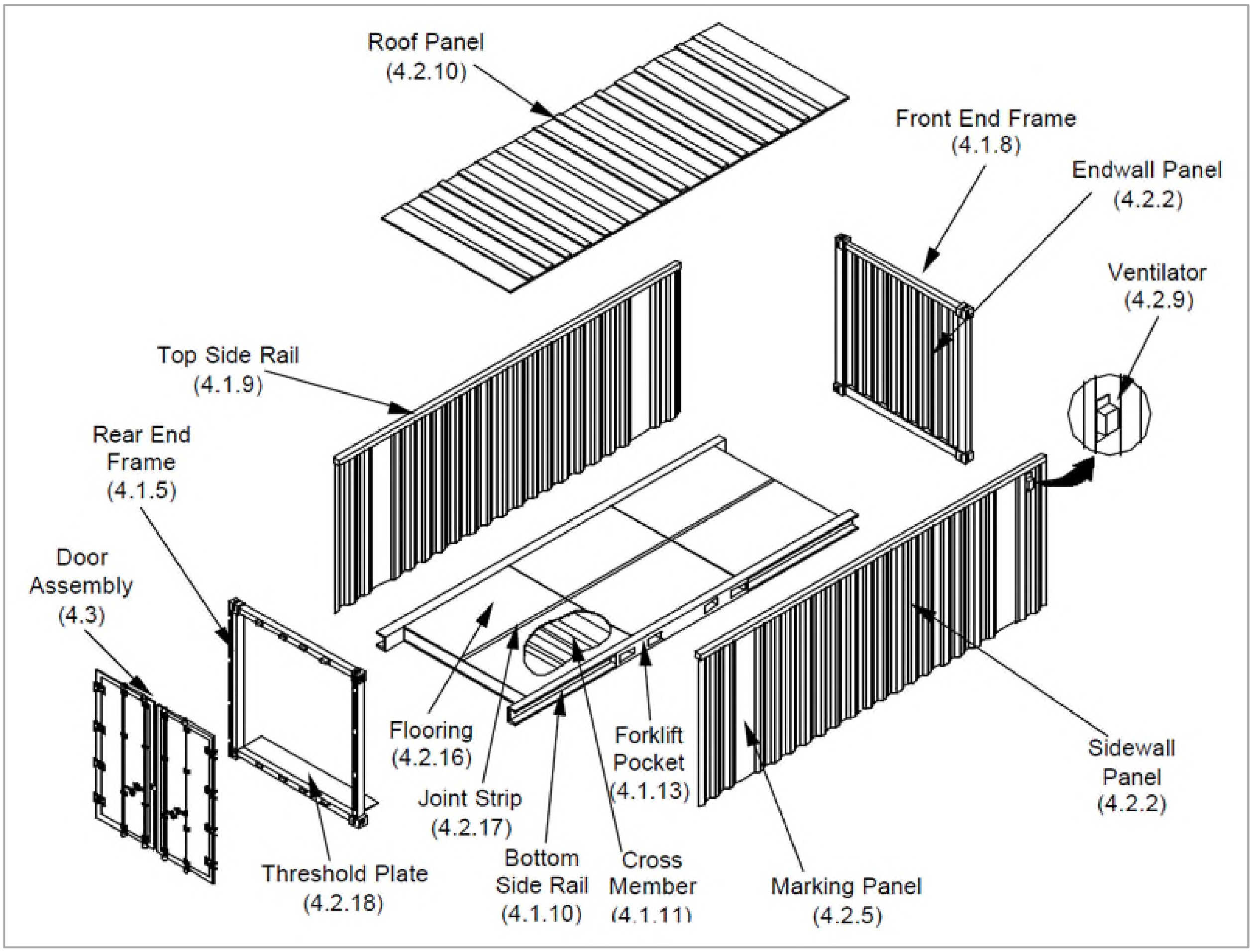

Figure 2- 4: Diagram of secondary structural components of a shipping container components. (Residential Shipping Container Primer, 2017)

Typical Prices for New & Used ISBU's

According to website of Container Homes Plans, shipping container costs are determined by the size and condition of the shipping container. New and used containers are typically priced as follows (Container Home Plans, 2016):

Typical Prices for New Shipping Containers

- 20′ Shipping Container: $3,000
- 20′ High Cube Shipping Container: $3,200

- 40′ Shipping Container: $5,600
- 40′ High Cube Shipping Container: $5,800

Typical Prices for Used Shipping Containers

- 20′ Shipping Container: $2,100
- 20′ High Cube Shipping Container: $2,200
- 40′ Shipping Container: $2,850
- 40′ High Cube Shipping Container: $2,950

Additional Costs

Delivery

According to the Shipping Container Plans website, delivery costs for shipping container home designs are typically calculated for deliveries within 300 miles of the site. A typical delivery cost for a 20’ and 40’ containers is approximately $400 & $780 respectively or about $1.33 per mile for a 20’ container and $2.60 per mile for a 40’ container (Container Home Plans, 2016).

Insulation

There are various methods to insulate shipping containers which have wide range in cost: Spray foam insulation, panel insulation, and blanket insulation. The costs for each method is listed below (Container Home Plans, 2016):

- Spray foam insulation (2” thick): approximately $1.75 to $3.00/sq. ft.
- Panel insulation (3” thick): required wood battens to be fitted into the container first and will be approximately $0.75 to $1.45/sq. ft.

- Blanket insulation: cheapest means and will also require wood battens fitted into the container first. The most popular blanket insulation is fiberglass and mineral wool- you need to make sure you are wearing gloves when fitting it. Approximately $0.30/sq. ft.

As listed above, in order to install spray foam or panel insulation in shipping containers, wood battens must be fitted first. Thus, subtracting from the original square footage which must be accounted for by the designer.

Foundations

Concrete piers are the typical foundations used to disperse weight from shipping containers into the ground. The piers are placed at the corners of the shipping container. The cost estimate for a 40’ containers is $550 (Container Home Plans, 2016). Another choice is a strip or trench foundations which entails laying a small strip of concrete around the perimeter of the container and is usually 2 feet wide and 4 feet deep (Container Home Plans, 2016). Strip foundations are used when the ground is too soft for pier foundations (Container Home Plans, 2016). This method is more expensive than piers because more concrete is used and more excavation is involved (Container Home Plans, 2016). Thus, the cost to provide a strip foundation for a 40’ containers is approximately $5,400. The one drawback of strip foundations is they are weak against wind and earthquakes making them only suited for small and medium size builds (Container Home Plans, 2016).

Advantages of ISBU's

There are several advantages to utilizing shipping containers or ISBU's in design as listed below (Wisley Green, 2017):

1) **Cost per unit**: Approximately $1,200 for a used container and usually no more than $6,000 for a new container.
2) **Structural Benefits:**
   - Steel construction: strong enough to endure harsh elements and high pressure from being stacked. The steel structure is ideal for a building material and can be adapted to a number of building purposes.
   - Simple foundation: Usually pier foundation to save money but is dependent on the location.
3) **Transportable:** Their dimensions make them easy to transport from place to place by various means of transportation.
4) **Availability:** Large volume of perfectly unused containers that can be purchased at a low price.
5) **Labor requirements:** With the correct labor team that specialize in shipping container construction, the costs for labor can be less that it would be for wood frame construction.
6) **Modular Design:** Uniformity in height and length measurements make for a variety of configuration arrangements.
7) **Eco-friendly:** Repurposing shipping containers saves steel and reduces the amount of conventional building materials used such as cement, bricks, and wood.

According to Aadhan Architecture, a firm that specializes in recycling shipping containers state the following advantages with using the containers for building (Aadhan, 2016) :

1) **Green Building:** Eco-friendly when containers are re-purposed. Reusing a single 40' containers upcycles about 3,500 kg of steel and saves about 8,000 kWh of energy that would be needed to melt it down. Repurposing containers uses only 400kWh.
2) **Cost Effective:** At a minimum, 30% cheaper than a comparable sized home built with brick and motor. The structural work is minimal which reduces cost more.
3) **Structural Stability**: Designed for heavy loads, to withstand harsh climatic conditions, and rough seas. Easily can be stacked for multiple stories. Safe for areas prone to earthquakes and hurricanes.
4) **Easy Speed of Construction:** A shipping container home can be constructed in 2-3 weeks compared to a brick and mortar structure which typically takes 4-6 months to complete.
5) **Off Site Construction:** Buildings can be built off site then delivered to the site. Reducing the amount of construction days lost due to inclement weather.
6) **Safety:** In remote areas, shipping containers are too heavy to steal without anyone noticing.

Disadvantages of ISBU's

Shipping containers also have several disadvantages to consider when deciding to use them in design which are listed below (Wisley Green, 2017):

1) **Building Permits**: Due to shipping containers are not a common building design choice, obtaining the required building permits may be troublesome.
2) **Indoor Climate Control**: Since steel conducts heat very well, the container will need to be insulated more than brick, wood, or block construction, especially in regions of extreme temperature variations.
3) **Flexibility**: Designers must adhere to the 20' and 40' containers when combining to make bigger spaces. Thus, cutting into the steel of the containers involves time and is expensive.
4) **Toxic Concerns**: Multiple toxic exposures in shipping containers from the timber floors which are treated with insecticides to the paint on the steel that has may contain dangerous solvents. Therefore, the internal surfaces must be sandblasted, sealed, and repainted which is time consuming.
5) **Construction Placement**: The containers require a crane or forklift to be placed at its destined location.
6) **Structural Weakness**: The corners provide great strength, but the roof is not as strong. Therefore, burying containers underground is not recommended unless additional support is provided.
7) **Container Damage**: Containers often become damaged during transport by collisions, heavy loads, and friction. Causing cracks, twisted frames, or holes in the steel.

Aadhan Architecture, lists the following disadvantages with using the containers in building design (Aadhan, 2016) :

1) **Insulation and Heat Control**: The steel absorb and transmit heat and cold well which makes them problematic in controlling the interior temperature. Insulation is required but will reduce the interior space. In order to increase the space, multiple containers must be joined together on-site.
2) **Refurbishing**: Rust, scratches, and dents must be refurbished correctly by the contractor. However, a container can last a minimum 20 years if repainted every few years.
3) **Ecological Footprint**: Carbon emissions are needed to transport the containers to the site. Before the container can be occupied, they must be sandblasted bare, flooring must be replaced or sealed, and all openings need to be cut with a torch resulting in carbon emissions as well.
4) **Health Hazards**: Contain elements such as chromate, phosphorus, and lead-based paints used on walls. In addition, arsenic and chromium is used to infuse the wooden floors to deter pest infestation.

As the aforementioned advantages and disadvantages suggest, there are many factors to consider when shipping containers becomes an option for constructing a building. The sources above are fairly consistent in their pros and cons. Leading to the next section, if these containers were to be utilized for buildings at Wallops Island for climate adaptation plans, what kinds of spaces could they potentially be made out of them and could the advantages be maximized and disadvantages be minimized?

Opportunities for Shipping Containers Buildings at Wallops Island

Taking the pros and cons of shipping container buildings into consideration for their potential for being incorporated into design options at Wallops Island, the types of buildings they will be utilized for encompass opportunities for NASA to invoke the agency's reputation for innovation. There are over 30 buildings at Wallops Island and shipping containers could be considered for new construction that replaces older buildings. Since most of Wallops Island buildings are associated with rocket launches, it is safe to assume if shipping containers are used on the island, they will likely require spaces for launch control operations, telecommunications, administration, offices, classrooms, testing, research, assembly, maintenance, storage of components, etc. Thus, the opportunity to explore how these spaces can be arranged within shipping containers is a relevant as it pertains to climate adaptation.

CHAPTER 3:

METHODOLOGY

Framework

The purpose of this research is to determine, in anticipation of the future impacts of climate change, if NASA Wallops Flight Facility can benefit from the implementation of shipping containers into its climate change adaptation plans. Thus, adding another approach to protecting the various assets located at the Island of WFF. To establish a basis for this MRP, a comprehensive literature review was utilized.

Data Collection and Analysis

The research will be formulated via cross-sectional, non-experimental research case study design through secondary data. Secondary data will be drawn from journals and reports pertaining to the following information about Wallops Island: topography, geography, shoreline change, hurricanes, and climate change predictions. In addition, the author will analyze information collected from a climate change sub-committee. Processing some of the secondary data will entail transferring pertinent information into tables and charts for quick reference and analysis.

Comparative Document Analysis

Additionally, NASA guidelines pertaining to climate change will be analyzed to showcase the efforts within the agency to address climate change adaption into strategies and to establish if any of those strategies have been implemented. In addition, demonstrate the disparity between the NASA's efforts of climate change adaption strategies as opposed to climate change mitigation.

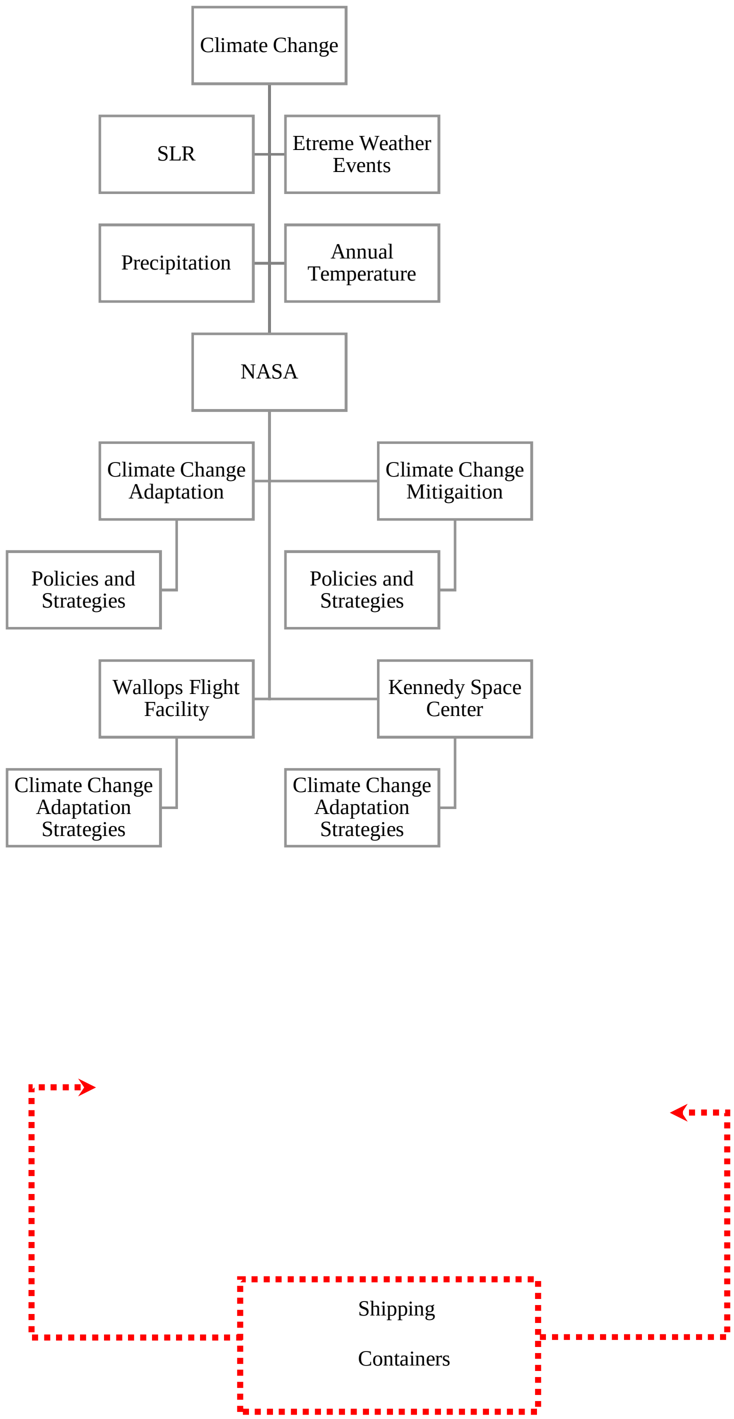

Figure 3- 1: Research Framework.

CHAPTER 4:

RESULTS

Wallops Island Topography and Geography

Wallops Island is a barrier island comprised mostly of marshland that is flanked by the Atlantic Ocean to the east and landward by wetlands. These wetlands also separate Wallops Island from Wallops Mainland. The topography of the Island is generally low-lying with elevations between 0 and 3 feet at the wetlands, 3-6 feet along the shoreline and portions of the existing buildings, 6 feet and above around most existing buildings as well as the roads as illustrated on Figure 2-4 (NASA , 2013).

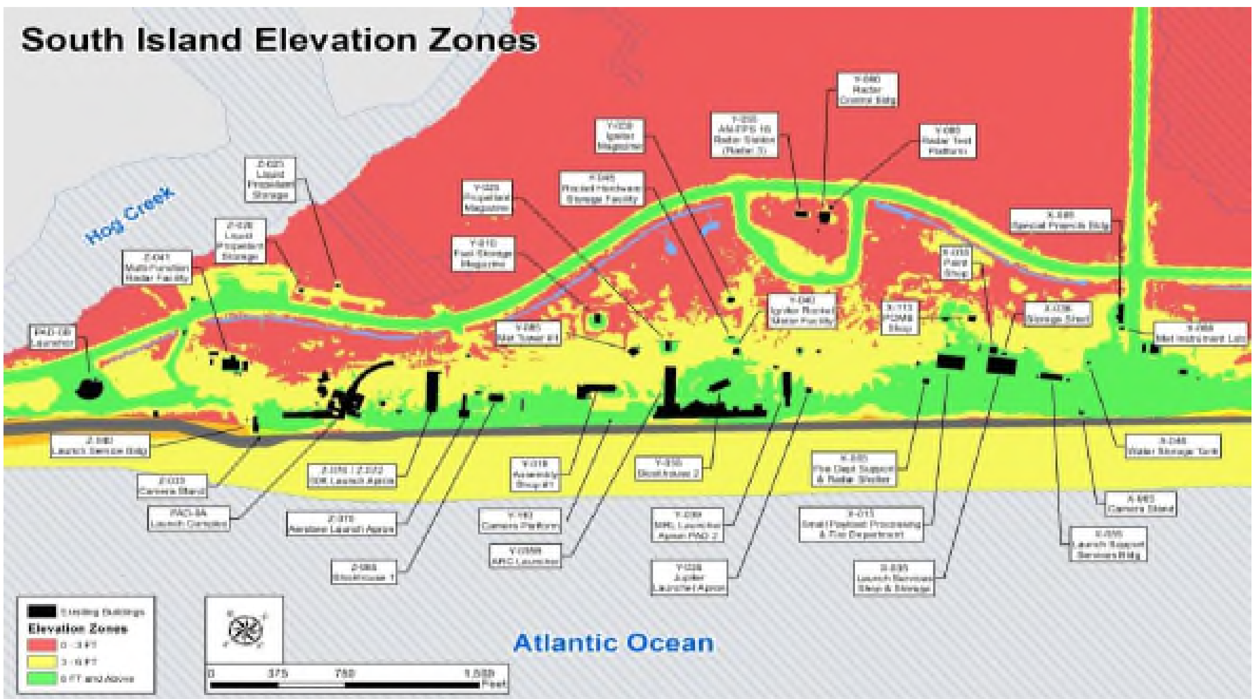

Figure 4- 1: South Island elevation zones at Wallops near launch facilities.

Regarding the wetlands proximity to assets at the Island, in the report, "Predicting the Future of Wetlands on NASA's Wallops Island", it states:

"Specifically to Wallops, wetlands neighbor infrastructure that is key to enabling site wide missions. These infrastructures include small and medium class size rocket launch pads, control centers, and design buildings such as the Horizontal Integration

Facility (HIF) where construction of the Antares vehicles, designed to resupply the International Space Station (ISS), take place…The proximity of Wallops Flight Facility's built environment to natural ecosystems and wetlands highlights the consideration of increasing SLR rates must be taken into account when considering future projects." (Massey, Moisan, Mitchell, & McAllen, 2014).

Shoreline Vulnerability at Wallops Island

In 1999, the barrier islands of the mid-Atlantic, including Wallops Island, ranked as "very high" for coastal vulnerability to SLR (Thieler & Hammar-Klose, 1999). Furthermore, the following statement reiterates the vulnerability of the Island's shoreline:

"Coastal areas are continuously threatened by storm events and long term shoreline change…and are at increased risk for more intensive erosion and sustained coastal flooding. WFF has been battling shoreline change and inundation by storms since the facility's inception." (King Jr., Ward, Williams, & Hudgins, 2010).

Various measures have been employed to counter shoreline change at WFF; from sheet piles to the current measure of a tall rock seawall as shown on table 4-1 (King Jr., Ward, Williams, & Hudgins, 2010). The shoreline of Wallops Island has transformed fairly through the years as evident in Figures 4-8 through 4-19. The southern portion has receded landward from the 1940 through the 1990's, but with the addition of the rock seawall in the 1990's, remains intact. Especially with the periodic beach replenishment projects to counter beach erosion and the pounding of storm surge. The northern and seaside portion of Wallops Island shows a dramatic change with nearly 300 yards of beach built since the 1940's. However, with the uncertainty of storms and the inevitably of sea level rise, measures for shoreline protection at the Island will likely continue well into the foreseeable future especially if SLR becomes compounded with storm surge resulting in a gradual increase beach erosion and flooding.

TIMEFRAME	INFO AND MEASURES TAKEN
1940's – 1950's	• First sea wall erected in 1945 via interlocking 18 ft. sections of sheet pile driven 12 ft. into the ground • United States Army Corps of Engineers recommended the installation of groin field when the high-water line came within 50 ft. of the seawall • In 1956, the Beach Erosion Board recommended that 8 groins be installed at 400 ft. intervals along 2,800 feet of beach which were built (Figure 2-5)
1960's – 1980's	• In 1960, the seawall was extended further north • Mechanically closed breach following the Ash Wednesday storm of March 6-8, 1962 • A total of 47 groins had been built along the shoreline by 1972. • Groins functioned well in the 1960's and early 1970's and considered a success • Groins showed signs of deterioration by the 1980's • Two experimental beach barrier projects were initiated in the mid 1980's and both failed
1990's – present	• Current rock sea wall was built in the mid 1990's (Figure 2-9) • Wooden groins removed at the same time • Rock seawall halted the shoreline retreat substantially but sub-aerial beach disappeared, excepted at the northern end • The sub-aqueous beach seaward of the sea wall has continued to erode • Because rock seawall is porous, storm waves frequently penetrate it, causing flooding and eroding sand on the landward side. • Major shoreline projection project completed August 2012 prior to Hurricane Sandy which removed 700 feet of protective berm and about 20% of the beach * (Gutro, 2013)

Table 4- 1: Timeframe and measures taken for shoreline protection at Wallops Island. (King Jr., Ward, Williams, & Hudgins, 2010) & (Gutro, 2013)

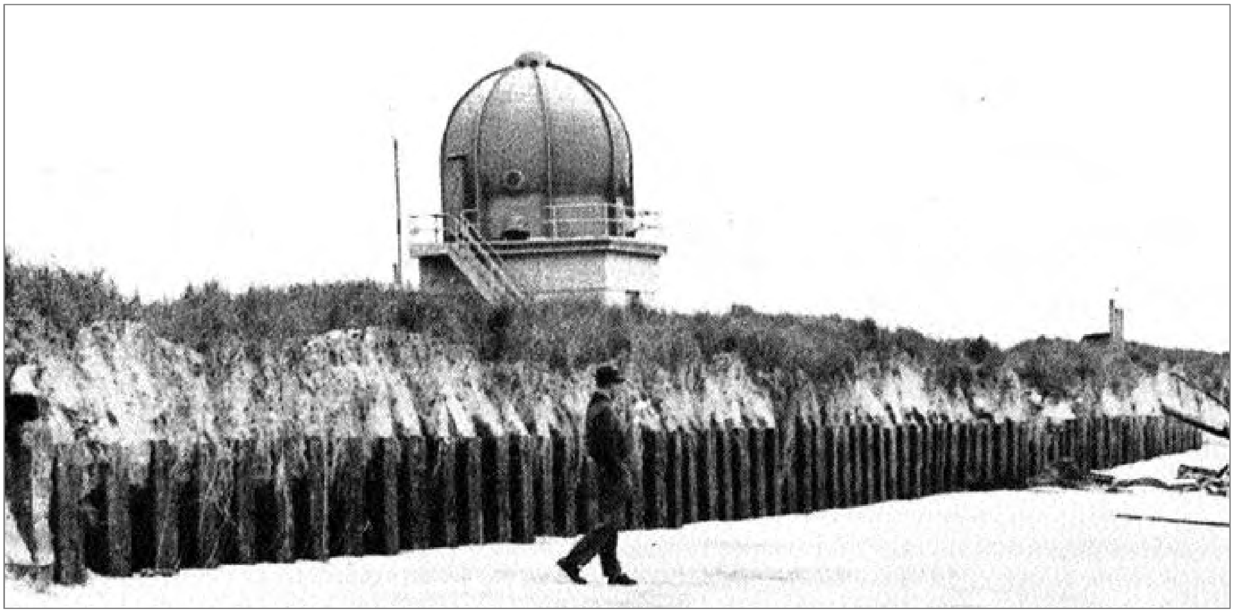

Figure 4- 2 Wallops Island seawall in 1956. (King Jr., Ward, Williams, & Hudgins, 2010)

Figure 4- 3: Wooden groins at Wallops Island 1959. (King Jr., Ward, Williams, & Hudgins, 2010)

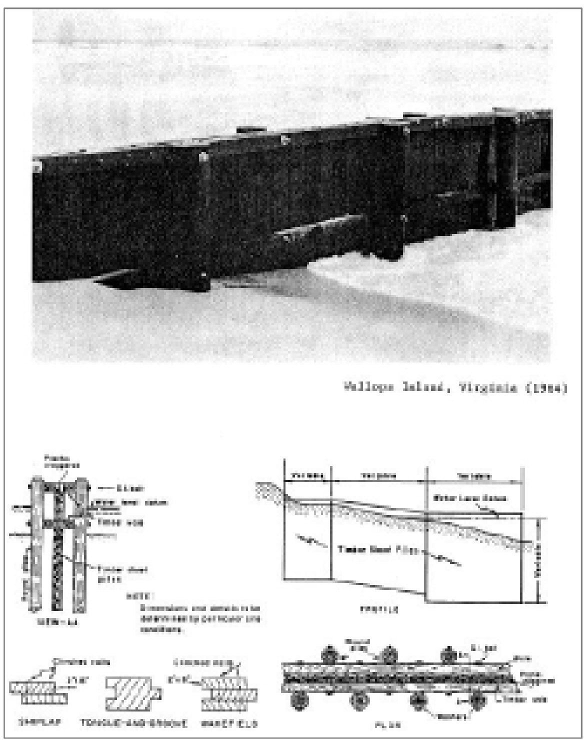

Figure 4- 5: Wallops Island groin wooden groins and diagram in 1964. (King Jr., Ward, Williams, & Hudgins, 2010)

Figure 4- 4: Wallops Island groin field in 1969. (King Jr., Ward, Williams, & Hudgins, 2010)


Figure 4- 6: Rock seawall at Wallops Island. Photo taken by author June 2017.


Figure 4- 7: Rock seawall at Wallops Island. Photo taken by author June 2017.

Figure 4- 8: Wallops Island Shoreline, 1949. (Coastal Resilience, n.d.)

Figure 4- 9: Wallops Island Shoreline, 1962. (Coastal Resilience, n.d.)

Figure 4- 10: Wallops Island Shoreline, 1975. (Coastal Resilience, n.d.)

Figure 4- 11: Wallops Island Shoreline, 1985. (Coastal Resilience, n.d.)

Figure 4- 12: Wallops Island Shoreline, 1994. (Coastal Resilience, n.d.)

Figure 4- 13: Wallops Island Shoreline, 2002. (Coastal Resilience, n.d.)

Figure 4- 14: Wallops Island Shoreline, 2004. (Coastal Resilience, n.d.)

Figure 4- 15: Wallops Island Shoreline, 2006. (Coastal Resilience, n.d.)

Figure 4- 16: Wallops Island Shoreline, 2009. (Coastal Resilience, n.d.)

Figure 4- 17: Wallops Island Shoreline, 2011. (Coastal Resilience, n.d.)

Figure 4- 18: Wallops Island Shoreline, 2013. (Coastal Resilience, n.d.)

Figure 4- 19: Wallops Island Shoreline, 2014. (Coastal Resilience, n.d.)

As Figures 4-8 through 4-19 show, the central and southern shoreline sections at Wallops Island have gradually receded while the shoreline at the northern section has gradually increased seaward.

Increase of Hurricanes impacting Wallops Island

According to the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management, since 1970, a total of twenty-one hurricanes, tropical storms, tropical depressions, and extra tropical have come within 65 nautical miles of Wallops Island as shown on the table 4-2. Hurricane Sandy, a 2012 storm that removed 700 feet of beach at the protective berm at Wallops Island and 20 percent of the beach (Gutro, 2013), was well out of the 65-nautical mile radius but within 100 nautical mile range of the island (NOAA, 2017). Close enough to cause tremendous beach erosion and damage to the beach replenishment project at the Island which was completed just months prior to Hurricane Sandy wreaking havoc on the east coast of the United States (Massey, Moisan, Mitchell, & McAllen, 2014). Thus since 1970, with the 65-nautical mile threshold in mind, there has been a steady increase of storms that have affected Wallops Island with 2004 being the busiest year to date and the remaining years of the 2010's is still to be determined.

YEAR	NAME OF HURRICANE	DURATION OF STORM	INTENSITY OF STORM (WITHIN 65 NAUTICAL MILES OF WALLOPS ISLAND)
1971	DORIA	August 20, 1971 to August 29, 1971	TROPICAL STORM
1971	GINGER	September 6, 1971 to October 5, 1971	TROPICAL DEPRESSION
1981	BRET	June 29, 1981 to July 1, 1981	TROPICAL DEPRESSION
1983	DEAN	September 26, 1983 to September 30, 1981	TROPICAL STORM
1985	DANNY	August 12, 1985 to August 20, 1985	EXTRA TROPICAL

1985	GLORIA	September 16, 1985 to October 2, 1985	CATERGORY 3 HURRICANE
1986	CHARLEY	August 13, 1986 to August 30, 1986	CATEGORY 1 HURRICANE
1992	DANIELLE	September 22, 1992 to September	TROPICAL STORM
1996	BERTHA	July 5, 1996 to July 17, 1996	TROPICAL STORM
1999	FLOYD	September 7, 1999 to September 19, 1999	CATEGORY 1 HURRICANE
2000	GORDON	September 14, 2000 to September 21, 2000	EXTRA TROPICAL
2001	ALLISON	June 5, 2001 to June 19, 2001	TROPICAL DEPRESSION
2004	BONNIE	August 3, 2004 to August 14, 2004	TROPICAL DEPRESSION
2004	CHARLEY	August 9, 2004 to August 15, 2004	EXTRA TROPICAL
2004	GASTON	August 27, 2004 to September 3, 2004	TROPICAL STORM
2004	IVAN	September 2, 2004 to September 24, 2004	EXTRA TROPICAL
2004	JEANNE	September 13, 2004 to September 29, 2004	EXTRA TROPICAL
2008	HANNA	August 28, 2008 to September 8, 2008	TROPICAL STORM
2011	IRENE	August 21, 2011 to August 30, 2011	CATEGORY 1 HURRICANE
2013	ANDREA	June 5, 2013 to June 8, 2013	EXTRA TROPICAL
2015	ANA	May 6, 2015 to May 12, 2015	TROPICAL DEPRESSION

Table 4- 2: Historical List of Hurricanes that came within 65 nautical miles of Wallops Island since 1970. (NOAA, 2017)

Figure 4- 20: Shoreline of Wallops Island August 2012 (left), post Hurricane Sandy in November 2012 (right). (Gutro, 2013)

Climate Projections for Wallops Flight Facility

CASI conducted climate project research findings for the NASA centers/facilities based on 33 Global Climate Models (GCM's) and 2 Representative Concentration Pathways (RCP 8.5 and RCP 4.5) that incorporate assumptions about future greenhouse gas levels (CASI, 2015). Those projections were originally published in 2012 and later updated in 2015. The baseline data are from 1971 to 2000 and was acquired from the NOAA National Climatic Data Center (NCDC) (CASI, 2015). In reference to the RCP 8.5 and RCP 4.5, here are how both pathways are broken down (CASI, 2015):

- The RCP 8.5 pathway most closely represents “Business as Usual” and follows a steadily rising trend of greenhouse gas emissions over this century.
- The RCP 4.5 pathway presumes some decrease in greenhouse gas emissions

With those pathways in mind, the CASI team were able to pursue the climate projection research with the following time variables: Baseline (1971-2000), the 2020’s, the 2050’s, & the 2080’s. The projections were the shown in the following percentile ranges: low estimate (10th percentile), middle range (25th and 75th percentile), and high estimate (90th percentile). Climate predictions published by CASI revealed the following climate variables were researched (CASI, 2015):

- Annual Temperature
- Annual Precipitation
- Annual Sea Level Rise
- Extreme Events
- Seasonal Changes

This MRP focused on the annual temperatures, annual precipitation, annual sea level rise, and extreme events by showcasing those predictions into tables for visual reference and analysis (Figures 4-21 through 4-29). In addition, the following tables, the averages between the 25th and 75th percentiles are shown for the middle range results.

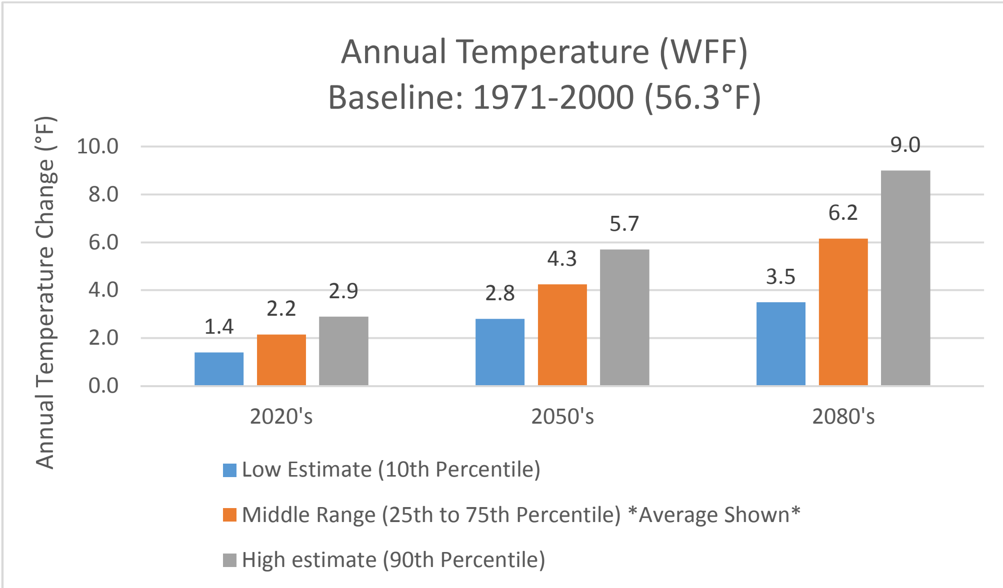

Figure 4- 21: Annual temperature change projections for Wallops Flight Facility. (CASI, 2015)

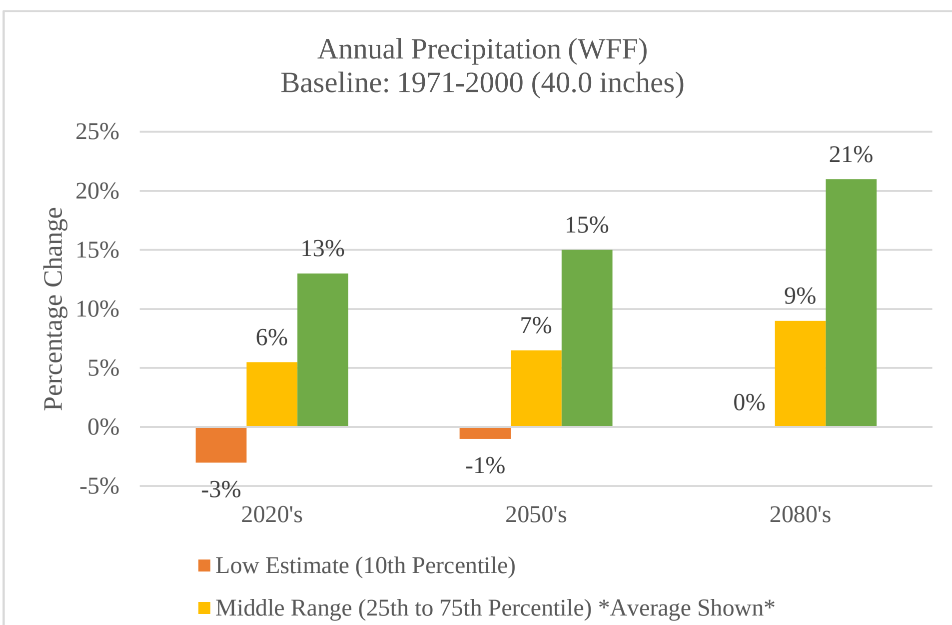

Figure 4- 22: Annual precipitation projections for Wallops Flight Facility. (CASI, 2015)

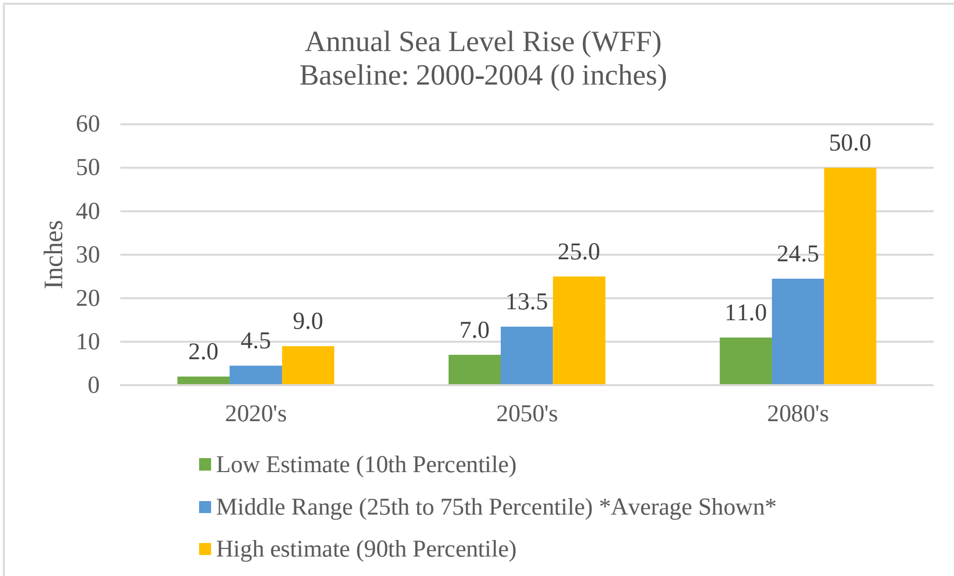

Figure 4- 23: Annual sea level rise projections for Wallops Flight Facility. (CASI, 2015)

Number of days/yr. with max temp at or above 90F

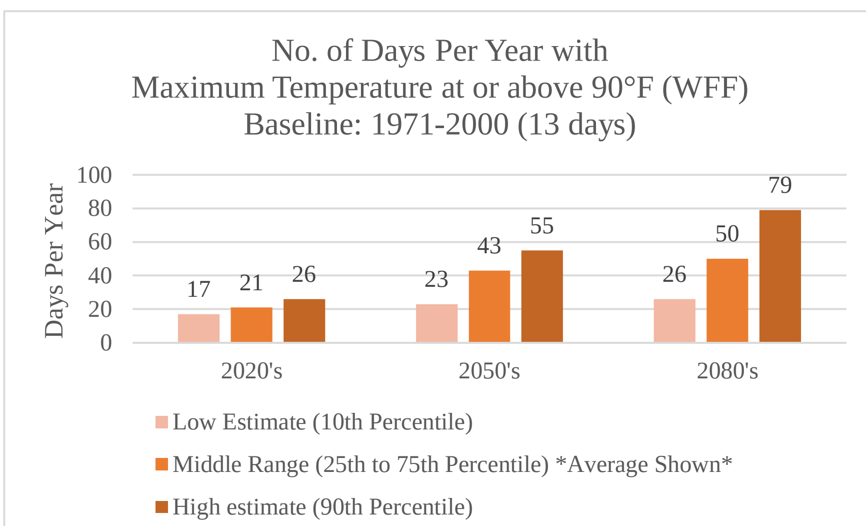

Figure 4- 24: Projections for no. of days/year with maximum temperature at or above 90°F at Wallops Flight Facility. (CASI, 2015)

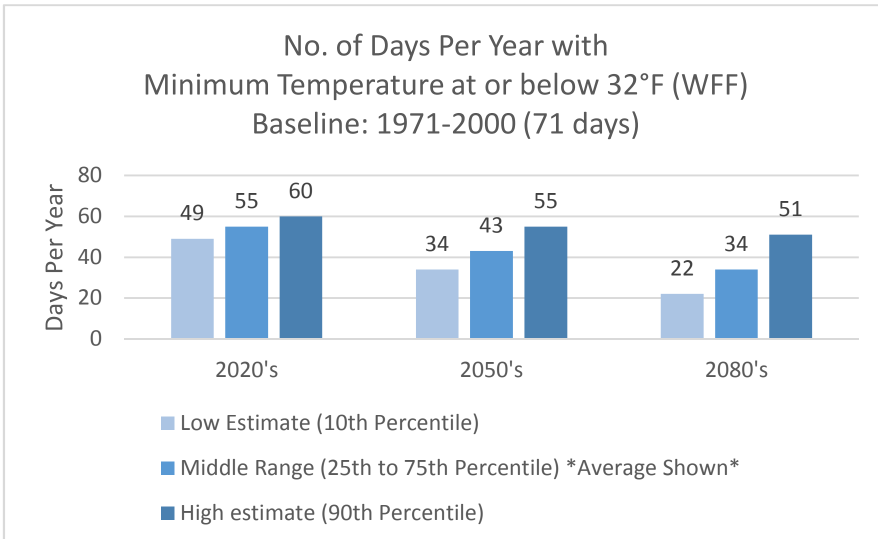

Figure 4- 26: Projections for no. of days/year with minimum temperature at or below 32F at Wallops Flight Facility. (CASI, 2015)

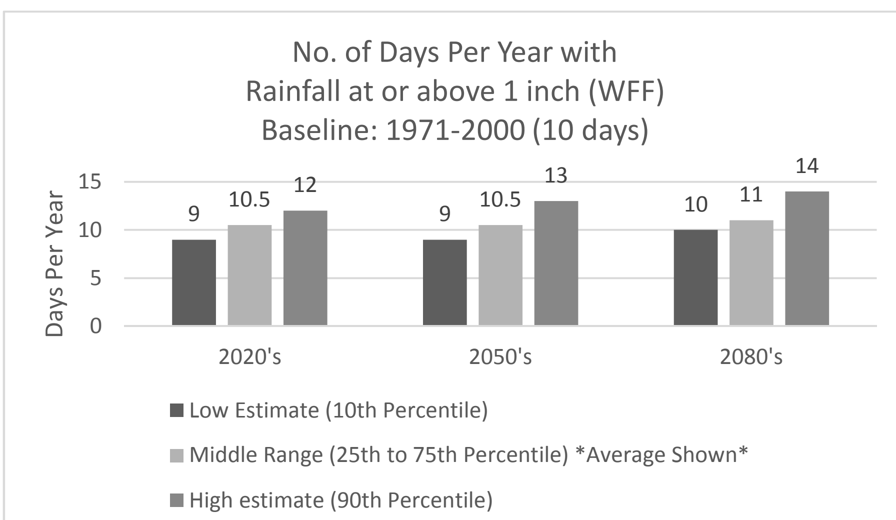

Figure 4- 25: Projections for no. of days/year with rainfall at or above 1 inch at Wallops Flight Facility. (CASI, 2015)

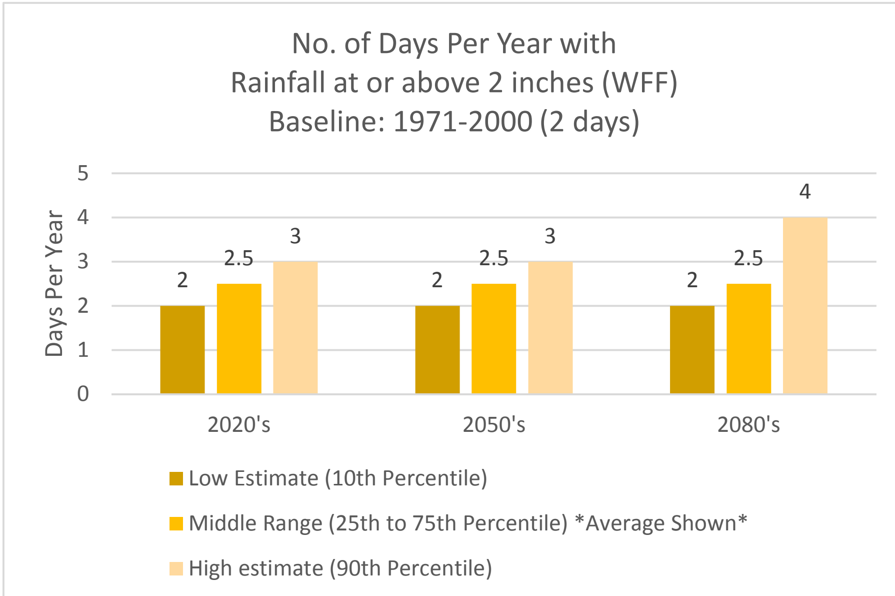

Figure 4- 27: Projections for no. of days/year with rainfall at or above 2 inches at Wallops Flight Facility. (CASI, 2015)

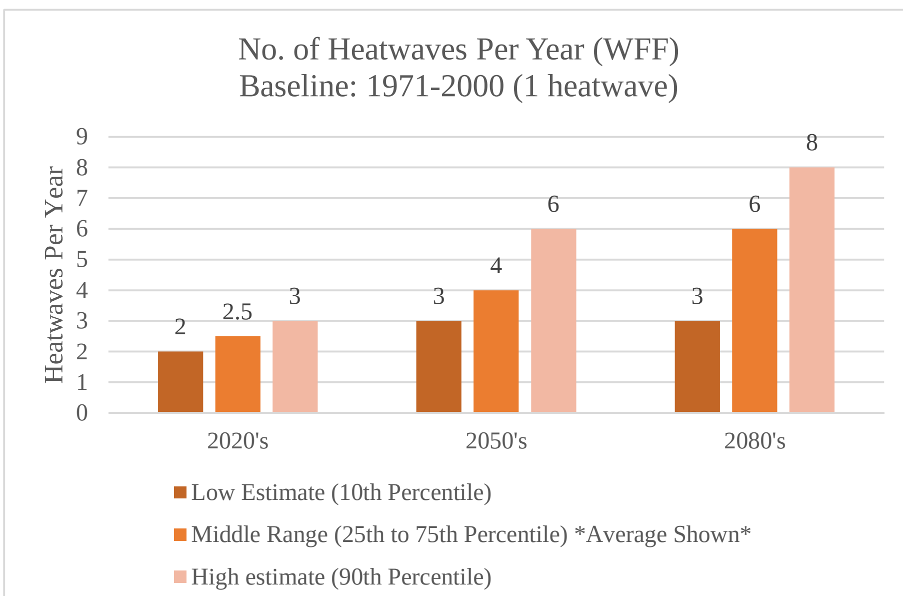

Figure 4- 28: Projections for no. of heatwaves/year at Wallops Flight Facility. (CASI, 2015)

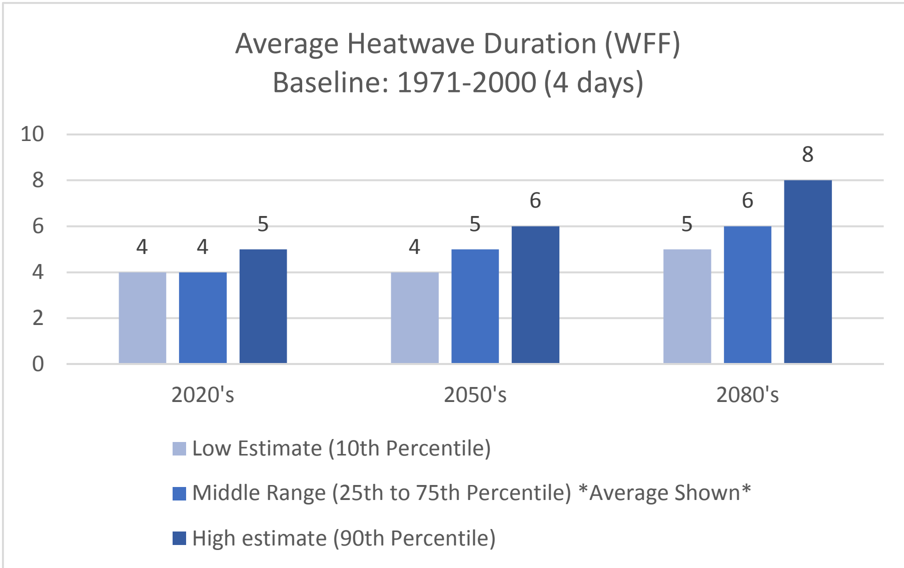

Figure 4- 29: Projections for the average heatwave duration at Wallops Flight Facility. (CASI, 2015)

Case Study: NASA Kennedy Space Center, Florida

Relevancy of KSC to the Research

Like WFF, KSC is also a NASA center located on the east coast of the United States. In addition, the low-lying topography of KSC (Figure 4-31) makes it susceptible to flooding, intense storms, as well as share similar assets and geography as WFF (NASA KSC, 2017). Comprised of 41,425 acres of wetlands, KSC also has issues with shoreline change and has periodic shoreline restoration projects crucial in protecting the assets located there with the last restoration complete in 2015 (Granath & Frank, 2014). The main assets at KSC are:

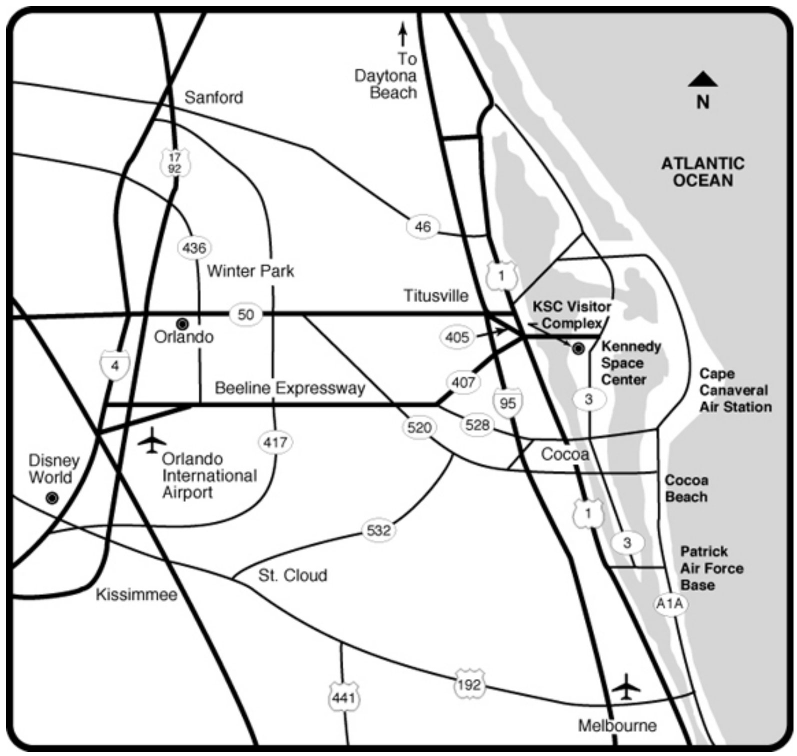

Figure 4- 30: Map of NASA Kennedy Space Center, Florida. (NASA KSC, 2017)

A. Central Campus Headquarters Building
B. Launch Abort System Facility
C. Commercial Crew Cargo Processing Facility
D. Launch Complex 39A
E. Launch Complex 39B (Figure 4-32)
F. Vehicle Assembly Building
G. Space Life laboratory
H. Shuttle Landing Facility

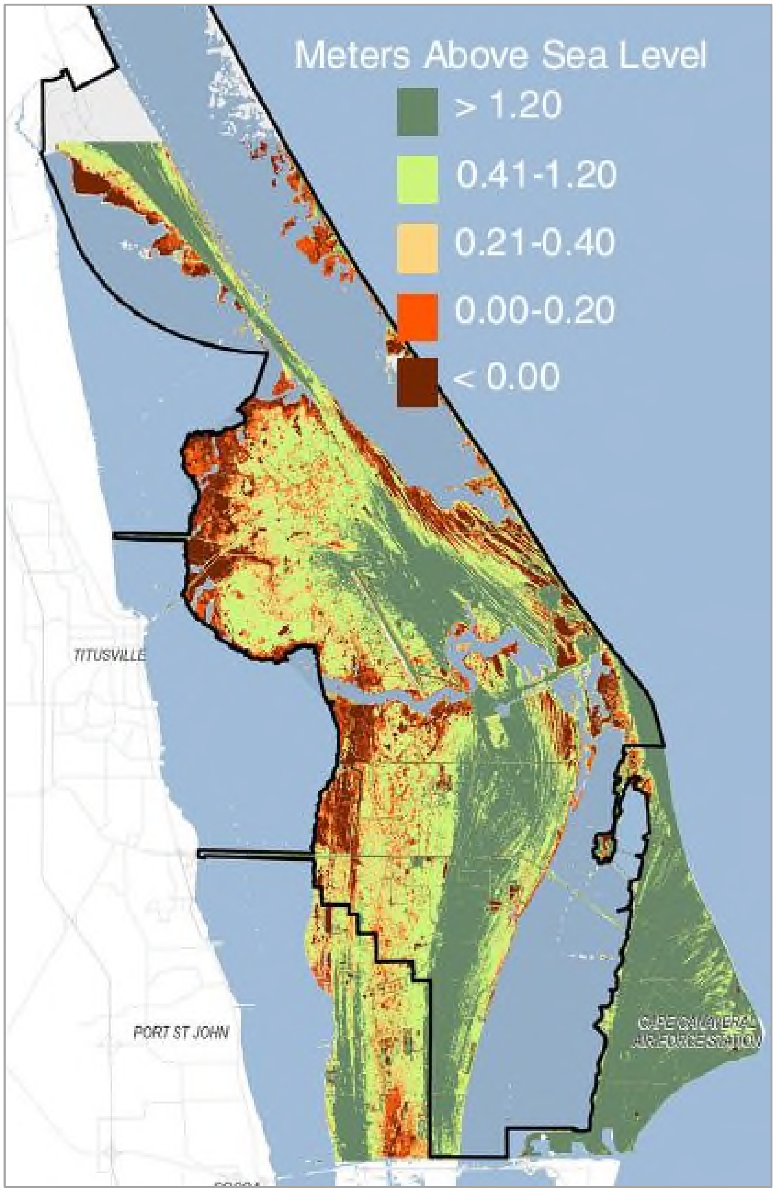

Figure 4- 31: Topography map of NASA Kennedy Space Center, Florida. (NASA KSC, 2017)

Figure 4- 32: Proximity of Launch Pad 39-B to the ocean. (Carlowicz, 2015)

Similar to the shoreline of Wallops Flight Facility, Kennedy Space Center's shoreline is also susceptible to beach erosion from the impact of intense storms like hurricanes. In 2012, Hurricane Sandy churned 200 miles off the coast of Florida as it slowly made its way up the east coast causing a dune to as much as 65 feet along a two mile stretch near Launch Pad 39B (Carlowicz, 2015). In addition, storm surge damaged 650 of railroad track and the high-tide line moved closer to a service road which has critical infrastructures under it such as natural gas, rocket fuel, and communications (Carlowicz, 2015). Overall, Hurricane Sandy caused much more damage at Kennedy Space Center compared to Wallops Flight Facility but when comparing shoreline damage, both locations suffered very similar outcomes. Both locations had to have beach restoration projects fulfilled to protect their respective assets near the shore, with KSC's dune replenishment project completed in 2014 (Granath & Frank, 2014).

In the Kennedy Space Center: Master Plan Executive Summary it states:

"Much of KSC land areas are low-lying, poorly drained, and vulnerable to inundation by periodic storm events. These low-lying areas are also most at risk to be affected by global climate change in future decades. Areas of existing facilities or structures that are in 0-1.20 meters NAVD (North American Vertical Datum) should be assessed relative to anticipated future climate and weather conditions. Where practical, the function within existing facilities should be relocated to ground 1.82 meters (approximately 6 feet) or above where required. Future critical facilities shall be constructed outside the 500-year flood plain. Where practical, existing critical facilities should be hardened to withstand a 500 year flood event, or their functions moved to an area outside the 500- year flood plain." (NASA KSC, 2017)

Thus, the directors at KSC have acknowledged the need for climate change adaption strategies targeted at flood inundation and weather conditions in general. Strategies such as relocating assets to locations 6 feet above sea level or constructing new facilities outside the flood plain are obvious approaches but land is limited due to conservation efforts by NASA as evident in the KSC Development Suitability Map shown in Figure 4-33. 95 percent of the approximately 141,829 acres of land at KSC remain undisturbed, leaving about 7,500 acres of land to support space mission operations (NASA KSC, 2017). Land available for development at KSC is limited due to those conservations efforts, vast wetlands, and low-lying topography. Therefore, with the variables for climate change inevitably on the rise, climate change adaptation strategies to protect current and future assets at KSC provide a means to investigate how incorporating shipping containers buildings into asset protection can be a viable solution for both WFF and KSC.

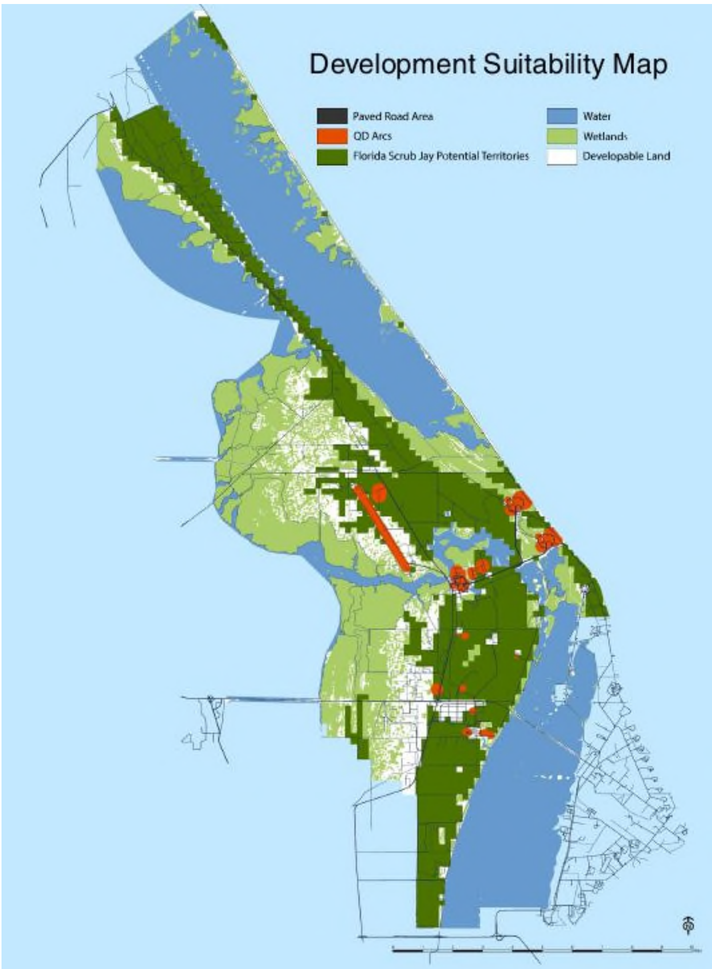

Figure 4- 33: Development Suitability Map of NASA Kennedy Space Center, Florida.

KSC is currently in the process of implementing a 20-year master plan via a series of planning development stages. The stages, listed below, are accompanied by one stage that includes climate change adaptation in the mix (NASA KSC, 2017) and although "climate change adaptation" is not included in the verbiage of the strategy, it certainly fits into the parameters of actions needed to put that strategy into action. The master plan for KSC includes the following stages/tasks (NASA KSC, 2017):

- Incorporates themes and concepts developed by KSC employees and stakeholders, identified in KSC's Future Development Concept (FDC)

- Combines written and graphical documentation to describe KSC's current state with implementation strategies for achieving the desired vision and future state
- Repositions resources to accommodate both NASA operations and the integration of the emerging commercial space market.
- Integrates development alternatives and corresponding operating models to support NASA programmatic needs as well as commercial space market opportunities
- **Identifies the most suitable areas of KSC for future development, taking factors including development capacity, the environment, and sea level rise into account.**
- Supports KSC's long-term end state with an asset consolidation and infrastructure divestiture strategy, enabled by implementation stages.

As aforementioned, compared to WFF, KSC has similar assets, has a low-lying topography, is prone to shoreline change, and is susceptible to flooding, storm surge, sea level rise and intense storms. Thus, KSC is a relevant location to apply as a case study for comparative assessment purposes.

Climate Projections for KSC

To find further correlations between the locations of KSC and WFF in reference to climate change adaptation, the same climate projection research conducted and published by CASI for WFF was produced for KSC as well. The following tables showcasing KSC climate projections reveal gradual increases in annual temperature, precipitation, SLR, and extreme weather events through the end of the century (CASI, 2015) almost parallel to the climate projections for WFF (Figures 4-34 through 4-42). The projections were conducted by CASI utilizing the same the same GCM's and RCP's used for WFF's projections.

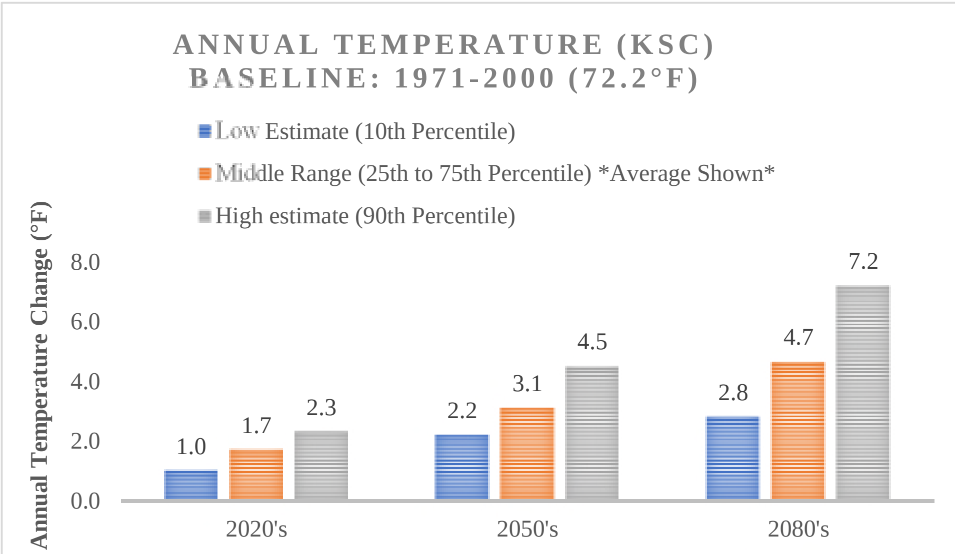

Figure 4- 35: Annual temperature change projections for Kennedy Space Center. (CASI, 2015)

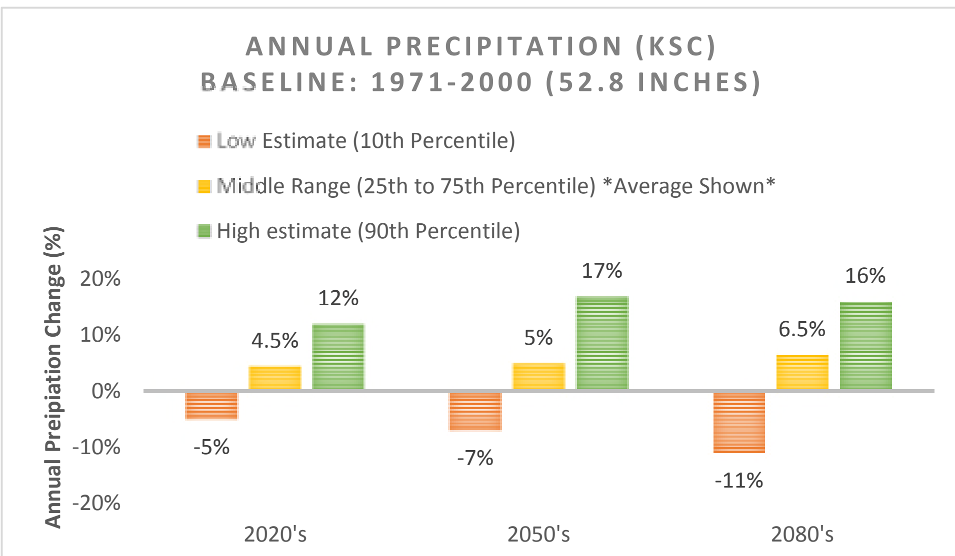

Figure 4- 34: Annual precipitation change projections for Kennedy Space Center. (CASI, 2015)

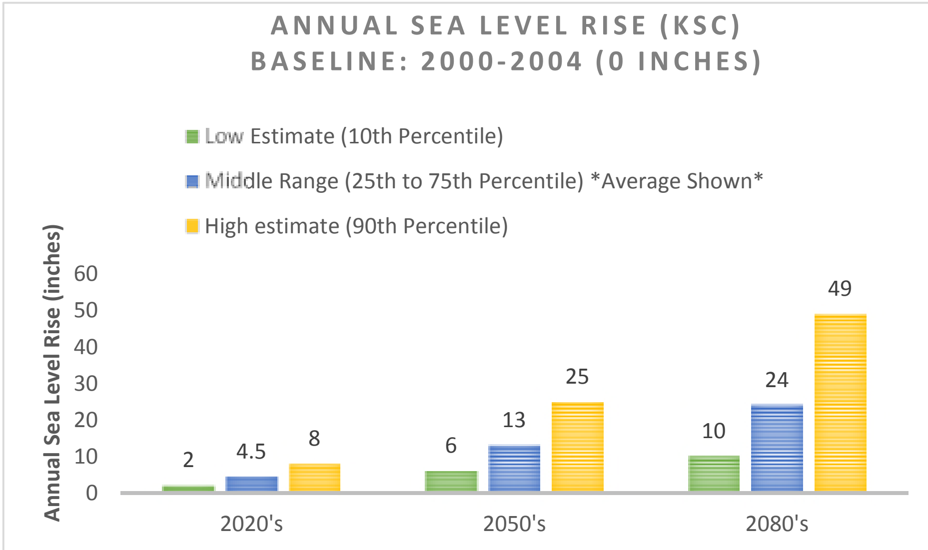

Figure 4- 37: Annual sea level rise projections for Kennedy Space Center. (CASI, 2015)

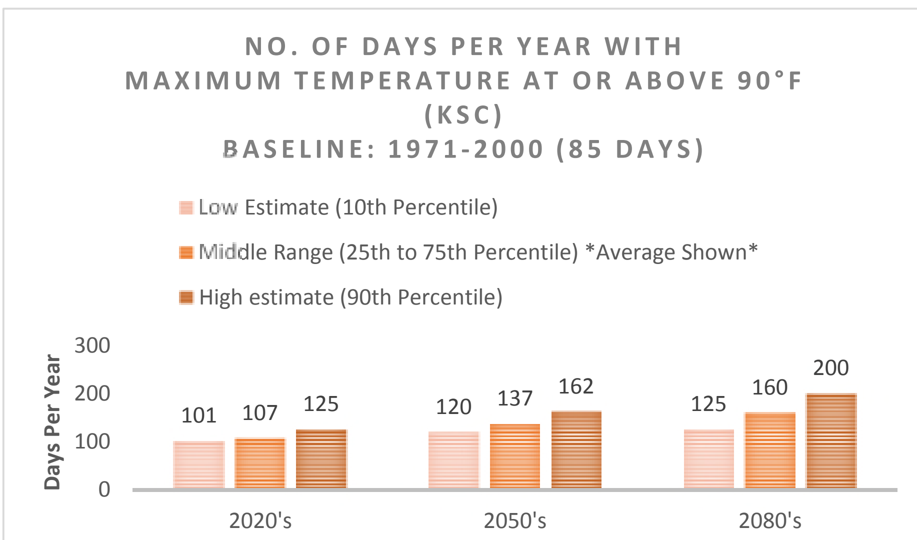

Figure 4- 36: Projections for no. of days/year with maximum temperature at or above 90°F at Kennedy Space Center. (CASI, 2015)

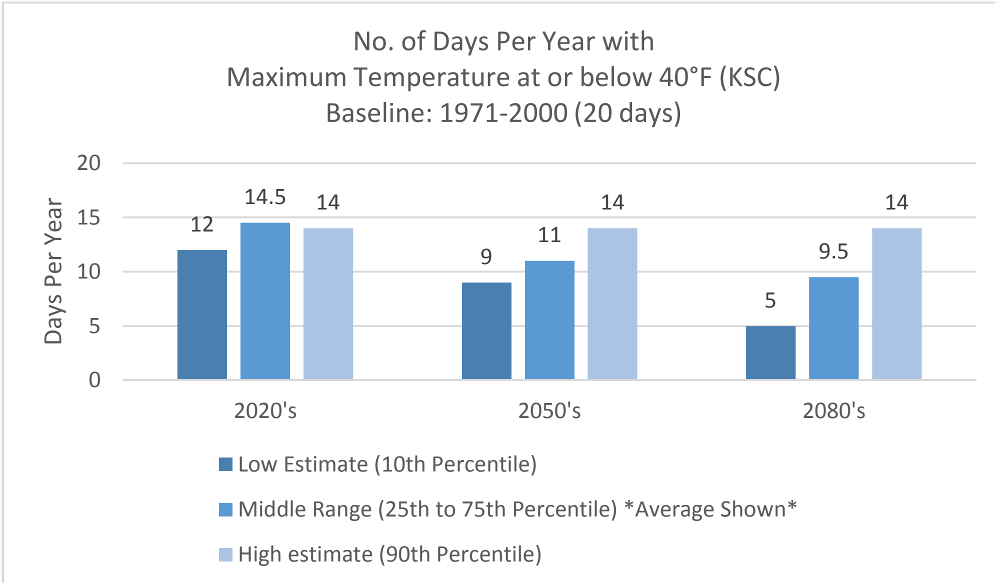

Figure 4- 38: Projections for no. of days/year with a minimum temperature at or below 40°F at Kennedy Space Center. (CASI, 2015)

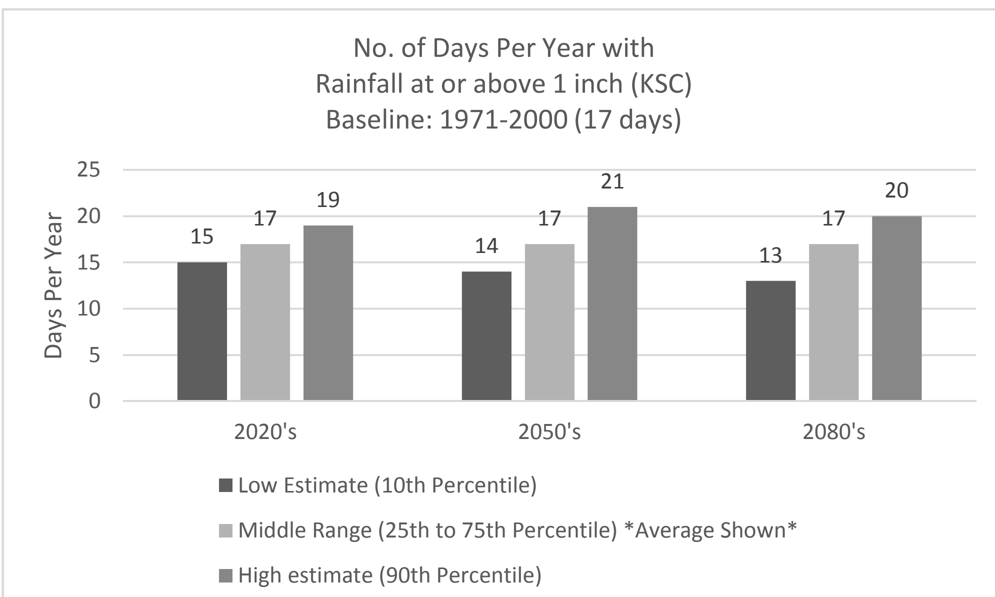

Figure 4- 39: Projections for no. of days/year with rainfall at or above 1 inch at Kennedy Space Center. (CASI, 2015)

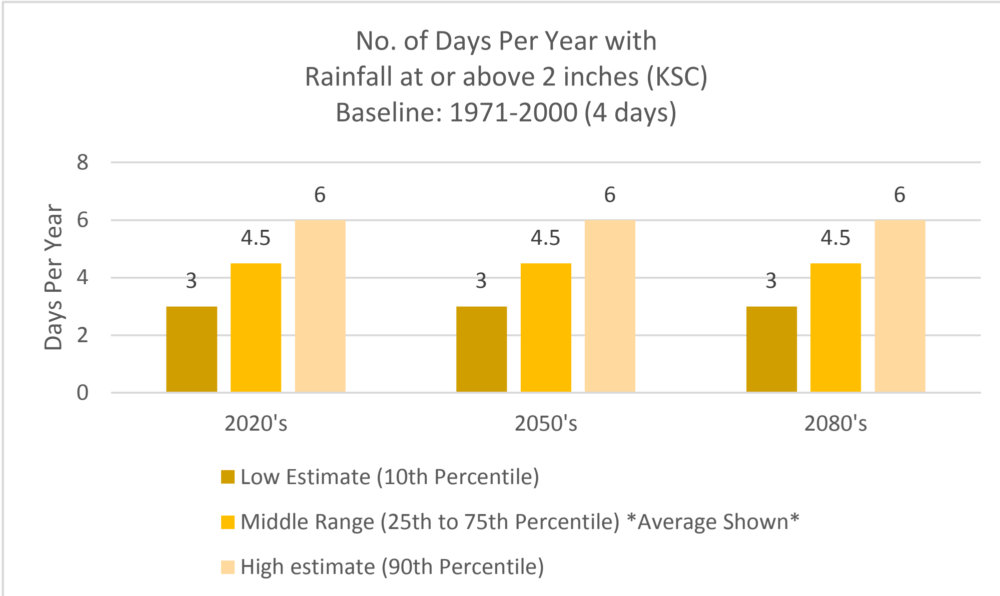

Figure 4- 40: Projected no. of days/year with rainfall at or above 2 inches at Kennedy Space Center. (CASI, 2015)

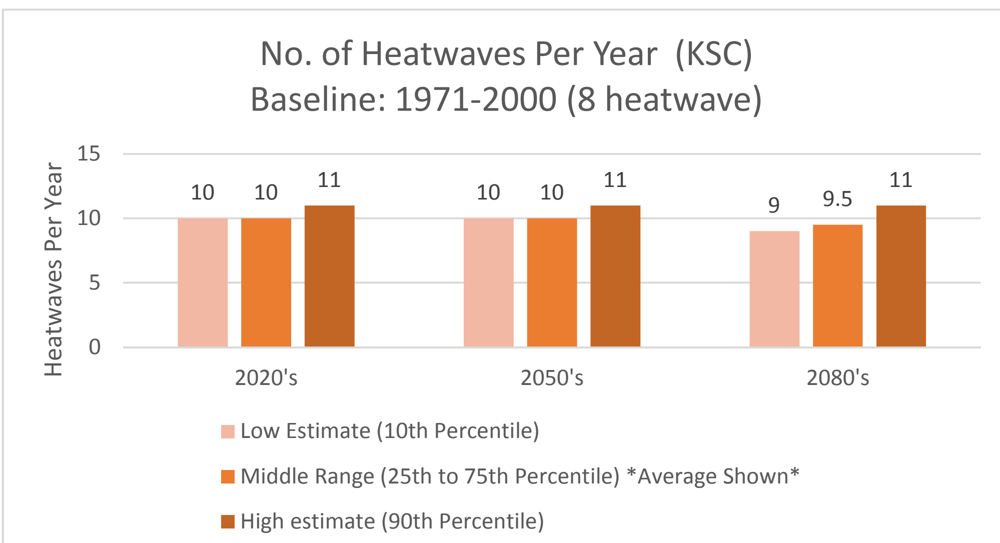

Figure 4- 41: Projected no. of heatwaves/year at Kennedy Space Center. (CASI, 2015)

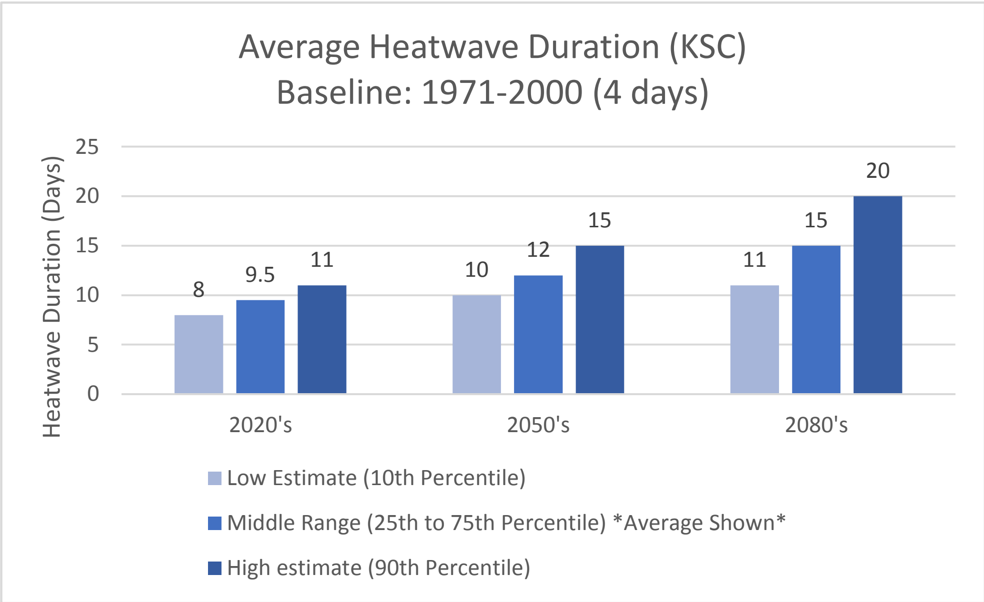

Figure 4- 42: Projection duration of heatwaves at Kennedy Space Center.

As evident in the climate projections for both WFF and KSC, there will be increases in almost all categories with the exception of the number of days with a minimum temperature of 32F and 40F respectfully, which are projected to decrease. The parallel results

Mitigation Efforts at NASA

Various NASA policies and guidelines do contribute to addressing climate change at its centers and facilities through risk analysis and sustainable means. Reducing gases is the biggest strategy for mitigation. In particular, building design and performance. For instance, in NASA's 2016 Strategic Sustainability Performance Plan, it highlights the following ten goals (NASA , 2015):

1. Greenhouse Gas (GHG) reduction
2. Sustainable Buildings
3. Clean & Renewable Energy

4. Water Use Efficiency & Management
5. Fleet Management
6. Sustainable Acquisition
7. Pollution Prevention & Waste Reduction
8. Energy Performance Contracts
9. Electronic Stewardship & Data Centers
10. Climate Change Resilience

Mitigation is literally the number 1 goal of the performance plan, while the goal most associated with climate adaptation is last. Goal number 1 is a great goal to have but seems to undermine the importance of climate adaptation. Furthermore, the goals of reducing GHG's in NASA buildings in direct correlation with earning points toward a Leadership in Energy Efficient Design (LEED) certification. The agency currently has 19 total (4 platinum, 9 gold, 5 silver, and 1 certified) LEED certified buildings at nine of its centers (NASA Facilities and Real Estate Division, n.d.). Wallops Flight Facility currently has two building slated for LEED silver pending certification. Goals 2, 3, 6, and 8 are directly related to goal 1 because of how each one assists in reducing energy, thus producing less GHG's. For instance, Goal 6, Sustainable Acquisition, could be utilized to acquire LED bulbs for a particular building that will reduce energy costs by "x" amount of dollars and in turn produce less GHG's in the long run. In this report, the overall goal for the agency is to reduce direct GHG emission by 18.3% by 2020, onsite or office and reduce indirect GHG emissions, for example commuting, by 12.3% by 2020 (NASA , 2015).

In Kennedy Space Center's Sustainability Plan 2016-2020, which covers the goals of the NASA's 2016 Strategic Sustainability Performance Plan, Goal 2 (Sustainable Buildings) is driven by energy conservation with objectives for implementing energy conservation projects and striving for Net Zero Buildings (NASA KSC, 2015). These objectives will help the agency reduce its GHG output and promote climate change mitigation.

Under the Architecture and Interior Design Philosophy section of the NASA Facilities Design Guide, much importance is given to having high performance buildings but there is no mention of how architects and designers account for climate change. In addition, the document includes several standard regulations but there are no sources solely devoted to climate projections for NASA's centers and facilities. Which leads to the next section, climate adaptation efforts at NASA.

Adaptation Efforts at NASA

In 2011, Former NASA Senior Sustainability Officer, Olga M. Dominguez, stated in her NASA Policy Statement for Adapting to a Changing Climate that in order to implement this policy NASA commits to the following (Dominguez, 2011):

- Undertake climate adaptation planning and apply the best science expertise and information available.
- Apply the "guiding principles" and planning "flexible framework" for climate change adaptation developed by the Interagency Climate Change Adaptation Task Force.
- Integrate climate adaptation planning and actions into agency programs, policies and operations.

- Consider potential climate impacts in long-term planning, setting priorities for scientific research and investigations, and making decisions affecting the agency resources, programs, policies, and operations.
- Develop an agency-wide adaptation plan.
- Coordinate with other agencies and interagency efforts, nationally and internationally, on climate change adaptation issues, and share climate change adaptation planning information with the world.

These policy commitments are slowly taking shape at NASA centers and facilities as evident with the ECIC sub-committee which will be discussed later in this chapter.

As mentioned earlier, in 2012, CASI published its “Adapting to a Changing Climate” reports on climate projections for several NASA centers and facilities. Those reports were then updated in 2015. Although the reports detail a plethora of climate projections, they do not offer any strategies for climate adaptation for any of the centers or facilities. They do however, suggests that the agency needs to develop short-term and long-term climate adaptation (CASI, 2015). To infuse the dialogue of climate adaptation into future and current buildings and infrastructure at NASA’s centers and accompanying facilities, workgroups were established to develop climate adaptation strategies. One of those workgroups is the NASA Engineering Constructions Innovations Committee (ECIC) Climate Change Sub-Committee which is led by Keith Britton of NASA Kennedy Space Center and has members representing other NASA centers and facilities. The members meet periodically via telephone conference call to discuss climate change adaption and mitigation concerns at their respective locations.

Utilizing info Goddard Space Center and the CASI climate projection reports, the representatives conducted further research to determine the effects that various climate variables will have on a select few buildings at their locations. Similar to the CASI climate projection reports, climate variables were separated into two categories: Gradual and Extreme Events. The “gradual” category was subdivided into three variables: sea level rise, precipitation variability, and higher average temperature. The “extreme events” category was subdivided into seven variables: sea level rise + storm surge, drought, heat waves, extreme cold, wildfire, and wind. Mr. Ron Simko, a mechanical engineer for the facilities management branch and ECIC sub-committee representative for WFF conducted this research and allowed the author of this MRP to participate in documenting portions of the research.

For Wallops Island, the selected building was Building Y-30, a one-story structure that is primarily used to as an observation location for sound rockets. In collaboration with various engineers from the Facilities Management Branch at WFF, applying the climate change projections from CASI directed the discussions on what impacts they would have on Building Y-30’s in relation to structure, building envelope, HVAC, plumbing, and telecom. The research found that the building envelope of Y-30 would incur the biggest impact due to a significant storm surge event in conjunction to SLR resulting in temporary facility closure, molding, work activity loss, significant damage to walls and insulation, and loss of furniture. Electrical, Telecom, and plumbing systems would also be inundated by a storm surge event and SLR. Thus, suggested adaptation responses to the likelihood of storm surge and SLR inundating Building Y-30 range from relocating services elsewhere, constructing a new building elevated to 11 to 13 feet above sea level, or raising the electrical, telecom, and pumping infrastructures to higher elevations.

Currently at Wallops Island, there are a few other climate adaptation strategies that have been implemented. For instance, along Island Road, many of the utility boxes have been raised 3-5 feet onto mounds to adjust to higher instances of flooding (Figure 4-43 & Figure 4-44). Also, due to flooding along Island Road, a 1-mile portion of that road was raised 18 inches and widened by 4 feet for “pavement performance maintenance” was completed in June 2017. In addition, the first floor of the new Island Firehouse is 12 feet above sea level while the engine bays are at 8 feet above sea level.

Figure 4- 44: Raised electricity utility boxes at Wallops Island. Photo taken by author June 2017.

Figure 4- 43: Raised electricity utility boxes at Wallops Island. Photo taken by author June 2017.

Shipping Container Space Versatility

One of the benefits of utilizing shipping containers for buildings is their versatility. Aside from storage, shipping containers or ISBU's are used to create spaces for homes, offices, and retail to name a few. For this section, the author chose one shipping container project from each of the following categories to analyze what attributes each could offer for shipping containers buildings at Wallops Island: residential, office, and retail.

The residential shipping container project chosen is Cité A Docks, a student-housing project in Le Havre, France comprised of 100 apartments (Figure 4-45). The shipping containers are stacked and staggered four stories high and two units wide. The side of the shipping container apartment units show minimal openings for light, however, the large doors at the end of the shipping containers have been replaced with floor to ceiling windows to allow light to infiltrate into the apartments. The span between the building sections serve multiple purposes: apartment access, patio, balcony, and various views of the area (Figure 4-46). The exterior of the

Figure 4- 45: Cité A Docks, Student Housing in Le Havre, France. (Contemporist, 2010)

containers have been coated with a firewall of reinforced concrete for thermal and sound insulation (Contemporist, 2010). Some of the first floor shipping containers are perpendicular to the top three floors creating cantilevers leaving an open space below. What could be useful for this open space, if applied at Wallops Island, is this space could allow storm surge and flooding to occur without affecting the main spaces located on upper floors. The first floor shipping container could be used only for egress with stairs and if needed, elevators. In addition, the first floor shipping containers could be sealed off from the outside to house infrastructures such as electrical, telecom, waste management, etc. If so, access to the first floor would be from the second story shipping containers via stairs. The first floor could offer additional structural support to the upper floor(s) as well.

Figure 4- 46: Site Plan for the Cité A Docks in Le Havre, France.

The office shipping container building chosen is “The Box Office” located in Providence Rhode Island (Figure 4-47). Thirty-two shipping containers make up the twelve offices spaces for The Box Office (Distill Studio, 2009). Similar to Cité A Docks, the typical arrangement of shipping containers is two-wide with the exception of the first floor. The middle section of the first floor offers a roof terrace for workers to gather during break or meetings. There are exterior stairs that lead from the ground to the upper floors and could be useful for shipping container buildings at Wallops Island since the recommended elevation for the first floor of new buildings is 12 feet above sea level. Thus one option for egress could either be through an exterior stair, landing, and door that leads into the second floor, third floor, etc. Another option would be for egress to take place within the shipping containers or an alternative structure made out of reinforced concrete.

Figure 4- 47: The Box Office in Providence, Rhode Island. (Distill Studio, 2009)

The Foghound Coffee Shop in Midran, South Africa was chosen as the retail shipping container project (Figure 4-48). Made of five shipping containers, storefront windows and doors, the coffee shop is two-stories high with the second floor arranged with two shipping containers that are separated by a short set of clerestory windows which allow more natural light into the spaces. The shipping containers wall panels sprayed with a polyurethane foam 8mm thick for insulated (Earthwood Architects, 2017). Minimal alterations have been made to the containers which

Figure 4- 48: The Foghound Coffee Shop in Midran, South Africa. (Earthwood Architects, 2017)

is a strategy that can be taken into consideration for shipping container buildings at Wallops Island. In particular for spaces that will be used for spaces that house data centers, electrical, and mechanical equipment.

For NASA centers and facilities on the coast, shipping containers buildings can be a long-term strategy for climate change adaptation as it pertains to flooding, increases in extreme weather, and sea level rise. Shipping containers are versatile, durable, modular, strong, and when upcycled are eco-friendly. NASA's climate adaptation efforts have not included shipping containers into the new building design choices. However, there is an opportunity to explore incorporating this building trend into the replacement of older buildings located at Wallops Island. Although a NASA wide comprehensive climate adaptation plan that encompasses all of its centers and facilities is in the development, there is optimism that the work of the various climate adaptation workgroups across the centers such as ECIC proves there is a building momentum towards an overlapping of efforts between both mitigation and adaptation efforts for the agency.

CHAPTER 5:

RECOMMENDATIONS

Climate workgroups and committees, such as the ECIC, are already using the CASI climate projections to access the potential impacts on buildings and infrastructures at several NASA centers/facilities. Despite being available to the public, the projections are not required for current design decisions at NASA. In addition, climate adaptation plans are unclear and do not actually offer distinct plans for the agency to carry out across its centers and facilities. Furthermore, in order to incorporate shipping containers into NASA's future climate adaptation plans, the author offers the recommendations below and answers the second question the author of this MRP has strove to answer: **What recommendations should be considered into NASA's policies/guidelines if shipping containers are utilized at NASA Wallops Flight Facility to protect its assets?**

1. **Include CASI's Climate Projections**
    a) Include CASI's climate projections (last updated in 2015) into a section of the NASA Sustainable Policy Handbook for Facilities, NASA Facilities Design Guide as they are updated where those involved in the design of a new building or design for an existing building rehabilitation can access their respective center or facility.
    b) At a minimum, include CASI's climate projections (last updated in 2015) into the standard and required reference list in the updated NASA Sustainable Policy Handbook for Facilities and NASA Facilities Design Guide.

2. **More Depth into Climate Adaptation Plans**

   a) Develop a standalone climate adaptation plan publication by the agency that is comprehensive and site specific; similar to the U.S. Army Corps of Engineers. (U.S. Army Corps of Engineers, 2014)

   b) Develop a class with audio visual materials for the facilities management branch of NASA to foster dialogue solely about climate adaptation, the CASI projections, and how workers need to incorporate climate adaption into design decisions in a similar fashion as climate mitigation is virtually required in new construction of NASA buildings.

   c) Include a new construction section on the plans, specifically building types where shipping containers or ISBU's will be listed. Pros and cons to be included as well as typical configurations for various types of spaces associated with NASA.

3. **Consider the Following for Shipping Container Buildings at Wallops Island**

   a) Main functionalities of the building should be at a minimum 12 feet above sea level in anticipation of SLR, storm surge, and flooding. (Offices, restrooms, kitchens, IT spaces, telecommunication spaces, storage, etc.) Thus, the first-floor shipping containers may be used for extra structural support for containers placed on top of them.

   b) Use first floor containers for stairways and if needed elevators.

   c) Although the first-floor containers are not for primary spaces, they can be used to route wires, cables, and pipes from the underground into the main spaces above. There must be sealant redundancies to the containers to assure the space doesn’t flood from the outside and causing damage to those infrastructures.

d) Spaces for data centers, electrical, HVAC, telecom will be located on the top floors to assure safe elevation from flood inundation.

e) If the first-floor containers are not used for egress up/down the building, then space must be allotted for either an exterior stairwell or an enclosed stairwell.

f) Type of foundations to choose from for the bottom floor containers: concrete slab (not the best in flood situations), concrete piers, or a combination of both.

g) Use a mixture of 20’ and 40’ high-cube ISBU’S to form the spaces needed in the building. High cubes offer an extra foot of height in the spaces and could offer space across the ceiling to run vents for HVAC, conduit for electricity and telecom cables, and piping for potable and non-potable water.

h) Two wide shipping container sets to give office spaces, breakrooms, lounges, conference rooms ample natural lighting when windows are applied.

i) When possible, add clerestory windows for added natural lighting.

4. Create a Partnership with the Port of Virginia

a) To establish a network with its nine facilities to inquire about abandoned ISBU’s

b) To acquire and upcycle abandoned ISBU’s

c) To determine which of its facilities have warehouse space to prefabricate ISBU’s for building application at NASA Wallops

d) To integrate its system of truckers for work to transport ISBU’s to Wallops Island.

Replace Older Buildings with Shipping Container Units

In the near future, an opportunity to replace older buildings with shipping containers units at Wallops Island will present itself due to aging buildings. For example, Buildings Y-30 (Figure 5-3) and W-20 (Figure 5-2) were built in 1945 and 1960 respectively. Y-30 is one story building with approximately 2,700 of space, is currently used as a sound rocket launch observation, and is located on the “Central Island” of Wallops (Figure 5-1). It sits at an elevation of 6 feet above sea level. As determined earlier in chapter four with findings by the ECIC, Building Y-30 has a high likelihood of having many of its building envelope and various infrastructures negatively impacted by sea level rise in conjunction with storm surge. Thus, if and when replaced, the new building must take into account the climate projections for sea level rise and higher instances of flooding. Therefore, a shipping container building could replace the old building with innovative spaces that are well above sea level and any predicted sea level rise or storm surge. Building W-20 is the current launch command center for Wallops Island and is located on the “South Island” of Wallops (Figure 5-1). The area surrounding W-20 is prone to flooding. Although W-20 has a replacement near completion on the Main Base, sounding rocket launches are still going to be operated out of W-20. Therefore, to accommodate the sounding rocket launch team in a replacement building, shipping containers units will function very similar to the units for the Y-30 replacement building. Placing the main spaces well above sea level.

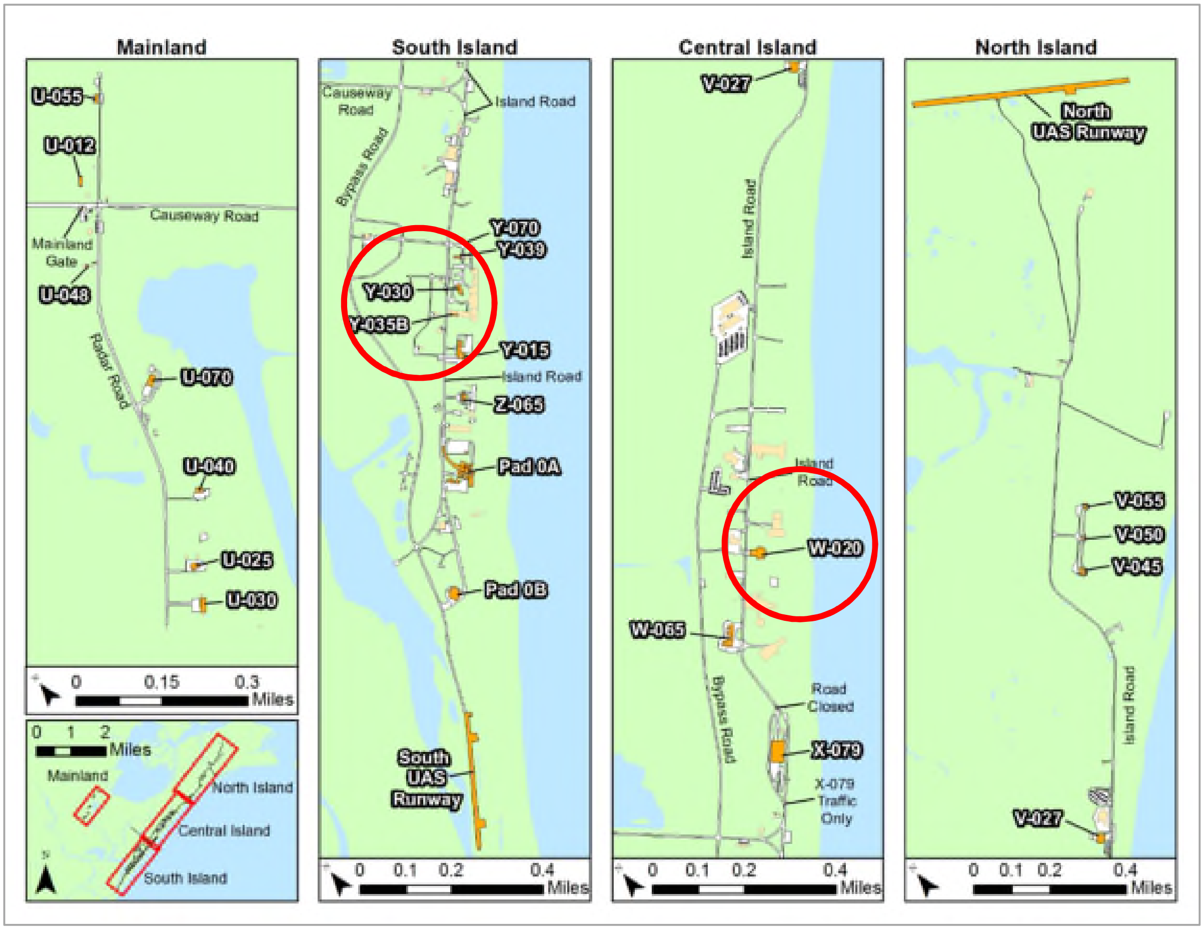

Figure 5- 1: Locations of Buildings W-20 and Y-30 at Wallops Island. Provided by staff at WFF.

Figure 5- 3: Building W-20 at Wallops Island. Photo taken by author May 2017.

Figure 5- 2: Building Y-30 at Wallops Island. Photo taken by author May 2017.

The scheme for the replacement for Building W-20 utilizes cantilevers to allow flooding to occur around the building (Figure 5-4). The first floor is comprised of shipping containers double wide to provide extra support for the upper floors and houses infrastructures such as electrical, telecom, plumbing for water/waste, etc. The first floor also contains means of egress to the upper floors. An option would be to have exterior stairs on opposite sides of the building that go up to the top floor. The scheme includes about 5,325 square feet of space for a launch control room, offices, restrooms,

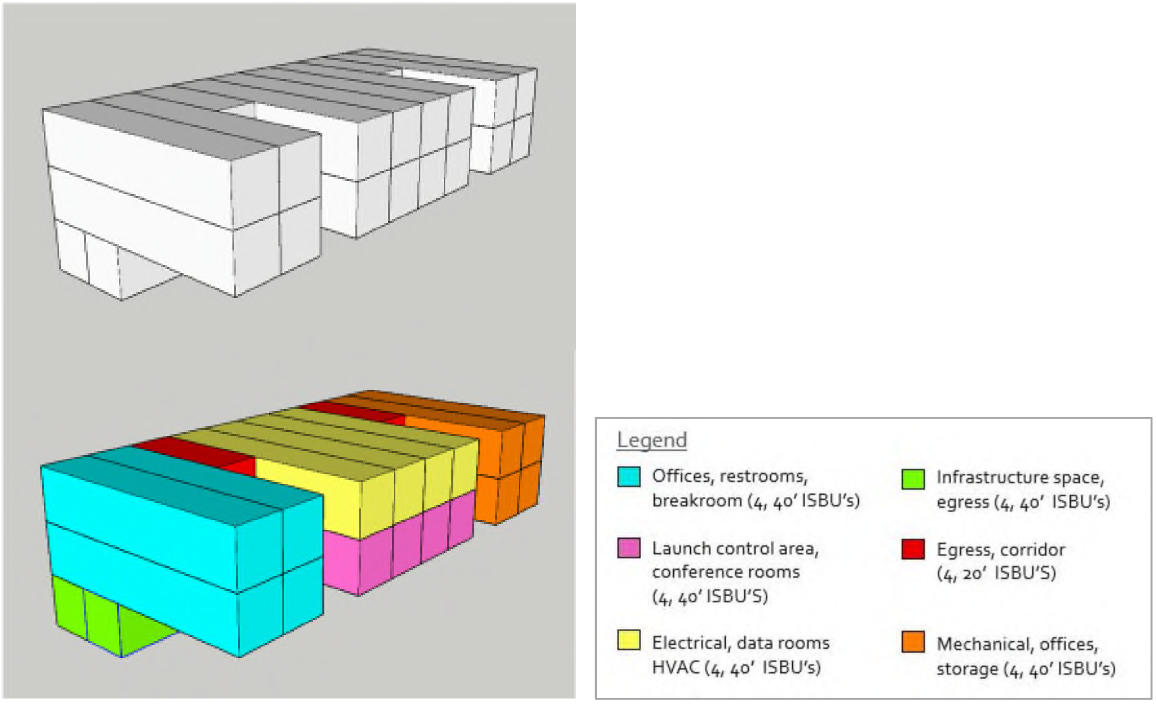

Figure 5- 4: Scheme diagram for shipping container building and Building W-20 replacement.

breakroom, spaces for HVAC, mechanical, electrical, storage, and data. Where possible, it is recommended to install clerestory windows for additional natural lighting. Next is a concept to replace Building Y-30.

The replacement scheme for Building Y-30, also has its main spaces on the top two floors with the ground floor being used for means of egress and housing infrastructure (Figure 5-5). The configuration calls for balconies on the third floor so

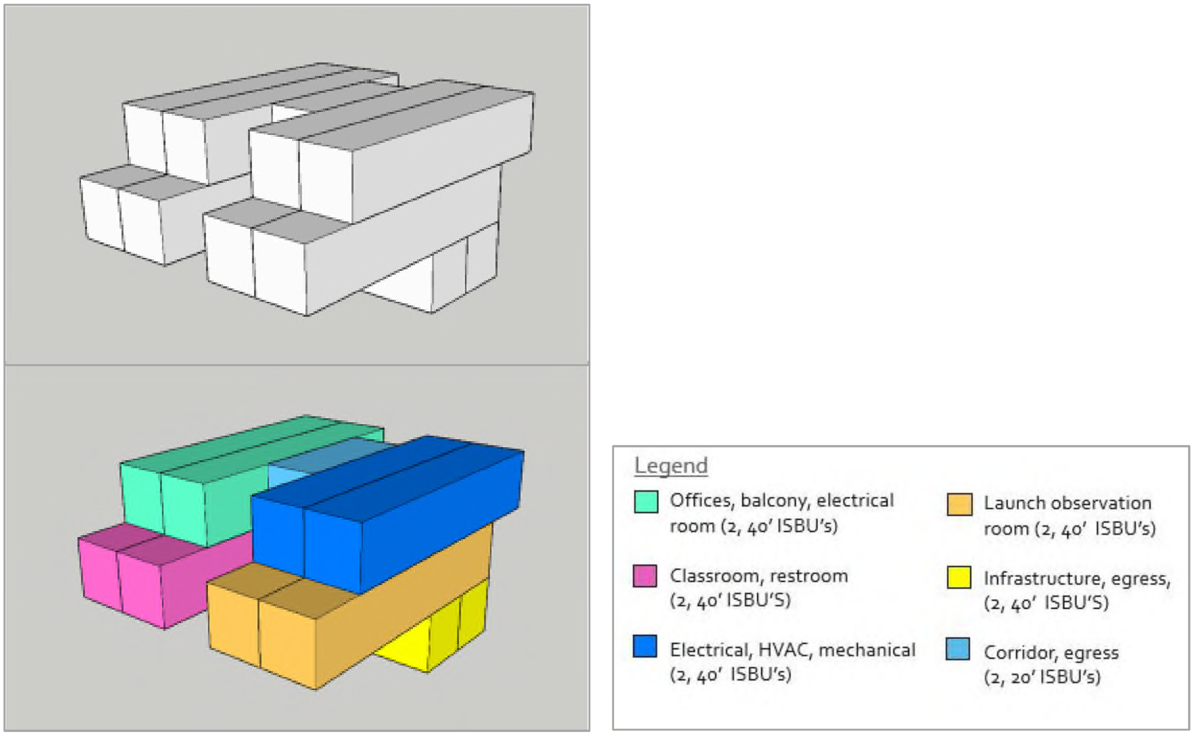

Figure 5- 5: Scheme diagram for shipping container building and replacement for Building Y-30.

launch observers can watch the launches of small rockets as well as enjoy the view of the Atlantic Ocean. This scheme is comprised of about 2,660 square feet of space that includes offices, a classroom, launch observation room, and first floor spaces to route conduits for wires and or cables into the upper floors of the building and plumbing for incoming and outgoing water and waste. Where possible, it is recommended to install clerestory windows for additional natural lighting.

The following images demonstrate what the spaces of these replacement buildings comprised of shipping containers could potentially look like.

Figure 5- 6: Classroom in a shipping container. (Royal Wolf, 2014)

Figure 5- 7: Data Center inside shipping container. (The Royal Blog, 2008)

Figure 5- 8: Conference room in a shipping container. (tumblr. container space, 2014)

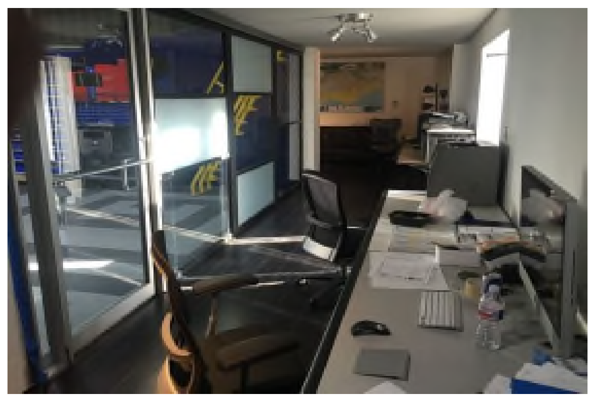

Figure 5- 9: Office Space inside a shipping container. (e-bay, 2017)

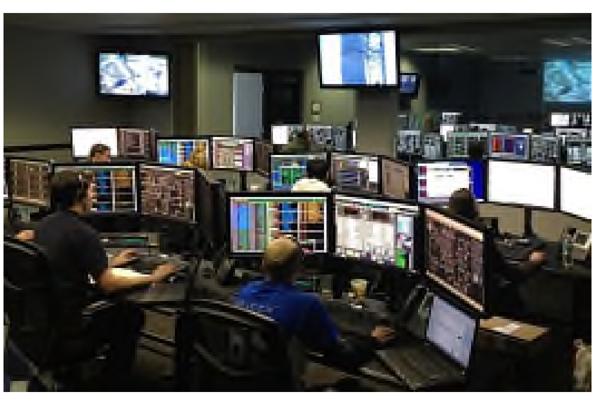

Figure 5-10: Launch center. (Space X, 2012)

CHAPTER 6: CONCLUSIONS

Although there are many benefits to shipping containers, the disadvantages of them were quite surprising. However, the benefits seem to outweigh those disadvantages and as more of shipping container buildings are built, more can be learned from them. Referencing back to the 1st question the author of this MRP has attempted to answer: **What are the benefits of incorporating shipping containers into the climate adaptation plans for the Island at NASA Wallops Flight Facility**?

1. ***Durability*.** I believe NASA in general can benefit from shipping container buildings because of their proven durability. They are made to withstand hurricanes an as the MRP research suggest, hurricanes are expected to increase throughout the rest of the century.
2. ***Versatility.*** In the kinds of spaces that can be configured out of shipping containers: offices, launch control rooms, data centers, classrooms, etc.
3. ***Innovation.*** They can highlight NASA's emphasis on how buildings need to adapt to impending climate change and transforming standard items known for toughness into well designed structures
4. ***Eco-Friendly:*** Shipping containers have eco-friendly, thus qualify as another building option for NASA to lead in what the agency is known for, fighting for the planet and innovation.
5. ***Off-Site Construction*:** The shipping containers can be prefabricated at a warehouse with careful collaboration with the NASA facilities management branch and contractors. When the units are complete with fabrication, they

can be transported to the site for construction. Prefabrication at an off-site location will result in less days lost to inclement weather and a faster construction time.

Furthermore, the Facilities Management Branch at Wallops Island is already implementing their own climate adaptation plans despite an unclear direction to do so. However, as the ECIC's research among many other climate workgroups are further analyzed and combined with CASI's climate projections, it is hopeful that NASA will be producing a standalone comprehensive climate adaptation plan with center or facility specific policies and criteria to take implement and adhere to. To further the direction of this MRP, I believe I will need to delve into shipping containers further. For instance, investigate roofing, building envelopes, insulation, energy, to name a few. Additional discussions needed are: 1. the dynamics of transferability in reference to shipping containers requirements that pertain to both Kennedy Space Center and Wallops Flight Facility; and 2. Fitting shipping containers into NASA's post disaster recovery plans?

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