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Ecological Impacts of the Space Shuttle Program at John F. Kennedy Space Center, Florida

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Executive Summary

Introduction

This report documents ecological effects of the U.S. Space Shuttle Program on regional ecosystems of east central Florida and specifically the John F. Kennedy Space Center (KSC) and associated Merritt Island National Wildlife Refuge (MINWR). As an agency, the National Aeronautics and Space Administration (NASA) takes stewardship responsibilities seriously including strong commitments to regulatory compliance and natural resource preservation, protection and enhancement. The Space Shuttle Program was one of NASA's first major undertakings to fall under the environmental impact analysis and documentation requirements of the National Environmental Policy Act of 1969 (NEPA).

In April of 1978, NASA Headquarters released the revised Final Environmental Impact Statement (EIS) for the Space Shuttle Program incorporating detailed information as required by NEPA to improve decision making. The American Institute of Biological Sciences (AIBS) was contracted to support development of an updated EIS for KSC based on the refined Shuttle Program operational requirements and the enhanced baseline environmental data developed for the regional ecosystems. The KSC Institutional EIS was published in 1979 incorporating the more detailed shuttle ground processing, launch and landing activities. AIBS was also involved with launch monitoring during the first four shuttle launches. One significant outcome was an AIBS recommendation that KSC implement a science based long-term monitoring program directed at both the shuttle launch event and the overall operations of the KSC physical plant. The goal was to develop local in house expertise that worked in partnership with the U.S. Fish and Wildlife Service at MINWR, universities, and other agencies to ensure NASA met the changing regulatory and natural resource protection and documentation requirements of previous and future environmental laws and policies. These evolving state and federal laws, regulations, and executive orders would forever change the manner in which operations and construction activities were conducted in the unique ecosystems of east central Florida.

In 1983, KSC established the Ecological Program to monitor potential launch impacts and develop management data and information for regulatory compliance and natural resource management. The program utilizes a holistic approach that relies on science-based peer review of methods and results to document findings related to the Space Shuttle Program and KSC operations in the context of both local and regional system dynamics. These results are summarized in the following five chapters and three appendices. Chapter 1 is an introduction to early development of the Space Shuttle Program and the regulatory environment in which it operated at KSC. Chapter 2 is an overview of the NEPA process,

related to the Space Shuttle Program, providing identified environmental concerns from construction, processing, and launch activities. Chapter 3 presents historic background information regarding the evolution and development of the east central Florida ecosystem up to and through the 40 year Space Shuttle Program. The information is intended to provide readers a feel for the dynamic nature of the ecosystem and an understanding of the transitions occurring in response to rapid urbanization and land development from the 1930s through 2012. Chapter 4 is focused on environmental effects of the shuttle launch event in the vicinity of launch pads 39A and 39B with emphasis given to concerns identified in the NEPA process (Chapter 2) as well as several issues not identified prior to the first launch. Chapter 5 focuses on KSC physical plant monitoring and management activities in response to both Space Shuttle Program influences and other land management and regulatory activities. The chapter concludes with identification of future issues and concerns for the Center related to commercial development, urban encroachment, and projected climate change influences. Appendix A provides a summary of shuttle launch information including date, time, pad and vehicle. Appendix B provides a list of Ecological Program publications to document the overall scope of activities conducted to support KSC environmental management. Appendix C provides a list of major partnerships, projects, and education outreach including support to students in Masters and Ph.D. degree programs.

Background

Kennedy Space Center was selected as the Space Shuttle launch, landing and servicing site based on the existing Apollo era infrastructure that could be utilized “as is” or with “modifications” and the close affiliation with the Eastern Range at Cape Canaveral Air Force Station (CCAFS). Existing infrastructure in the Launch Complex 39 area included the Vehicle Assembly Building (VAB), turn basin, crawlerway, and launch pads. This infrastructure, although extensive, was not designed to support the mission of the reusable Space Shuttle and an era of new construction and modification was initiated.

Major construction activities conducted prior to and during the Space Shuttle Program included:

- creation of the 1350 acre Shuttle Landing Facility (SLF),
- modification of the launch pads with fixed and rotating service structures,
- maintenance dredging of the Banana River section of the Intracoastal waterway, and modifications to Hangar AF for booster recovery and cleanup operations,
- construction of Orbiter Processing Facilities (OPFs), the Assembly and Refurbishment Facility (ARF), and the Rotation, Processing and Surge Facility (RPSF),

- construction of the Space Station Processing Facility (SSPF), the Space and Life Sciences Laboratory (SLSL), Operations Support Buildings (OSB I and II) and the Logistics building.

Many of the new facilities were constructed in existing industrial areas or abandoned citrus groves to minimize cost and impacts.

KSC and the associated MINWR, CCAFS, and Canaveral National Seashore (CNS) are co-located on the Cape Canaveral Barrier Island Complex of east central Florida. The area has high biodiversity, rich ecosystem services, and roughly 11 billion dollars of national assets for assured access to space as of 2010. Tourism in the area, associated with KSC and the natural resources of the Indian River Lagoon and its watershed, has been valued at more than 1 billion dollars annually. The Cape Canaveral Barrier Island complex including KSC is part of the Indian River Lagoon (IRL) ecosystem stretching 156 miles along Florida's east central coast from Ponce Inlet in the north to Jupiter Inlet in the south. This system is composed of three estuaries, the Mosquito Lagoon, Banana River Lagoon, and Indian River Lagoon, and is adjacent to the western Atlantic Ocean. This unique geographic feature contributes to the area being recognized as one of the most biologically diverse estuaries in North America with more than 2,200 different species of animals and 2,100 species of plants. The terrestrial and wetland communities of the regional ecosystem evolved in the presence of fire. The sandy soils with typically low carbon content hold little moisture, and evapotranspiration rates are high during the hot long summers. Afternoon sea breezes produce almost daily thunderstorms with a high frequency of lightning strikes in June, July, and August.

Prior to 1930, Brevard's population, which depended mainly on fishing and agricultural resources, was less than 5,000 individuals. By 1950 the population increased to about 23,700 as a result of heavy federal spending associated with World War II. When new government programs began developing missiles for defense in support of Cold War activities, the 45th Space Wing and Eastern Range constructed needed facilities at Patrick Air Force Base and CCAFS, and with urging from the Navy, NASA, and local developers the Corp of Engineers constructed Port Canaveral and the cross Merritt Island Barge Canal.

This explosive growth raised Brevard's population past the 100,000 mark in the early 1960s. The decision to bring the Apollo Program to north Merritt Island produced another large and relatively long-term injection of federal spending; the population soared to more than 230,000 by 1970. Employment at KSC peaked in 1968, with 26,500 people working on the Apollo program. Population growth and associated environmental and ecological issues

continued to trend upward with the onset of the active Space Shuttle Program between 1980 and 2011. Employment at KSC fluctuated between 12,000 and 17,000 depending on mission schedules and demand. Other industries such as tourism, real estate development, aerospace, Port operations, and light manufacturing all continued to expand, putting increasing demands on local ecosystems.

Space Shuttle Program Effects

Through the 30 year flight history of the Space Shuttle Program there were 135 launches, 82 from Pad 39A and 53 from Pad 39B. The three shuttle main engines (SME) burned liquid oxygen and liquid hydrogen producing an exhaust of water vapor. The Solid Rocket Booster (SRB) exhaust, composed primarily of aluminum, hydrogen, nitrogen, carbon, oxygen, and chloride compounds including hydrochloric acid (HCl), was directed northward from the launch pads by the split flame trench. At each pad, a water based sound suppression system was utilized to protect the shuttle and payloads from damage by acoustic energy reflected from the mobile launch platform during launch. At launch minus 12 seconds, the sound suppression system was activated, starting flow of roughly 300,000 gallons of water onto the launch pad and structure. At minus nine seconds, the three shuttle main engines were ignited and throttled toward full power. At zero, the two SRBs are ignited. The initial blast hit the sound suppression water that has been pouring onto the pad, instantly vaporizing and atomizing it. The resulting mixture of deluge water, debris, and exhaust chemicals exploded from the flame trench at a velocity of approximately 85-100 meters per second. During the first 10-12 seconds of flight, as the shuttle rose from the launch pad, the exit velocity and percent of SRB exhaust exiting the flame trench decayed to zero. At this point, the exhaust ground cloud formation ceased and column cloud formation predominated. The typical ground cloud was approximately $1.4 \times 10^6 \text{ m}^3$ in volume. This cloud was composed of the complex mixture of gases and dissolved and particulate exhaust products formed by SRB fuels, sound suppression water, and materials ablated from the physical surfaces on and around the launch pad.

Near-field deposition was created by the ground cloud sweeping turbulently across the ground, vegetation, and lagoon waters to the north of the launch pads in line with the SRB flame trench. For each launch, the area impacted by near-field deposition was mapped based on the visible effects on vegetation and structures. The area of cumulative near-field impacts at Pad 39A was about 90 ha (221 ac), and the area of cumulative near-field impacts at Pad 39B was 62 ha (154 ac). The solid rocket motors produce a fine particulate mixture of aluminum compounds that were generally less than 63μ in diameter. These fine particulates made up roughly 40% of the deposition found in the near-field area, but in background soils only about three percent of particles occurred in this silt and clay fraction.

Near-field deposition greater than 63 μ was composed in large part of fine silica sand, shell fragments, and other debris entrained in the exhaust cloud from the pad surface north of the flame trench.

Different size classes of particulates were analyzed for aluminum (Al), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), and zinc (Zn) content. As expected, Al concentrations were highest in the launch derived fine fraction of the deposition while larger size classes displayed values similar to background soils. Copper deposition displayed a peak in the 63-125 μ size class, but the source was not readily apparent. Two metals, Fe and Mn, were observed well above background levels, primarily in the largest particle size class. These two metals are associated with steel structures. Examination with a microscope revealed the presence of numerous metal flakes in this fraction and exposure to a magnet indicated they contained iron. These metal flakes were blown off of Apollo era railroad tracks that were used to position the flame splitter beneath the mobile launch platform inside each launch pad flame trench. These railroad tracks were removed from the pad surfaces during renovations and upgrades. Lead levels were consistently low but were higher than background soils in the 63-250 μ range. Zinc concentrations were above background levels and the source was believed to be the large amount used in corrosion control on the pad and mobile launch platform surfaces. SRB exhaust blasts were known to strip the coating off of these exposed surfaces.

Soils in the most frequently impacted area north of Pad 39A were sampled after nine launches and again after 24 launches from the same sites. These soils near the launch complexes are heterogeneous but can be divided into saline and non-saline groups. Within these groups, changes between conditions after nine launches and after 24 launches differed. In the non-saline soils, there were increases in conductivity, calcium (Ca), potassium (K), sodium (Na), and Zn and decreases in phosphorus (P), nitrate nitrogen ($\text{NO}_3\text{-N}$), and ammonium as N ($\text{NH}_4\text{-N}$). In the saline soils, there were increases in Ca, K, Na, Zn, and P but not conductivity, and decreases in $\text{NH}_4\text{-N}$ but not $\text{NO}_3\text{-N}$. Increases in conductivity, Ca, K, and Na between nine and 24 launches may be due to leaching of soil material including shell fragments. Increases in Zn could be from soil leaching or from deposition of material derived from paint or plating on pad structures. Soils in the impact area remained well buffered; even after 24 launches, soil pH was still alkaline.

Background pH in the estuarine system generally ranges between 7.8 and 8.8 units. At launch, the surface layer of the lagoon receives up to 1700 kg (3748 lbs) of hydrochloride (HCl) from deposition. This acid mixed downward into the water column through advection and diffusion, eventually impacting approximately the upper 1.5 m (four ft). The rate of mixing is driven primarily by wind speed and direction across the lagoon. Levels of impact

were highly variable spatially and temporally depending on meteorological conditions at the time of launch. Maximum pH reductions (about six to seven units) were found at the surface and in the area adjacent to the storm water drainage ditch in line with the flame trench at each pad. In these areas, pH depression may be acute and lethal to organisms utilizing gills for respiration. Minimal effects were observed around the edges of the near-field ground cloud footprint and at depth where buffering and dilution minimize chemical impacts.

For most launches, a fish kill was observed in the shallow surface waters immediately north of each launch complex in line with the flame trench. This fish kill was the direct result of surface water acidification. The rapid drop in pH produced severe damage to the gill lamella of fish exposed to the near-field launch deposition. Field surveys conducted after each launch indicated that this event was generally limited to the shallow shoreline closest to the pad and the stormwater ditches leading away from the north side of the pad surface. In every event, the fish kill occurred in direct relation to the spatial pattern of the near-field deposition footprint.

Cumulative impacts to vegetation in the most frequently exposed area north of Pad 39A included reduction in the number of plant species present, and reduction in total cover. The reduction in total species number included both loss of sensitive species and invasion of more weedy ones, but losses exceeded new invasion. Vegetation effects differed by strata; shrubs and small trees were eliminated by repeated defoliation more rapidly than forbs and graminoids. The community level effects consisted of retrogressive changes however, during the post-Challenger period of no launches vegetation recovered to near pre-launch conditions. Aerial photography was collected before and throughout the Space Shuttle program to document vegetation community changes that might result from launch impacts as recommended by AIBS. At Pad 39A the general pattern was an expansion of disturbance tolerant wax myrtle (*Myrica cerifera*), Brazilian pepper (*Schinus terebinthifolius*), and mangroves filling bare ground and some areas of wetland and herbaceous cover. At Pad 39B mangroves have increased in abundance in the impounded areas northwest of the pad, and wax myrtle, Brazilian pepper and other disturbance tolerant taxa have expanded in coverage. At both pads the amount of bright reflective bare ground has been greatly reduced by expansion of vegetation communities.

Far-field deposition occurred outside of the near-field plume zone, as a result of movement of the launch cloud with prevailing meteorological conditions at cloud stabilization height. The ground tracks of deposition from every launch were mapped for each pad and a cumulative far-field map was prepared for all areas of KSC receiving deposition. Spots of acid or dry deposition on leaves of plants or on structures indicated the area received far-field deposition. The geographic distribution of far-field deposition was far more variable

than that of near-field deposition, and much of KSC received deposition from at least one launch. After 135 launches, 23,124.7 ha (57,142.2 ac) received far-field deposition at least once, but 14,065 ha (34,755.2 ac) were impacted no more than two times. No changes in plant community composition or structure due to cumulative effects of far-field deposition were observed.

The highest acoustic noise levels generated by launch are recorded within the first two minutes. In the launch pad vicinity, noise levels could exceed 160 dBA. Noise levels recorded at the Launch Impact Line near the VAB area did not exceed the 115 dBA maximum level established for short exposure by the Department of Labor standards. For maximum protection, observer areas and security zones were set at distances beyond which the 115 dBA sound level is not exceeded.

Acute impacts of Space Shuttle launches to wildlife populations were minimal. Birds in the vicinity of the launch pad flee the area in a fright response to the ignition of the shuttle main engines prior to the ignition of the SRBs. On occasion, some individuals were caught in the exhaust blast and were killed or injured. Examples of species observed included frogs, alligators, armadillo, marsh rabbits, snowy egret, and killdeer. No federally listed threatened or endangered species were observed killed based on post launch surveys conducted in the area.

Results of monitoring launch impacts have shown no long-term macro-scale negative responses. Ecological communities persisted through the duration of the Space Shuttle Program with no dramatic change in species composition or spatial distribution based on launch rates achieved. Ongoing assessments of potential launch impacts include a comprehensive Ecological Risk Assessment being conducted by the KSC Remediation Program Office in response to preliminary Resource Conservation and Recovery Act (RCRA) Facility Investigation findings. This project will evaluate the likelihood that sub-lethal adverse ecological effects are occurring, or may potentially occur, as a result of site-specific constituents including metals, semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides (OCPs), perchlorate, and total petroleum hydrocarbons (TRPH)..

Long-term Monitoring

The Ecological Program's long term baseline monitoring was designed to provide information on ambient air quality, rainfall, surface and ground water quality, sediments, soils, vegetation, and species of special concern for use in assessing natural variation and man-made alterations of KSC and surrounding ecosystems with emphasis on the Space

Shuttle Program. These data and information are available for use in environmental decision making, regulatory compliance, and NEPA documentation. By the mid-1980s it was recognized that regulatory requirements, facilities construction and operations, and land management activities were going to be more significant to protection, preservation, and enhancement of natural resources than direct launch impacts.

Major construction projects required to support the Space Shuttle and its payloads included the 1350 acre SLF in the early 1970s and the 28 acre SSPF in the early 1990s. Other construction and facility modification projects occurred within existing industrial areas or abandoned orange groves. Construction of the SLF created 173 acres of impounded waters that served as a storm water and chemical spill management system. The impounded waters support a healthy aquatic community including high densities of turtles, alligators, and sport fish such as red drum, seatrout, snook, largemouth bass, and sunfish. The single largest ecological effect of the SLF is its contribution to landscape fragmentation and influence on fire management planning and the spread of fire across the landscape. The SLF occupies approximately one percent of the 140,000 acre KSC property and represents roughly 22 % of the area used for KSC operations.

Construction of the SSPF occurred after the Florida Scrub-jay was listed as a Threatened Species by the U.S. Fish and Wildlife Endangered Species Office in 1987. Through the Endangered Species Act consultation process, KSC developed a Habitat Compensation Plan that proposed a phased approach to compensation for the SSPF and future projects that would restore and create up to 300 ac (121.5 ha) of scrub habitat at several locations on KSC containing marginal or declining habitat value for Scrub-jays.

Long-term monitoring of air quality, rainfall volume and chemistry, water quality, and select protected species has generally displayed improvement in areas where regulatory requirements have been implemented. Ambient air quality has improved and no exceedances of quality standards have been documented outside of controlled burn smoke plumes. Reductions in sulfur emissions have been associated with increasing rainfall pH levels. During the Space Shuttle Program, RCRA Corrective Action requirements were implemented to locate and assess potential areas of soil and groundwater contamination and clean up those areas created during the Mercury, Gemini, Apollo, and the Space Shuttle Program. The Clean Water Act, National Pollution Discharge Elimination System (NPDES) permitting program for point and non-point source discharges reduced the volume of contaminants entering water ways around KSC. In the mid-1980s, sewage discharge from KSC waste water processing facilities and local municipalities was greatly reduced or eliminated. This reduced nitrogen and phosphorous loadings to receiving waters. At KSC more than 100 surface water management systems were constructed to control stormwater

runoff. Even with these controls, water quality in the surrounding lagoons continued to decline as a result of regional population growth and urban development on the surrounding watershed through the process known as cultural eutrophication. The low flushing rate of the Indian River Lagoon system makes it extremely susceptible to nutrient loadings from sources such as runoff from impervious surfaces and fertilized lawns. Extensive spring and summer algae blooms around KSC post Space Shuttle Program have reduced seagrass coverage in some areas by more than 90%.

Vegetation communities at KSC, like most areas in east central Florida, have been fragmented by land development and altered by wild fire suppression and invasion of non-native species. Expansion of non-native species populations continues to be a threat to local natural resources. Beginning in the early 1980s, USFWS initiated a controlled burn program to reduce risks associated with wildfire. Regional populations of Scrub-jays continued their decline through the duration of the Space Shuttle Program across their range. Launch operations, including payload clean room requirements at KSC and CCAFS, in conjunction with strict weather limitations constrained the rate of controlled burning for habitat enhancement. Post Space Shuttle Program, KSC established a Fire Action Team to address fire management on the federal properties by improving communications, minimizing constraints, and researching burn methodologies.

Kennedy Space Center is home to more federally endangered and threatened species than any other federal installation in the continental United States and provides core populations for many listed species because of its geographic context and variety of habitats. KSC provides nesting habitat to three species of marine turtles, loggerheads, green turtles, and leatherbacks. Light pollution at night from facilities and operations continues to be a problem along the nesting beach causing disorientations of both adult females and hatchlings.

Manatee use of the area has increased dramatically since the start of Space Shuttle flight activities in 1980. It is speculated that this increase is in response to habitat degradation in other areas of the lagoon as well as some recovery of region wide population numbers. In 1990, to further protect this endangered species, the USFWS created a sanctuary for manatees covering the majority of the KSC section of the Banana River. There were no known mortalities resulting from external tank transportation or SRB recovery ship operations.

The KSC ecosystem provides for one of the three most important populations of the Florida Scrub-jay. The edge of the largest core KSC population occurs near the LC-39 complex. This population declined substantially from degraded habitat quality caused by a reduced fire regime, which began in the 1950s. Similar population declines are characteristic of

statewide trends. However, the Happy Creek population appears to be stabilizing because of a collaborative effort in habitat restoration between MINWR and KSC.

Records of bald eagle nesting have been kept on KSC continuously since 1978 by MINWR or Florida Fish and Wildlife Conservation Commission (FWCC). The numbers of nests have increased steadily over the years, in keeping with the general recovery of bald eagle populations in the U.S. since the banning of the pesticide DDT. Nesting at KSC increased from six sites in 1979 to 12 during the Space Shuttle Program.

KSC and CCAFS provide the last stronghold for the Southeastern Beach Mouse. The population occupies primarily the coastal dune and strand but it may also occur in scrub habitats. The population continues to exist in areas adjacent to the launch pads, and currently coastal erosion and sea level rise appear to be the major threats to the species.

Conclusion

The Space Shuttle Program at KSC contributed directly and indirectly to both negative and positive ecological trends in the region through the long-term, stable expenditure of resources over the 40 year life cycle. These expenditures provided support to regional growth and development in conjunction with other sources that altered land use patterns, eliminated and modified habitats, and contributed to cultural eutrophication of the IRL. At KSC, the majority of Space Shuttle Program related actions were conducted in previously developed facilities and industrial areas with the exception of the SLF and SSPF. Launch and operations impacts were minimal as a result of the low launch rate. The majority of concerns identified during the NEPA process such as weather modification, acid rain off site, and local climate change did not occur. Launch impacts from deposition of HCl were assimilated as a result of the high buffering capacity of the system and low launch and loading rates. Metals deposition did not produce acute impacts, and sub-lethal effects are being investigated as part of the RCRA Corrective Action process.

Major positive Space Shuttle Program effects were derived from the adequate resources available at the Center to implement the numerous environmental laws and regulations designed to enhance the quality of the environment and minimize impacts from human activities. This included reduced discharges of domestic and industrial wastewater, creation of stormwater management systems, remediation of past contamination sites, implementation of hazardous waste management systems, and creation of a culture of sustainability. Working with partners such as the USFWS and the St Johns River Water Management District (SJRWMD), wetlands and scrub restoration and management initiatives were implemented to enhance fish and wildlife populations at the Center. KSC remains the single largest ecological preserve on the east coast of Florida in large part due

to NASA's commitment to Stewardship. Ongoing Ecological Program projects are directed at development of information and knowledge to address future KSC management questions including the transition to a joint government and commercial launch facility, enhanced habitat management requirements for wetlands and scrub, potential impacts of emerging contaminants, and adaptation to climate change including elevated CO₂ and projected sea level rise over the next 50-75 years.

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Ecological Impacts of the Space Shuttle Program at John F. Kennedy Space Center, Florida

1.0 Introduction

1.1 Background

The first mission of the Space Shuttle flew from Launch Pad 39A at the John F. Kennedy Space Center (KSC), Florida on April 12, 1981, six years after the joint American and Russian Apollo-Soyuz Earth Orbital mission ended in 1975 (Figure 1). This was the culmination of more than 15 years of planning, numerous design changes, complex systems engineering, continual budgetary constraints, and creation of one of America's finest management organizations (Dethloff, 1998). On January 5, 1972 President Nixon gave the National Aeronautics and Space Administration (NASA) approval to proceed with a revised and less costly Space Shuttle Program stressing both civilian and international aspects of development and future missions. In 1974, Congress approved the first shuttle-specific funding in the NASA budget. The NASA management team, located at every field center, integrated and coordinated the work of hundreds of private industry contractors and sub-contractors to build what came to be known as "man's most complex machine". NASA Headquarters assigned Marshall Space Flight Center responsibility for developing the booster stages and the shuttle main engines. Stennis Space Center had responsibility for engine testing. Johnson Space Center had responsibility for developing the orbiter and training the astronaut crew, and KSC had responsibility for launch, processing, and recovery of shuttle flights (Dethloff, 1998).

During this same period the United States Congress and Executive Branch began addressing growing national and global concerns over environmental degradation resulting from the minimally controlled but rapidly expanding private and public sectors post World War II. They passed numerous laws and executive orders to improve the quality of life in America. These laws and their primary targets are summarized in Table 1. The National Environmental Policy Act (NEPA) of 1969 created environmental policies and goals for the country and established the President's Council on Environmental Quality (CEQ). NEPA's most important feature is its requirement that federal agencies conduct thorough assessments of the environmental impacts of all major activities undertaken or funded by the federal government. Each federal agency is required to develop and implement an Agency specific NEPA process. NASA published and periodically updates their procedures and

NEPA requirements (NASA, 2112; NPR8580.1A). KSC established Kennedy NASA Procedural Requirements (KNPR) and Kennedy Procedures Document (KNPD) to guide compliance with the NEPA process and other regulatory requirements (KNPR 8500.1, KNPD 8500.1).



Figure 1. Launch of the Space Shuttle (STS-1) on April 12, 1981. A deflector in the flame trench beneath the mobile launch platform directed the shuttle main engine exhaust to the south (left) and the solid rocket motor exhaust to the north (right) of the pad away from the vehicle.

Table 1. Examples of environmental laws and executive orders having relevance to the operations of KSC and the management of the Space Shuttle Program processing launch, and retrieval activities.

National Environmental Policy Act (1969): Was the first of the modern environmental statutes. NEPA created environmental policies and goals for the country, and established the President's Council on Environmental Quality. Its most important feature is its requirement that federal agencies conduct thorough assessments of the environmental impacts of all major activities undertaken or funded by the federal government. Many states have enacted similar laws governing state activities.
Endangered Species Act (1973): Is designed to protect and recover endangered and threatened species of fish, wildlife and plants in the United States and beyond. The law works in part by protecting species habitats.
Clean Air Act (1970): Sets goals and standards for the quality and purity of air in the United States. By law, it is periodically reviewed. A significant set of amendments in 1990 toughened air quality standards and placed new emphasis on market forces to control air pollution.
Clean Water Act (1972): Establishes and maintains goals and standards for United States (U.S.) water quality and purity. It has been amended several times, most prominently in 1987 to increase controls on toxic pollutants, and in 1990, to more effectively address the hazard of oil spills.
Emergency Planning and Community Right-to-Know Act (1986): Requires companies to disclose information about toxic chemicals they release into the air and water and dispose of on land.
Resource Conservation and Recovery Act (1976): Seeks to prevent the creation of toxic waste dumps by setting standards for the management of hazardous waste. This law includes provisions for cleanup of existing contaminated sites.
Toxic Substances Control Act (1976): Authorizes the Environmental Protection Agency (EPA) to regulate the manufacture, distribution, import, and processing of certain toxic chemicals.
Executive Order 11988 Floodplains Management: Requires all agencies to assess effects of actions on floodplains and potential to cause flooding. Requires public review and notification.
Executive Order 11990 Protection of Wetlands: Requires all agencies to avoid and or minimize impacts to wetlands unless there is no practicable alternative.
Executive Order 13514 Federal Leadership in Environmental, Energy, and Economic Performance: Requires all agencies to develop sustainability plans and to achieve long-term sustainability goals through planned efforts in energy conservation, recycling, water management, pollution prevention, design and construction, maintenance and operations, and master planning.

Implementation of NEPA led NASA Headquarters to develop the Programmatic Shuttle Environmental Impact Statement (EIS) in 1978. This document identified and projected environmental concerns based on best available information and knowledge, including launch experience with the Mercury, Gemini and Apollo Programs as well as the USAF experience with Delta, Atlas, and Titan Programs (NASA, 1978). Prior to the Space Shuttle Program the Titan was the launch vehicle with the largest solid rocket boosters ever flown. Many environmental concerns identified during the initial NEPA process were focused on activities that would take place at KSC since it was designated by Headquarters as the vehicle launch, recovery and processing center (Dethloff, 1998). Implementation of the NEPA process at KSC in preparation for the new mission led to the initiation of a series of baseline studies and research projects to develop background information on local ecosystems (AIBS, 1982; FIT, 1975; Sweet et al., 1976; Stout et al., 1979, 1980; Heck et al., 1980; FIT, 1978; NASA, 1979) and potential responses of vegetation to the exhaust products projected to be produced during the upcoming launch events. Launch rates of 20-40 missions per year from two launch pads were projected (NASA, 1978). Under NEPA, a federal agency has a continuing duty to gather and evaluate new information relevant to the environmental impact of its actions, as stated in 42 U.S.C. § 4332(2)(A). For agency decisions based on an EIS, the regulations require that, “a monitoring and enforcement program shall be adopted...where applicable for mitigation.” (40 C.F.R. §1505.2(c)). In addition, the regulations state that agencies may “provide for monitoring to assure that their decisions are carried out and should do so in important cases.” (40 C.F.R. §1505.3).

The initial environmental work addressing potential launch effects was carried out by university and private contractors under the guidance of the American Institute of Biological Science (AIBS) under the direction of Dr. Herb Ward at Rice University and Dr. William Knott III and Dr. Al Koller in the Biomedical Operations Office at KSC (AIBS, 1982). Results of baseline ecological data collection exposed the highly sensitive and diverse nature of the Cape Canaveral Barrier Island Complex of which KSC is a part (NASA, 2010). The unique ecosystems and history that make up KSC and the associated Merritt Island National Wildlife Refuge (MINWR) and Canaveral National Seashore (CNS) are described briefly in the following sections to provide a reference framework against which local, regional, and cumulative Space Shuttle Program effects can be assessed. Throughout the duration of the Program, KSC management has recognized the value of the ecosystem services provided by the region and have worked tirelessly to fulfill the intent of the legislation establishing the Agency including the commitments to “use all practicable means, consistent with NASA's statutory authority, available resources, and the national policy, to protect and enhance the quality of the environment” and “initiate and utilize ecological and other environmental information in the planning and development of resource-oriented projects” (40 CFR, Title 14, Section 1216.102).

In addition, observations of potential human health concerns and ecological impacts from the first 15 STS launches (NASA, 1983; Hawkins, et al., 1984; Schmalzer, et al., 1993; Hinkle et al., 1986; Dreschel and Hall, 1985) indicated the original Programmatic Shuttle EIS had not captured the scope and magnitude of local KSC effects. At this point, a decision was made to establish the long-term KSC Ecological Program, through contractor support, to monitor, model, and address long-term effects of the Space Shuttle Program on the unique and sensitive regional ecosystems. This decision fulfilled the CEQ intention of requiring agencies to be “capable (in terms of personnel and resources) of complying with requirements of section 102(2)(G).” (40 C.F.R. § 1507.2(f)). The KSC Ecological Program was developed utilizing goals and objectives identified during a three day workshop consisting of local land managers, interested parties and university partners (Hamilton, et al., 1985). The Program design was holistic in approach focusing first on STS launch and operations but including KSC operations support, baseline monitoring, and special investigations to answer specific information needs (AIBS, 1982; NASA, 1983, 1988; Hall, et al., 1992). As knowledge of launch effects grew and projections of launch rates fell to fewer than 10 per year, the focus of the Ecological Program shifted to accommodate the changing regulatory environment that included listing of more than 20 resident species as threatened or endangered under the Endangered Species Act. Through the last 12-15 years the Program has developed a broader-based KSC land management information and knowledge focus in response to requirements of the numerous laws, regulations, and executive orders (see Table 1) that were implemented during the life of the 40 year Space Shuttle Program.

1.2 Impact Assessment Approach

This document provides a summary of ecological impacts of the Space Shuttle Program at KSC. It begins with basic historical information for a frame of reference and continues to explain environmental conditions monitored throughout the program, along with regulatory and land management issues and strategies that evolved during this forty year period of rapid population growth and land development on Florida’s Space Coast. At the end there is a discussion of the anticipated and realized effects of the program on the local and regional natural and human environment.

In Section ***2.0 Space Shuttle Program at KSC***, the significant features of Space Shuttle Program development and operations at KSC are summarized including both required new construction of the 1350 acre Shuttle Landing Facility (SLF), beyond the roughly 5500 acres of KSC developed for the Apollo Program, and Space Shuttle Program processing and launch activities (NASA, 1972, 1978, 1979). Section ***3.0 Dynamic Baseline*** provides a summary of the evolution of the east central Florida ecosystem including:

- geologic history and the barrier island creation,
- natural ecosystems diversity and uniqueness,
- arrival of human influences, early settlers, and
- the period of rapid population growth, land development and urban sprawl, landscape fragmentation, and watershed cultural eutrophication.

Section **4.0 Shuttle Operations Impacts** summarizes results of extensive monitoring conducted during the first 25 launches up to and including the Challenger launch on January 28, 1986. This period represents the highest annual shuttle launch rates achieved and defined the scope and magnitude of impacts from the launch phase of the program at Pad 39A. Challenger was the first launch from the newly refurbished Pad 39B. No launches occurred for the following 32 months, and many upgrades were made to the launch pads during this hiatus, including the industrial wastewater management system. Launch monitoring activities were greatly reduced for the remainder of the Space Shuttle Program based on:

- results observed during the first 25 launches,
- the reduction proposed in launch rates,
- improvements to the deluge and sound suppression capture and treatment system, and
- the use of two launch pads, further minimizing local ecosystem loading rates.

Post-Challenger monitoring transitioned from a shuttle centric monitoring program to a broader-based KSC wide physical plant monitoring program geared toward assessing effects of KSC operations supporting the shuttle and development of management data needed to ensure compliance with the evolving regulatory requirements related to ecosystem services and protected species management.

In Section **5.0 Area Wide Monitoring**, the role of the Space Shuttle Program's influence on regional and local ecosystems is examined. This includes topics such as landscape fragmentation and potential influences on fire regimes and habitat quality, point and non-point source water quality management practices, remediation activities for Mercury, Gemini, Apollo and Space Shuttle era releases, and efforts to partner with regional land managers to reverse environmental trends initiated during the rapid period of population growth and urban sprawl that occurred between 1950 and the onset of the Space Shuttle Program. NASA's proactive long term approach to environmental management and stewardship through the 40-year Space Shuttle Program is highlighted.

Appendix A provides a chronological list of all shuttle launches with date, pad, and vehicle.

Appendix B provides a current list of publications developed by the KSC Ecological Program and partners.

2.0 Space Shuttle Program at Kennedy Space Center

2.1 New Construction and Facility Modifications

KSC was selected as the shuttle launch, landing and servicing site based on: 1) the existing Apollo era infrastructure that could be utilized “as is” or with “modifications” and 2) the close affiliation with the Eastern Range at Cape Canaveral Air Force Station (CCAFS). KSC, previously the Launch Operations Directorate of Marshall Space Flight Center, was established at Cape Kennedy, Florida in 1963 as the Center responsible for assembly, test, checkout and launch of NASA space vehicles including launches from KSC, CCAFS and Vandenberg Air Force Base (NASA, 1978). In the period 1971 to 1973, about the time President Richard Nixon gave approval for funding of the Space Shuttle Program, KSC had plans for two Apollo launches, four Skylab launches, 24 unmanned launches from CCAFS, and 11 launches from Vandenberg. Existing infrastructure at Launch Complex 39 Area included the Vehicle Assembly Building (VAB), turn basin, crawlerway, and launch pads. This infrastructure, although extensive, was not designed to support the mission of the reusable shuttle and an era of new construction was initiated.

Major construction activities conducted prior to and during the program included:

- creation of the 1350 acre SLF,
- modification of the launch pads with fixed and rotating service structures,
- maintenance dredging of the Banana River section of the intracoastal waterway, and modifications to Hangar AF for booster recovery and cleanup operations,
- construction of Orbiter Processing Facilities (OPFs), the Assembly and Refurbishment Facility (ARF), and the Rotation, Processing and Surge Facility (RPSF),
- construction of the Space Station Processing Facility (SSPF), the Space and Life Sciences Laboratory (SLSL), Operations Support Buildings (OSB I and II) and the Logistics building.

Modifications, facility upgrades, and new facilities construction continued throughout the Shuttle era to accommodate the changing and maturing Space Shuttle Program and evolving federal, state and local environmental regulations and requirements (NASA, 2010). Many of the new facilities were constructed in existing industrial areas or abandoned citrus groves to minimize cost and impacts. Compliance with the Clean Water Act and the National Pollution Discharge Elimination System (NPDES) regulations required modifications to sewage treatment and disposal facilities and operations, industrial waste water permits and process modifications, addition of stormwater management systems, and wetlands mitigation and monitoring. Clean Air Act requirements were applied to atmospheric

discharges of hydrocarbons and particulates, while RCRA Corrective Action requirements lead to development and implementation of a comprehensive investigation and remediation program for sites contaminated by previous NASA operations. Figure 2 shows the configuration of NASA facilities at KSC as it existed at the end of the Space Shuttle Program.



Figure 2. High resolution aerial photograph of KSC showing the configuration of NASA facilities in 2012 that were utilized to support Space Shuttle Program operations and payload processing activities.

2.2 National Environmental Policy Act Documentation

The Space Shuttle Program was the first and largest NASA activity to be initiated under the requirements of NEPA and environmental laws and regulations promulgated in the following decades designed to improve the quality of the environment (see Table 1). Early in the Space Shuttle Program, KSC was established and identified as having or being responsible for developing the institutional facilities for receiving, inspection, checkout, launch, recovery, and refurbishment of shuttle flight hardware (NASA, 1971, 1972, 1973, 1978, 1979). Under NEPA and the 1971 CEQ guidelines this responsibility led to the creation of numerous NEPA documents and reports in addition to the Shuttle Program Office requirement to document potential impacts from their activities and expenditures of federal funds. A list of major NEPA documents developed to support institutional and programmatic actions is shown in Table 2.

Table 2. List of major NEPA documents developed by NASA to address environmental concerns associated with KSC facilities and infrastructure, the Space Shuttle Program, and potential environmental consequences at KSC.

Year	Title
1971	Kennedy Space Center Institutional Environmental Impact Statement
1972	Environmental Statement for the Space Shuttle Program, Final Statement
1973	Space Shuttle Development and Operations (Amendment 1) Kennedy Space Center Institutional Environmental Impact Statement
1973	Space Shuttle Landing Facility Environmental Assessment
1978	Space Shuttle Program Environmental Impact Statement
1979	Environmental Impact Statement for the Kennedy Space Center
1986-2010	KSC Environmental Resources Document (revisions and updates)

Results from these analyses and their extensive supporting baseline studies and documents indicated that the Space Shuttle Program would have primarily local short-term impacts based on best available engineering and environmental data for the vehicle and KSC area ecosystems. These findings of no significant impacts (FONSI) allowed the program to proceed with minimal alterations. During the period 1978 to 1982, KSC contracted with AIBS to coordinate and support development of the 1979 KSC EIS, and a monitoring

program for the KSC institutional activities, as well as the first four launches to assess the validity of projected impacts. AIBS is a consortium of biological societies representing thousands of biologists from almost every facet of the field making them uniquely qualified to provide scientific assistance to NASA and KSC (AIBS, 1982).

2.3 Launch Issues and Monitoring Needs

Prior to initiation of shuttle flight operations at KSC, numerous studies and evaluations were conducted to continue development of baseline information needed for NEPA compliance and environmental and engineering management decision making under the review and guidance of AIBS (AIBS,1982). The Space Transportation System (STS), consisting of the Space Shuttle with three liquid oxygen and liquid hydrogen engines, the external tank, and the two solid rocket boosters that are the largest ever flown, posed many unique and challenging opportunities. During these evaluations, prior to commencement of launch, many questions were raised. These are summarized in Table 3 and are addressed in the launch effects discussion along with observed impacts. All processing activities were found to be of little environmental concern since most were conducted indoors. Landing was identified as a possible concern due to the sonic boom and potential noise impact. The major identified concerns were related to the launch event including exhaust products and noise, and long-term cumulative impacts associated with construction and KSC operations in general over the life of the Space Shuttle Program.

Table 3. Concerns identified prior to launch of the Space Shuttle.

Topic	Concern
Regional Air Pollution	Release of carbon monoxide, HCl gas, Al ₂ O ₃ particulates
Acid Rain	Possible if HCl exhaust mixes with a rain cloud, resulting in damage to citrus and other crops, cars and homes.
Weather Modification	Increased or suppressed rainfall for up to two days at a distance of up to eight miles away
Stratospheric Ozone Reduction	Chlorine in Solid Rocket Motor (SRM) exhaust injected into upper atmosphere causes a hole in the ozone layer.
Climate Change	Stratospheric Al ₂ O ₃ reducing solar radiation reaching earth
Increase Skin Cancer	Increase harmful UV radiation reaching earth through the ozone hole created by the launch event
Water Pollution	On pad accident, propellant spill, external tank and booster processing, cooling and acoustic deluge water release
Turbidity	Construction of SLF
Cryogenic Release	Failure of storage tanks or cross country lines
Noise Concerns	Engine noise at launch, sonic booms on launch path or landing path

In 1982, AIBS published a summary document that identified conclusions and recommendations for KSC monitoring based on the first four launches and the previous NEPA assessments. They also provided a peer review of existing baseline data and the long-term environmental effects operational monitoring program developed by KSC staff and contractors (AIBS, 1982). AIBS found the proposed KSC Environmental Effects Operational Monitoring Plan to be a well-conceived approach to assessing both acute (launch event) and cumulative (long-term) effects that may result from Space Shuttle Program operations at KSC. A major strength of the plan was that it called for a joint effort between NASA and its contractors and the Fish and Wildlife Service with focus on hydrology and water quality, fire ecology, and anthropogenic impacts (USFWS, 1983). The following were suggested media monitoring actions:

- Soil sampling to assess effects of acid and particulate deposition
- Water quality sampling to assess acute and long-term effects on biota
- Noise monitoring to assess effects on human health and biota
- Exhaust cloud chemical and physical characteristics
- Air quality and rainfall monitoring for long-term trends
- Vegetation monitoring for acute launch effects and long-term trends
- Wildlife population census for select taxa for acute and long-term trends
- Utilize remote sensing for long-term trends

Results of these monitoring activities are presented in Sections 4.0 and 5.0.

3.0 The Dynamic Baseline

3.1 Introduction

The objective of this section is to provide an overview of the geological and ecological history of the Cape Canaveral Barrier Island Complex and KSC as it existed and evolved prior to and during the 30 year Space Shuttle Program. This knowledge provides the relevant long-term context against which ecological effects can be compared for assessment of their scope, importance, and significance to local and regional ecosystem functioning. Included are brief discussions of geology, soils, vegetation, wildlife, sensitive species, and manmade alterations including regional development and land management strategies. The KSC Environmental Resource Document (ERD) (NASA, 2010) contains detailed discussions of these and other topics. Readers familiar with the topic can skip to Section **4.0. Shuttle Launch Monitoring**.

KSC and the associated MINWR, CCAFS, and CNS are co-located on the Cape Canaveral Barrier Island Complex of east central Florida. The Cape provides an ideal location for launching rockets into equatorial orbit without having to fly over populated areas. These unique federal properties are in the transition zone between the temperate Carolinian and sub-tropical Caribbean zoogeographic provinces (Figure 3). The area has high biodiversity, rich ecosystem services, and roughly 11 billion dollars of national assets for assured access to space in 2011. Infrastructure includes space vehicle launch and landing facilities, the VAB, numerous vehicle and payload processing facilities, fuel handling systems, and several industrial, laboratory, clean rooms, and office complexes (Figure 4). Tourism in the area, associated with KSC and the rich natural resources of the Indian River Lagoon and its watershed, has been valued at more than one billion dollars annually (Hazen and Sawyer P.C., 2008).

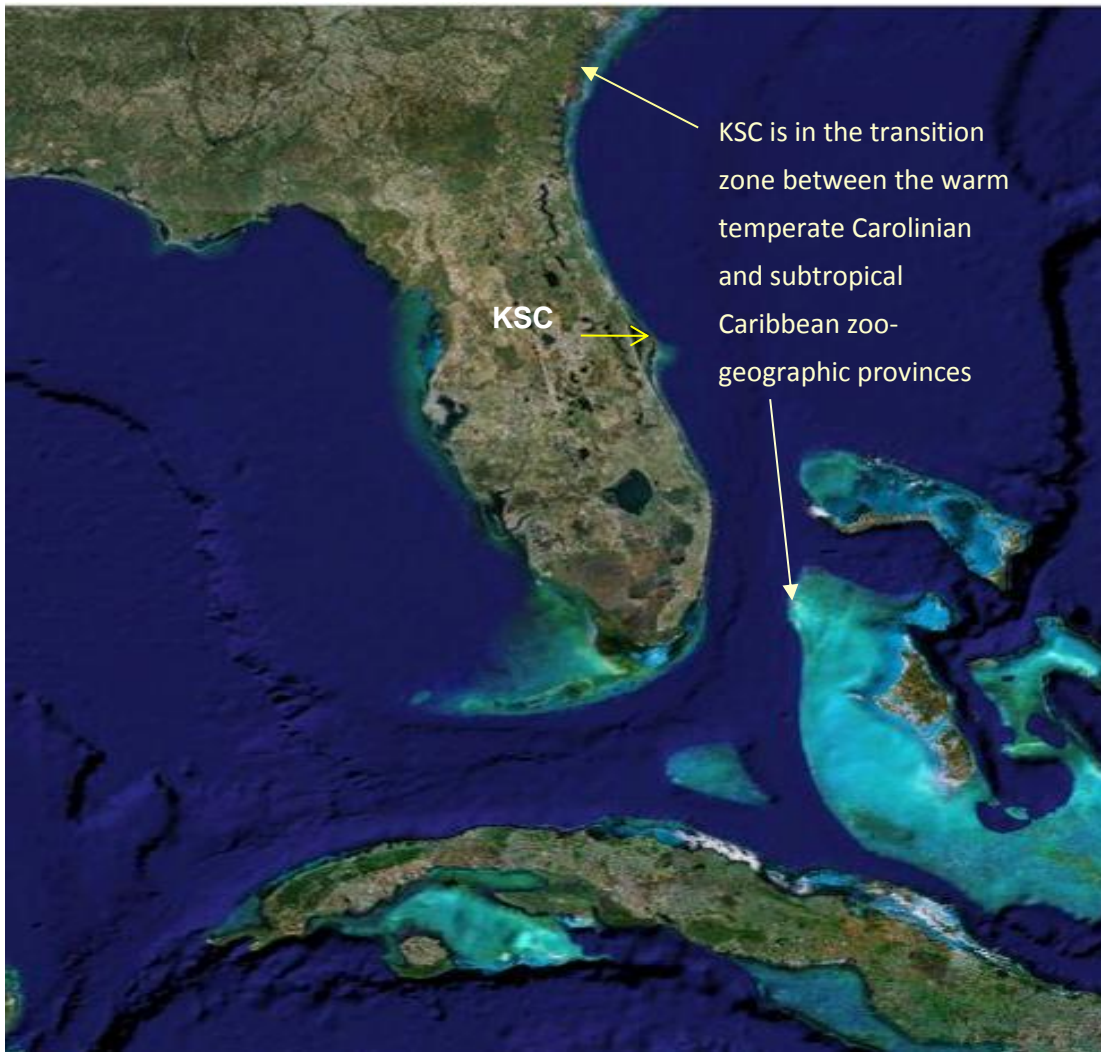


Figure 3. Location of KSC and the Cape Canaveral Barrier Island Complex on the east central Florida coast. The region supports a multi-billion dollar a year economy based on tourism, recreation, private sector and government employment, agriculture, fisheries, and commercial and private real estate.



Figure 4. Landsat image of KSC and CCAFS showing facilities and surrounding urbanization to the west and south. Buildings, roads, cleared land, and infrastructure appear bright.

3.2 Geologic History

The Florida peninsula had its origins in the creation of the super continent of Pangaea some 300 million years ago (mya) when the North American continental land mass, which was part of the super continent called Euramerica, collided with the northwest edge of the African continental plate, which was part of the super continent called Gondwana. This continental collision produced faulting and uplifting to form the Appalachian mountain range along the eastern edge of the North American plate. The base material below the Floridan Plateau is very similar to that found along the northern coast of Africa (Hine, 2013). During the late Triassic and early Jurassic period, some 200 to 180 mya, tectonic plate movement began rifting Pangaea to create the Atlantic Ocean between America and Africa (Figure 5). As the

continents spread, the Florida shelf attached and moved with the southern edge of the North American Continent in the area now known as the state of Georgia (Hine, 2013).

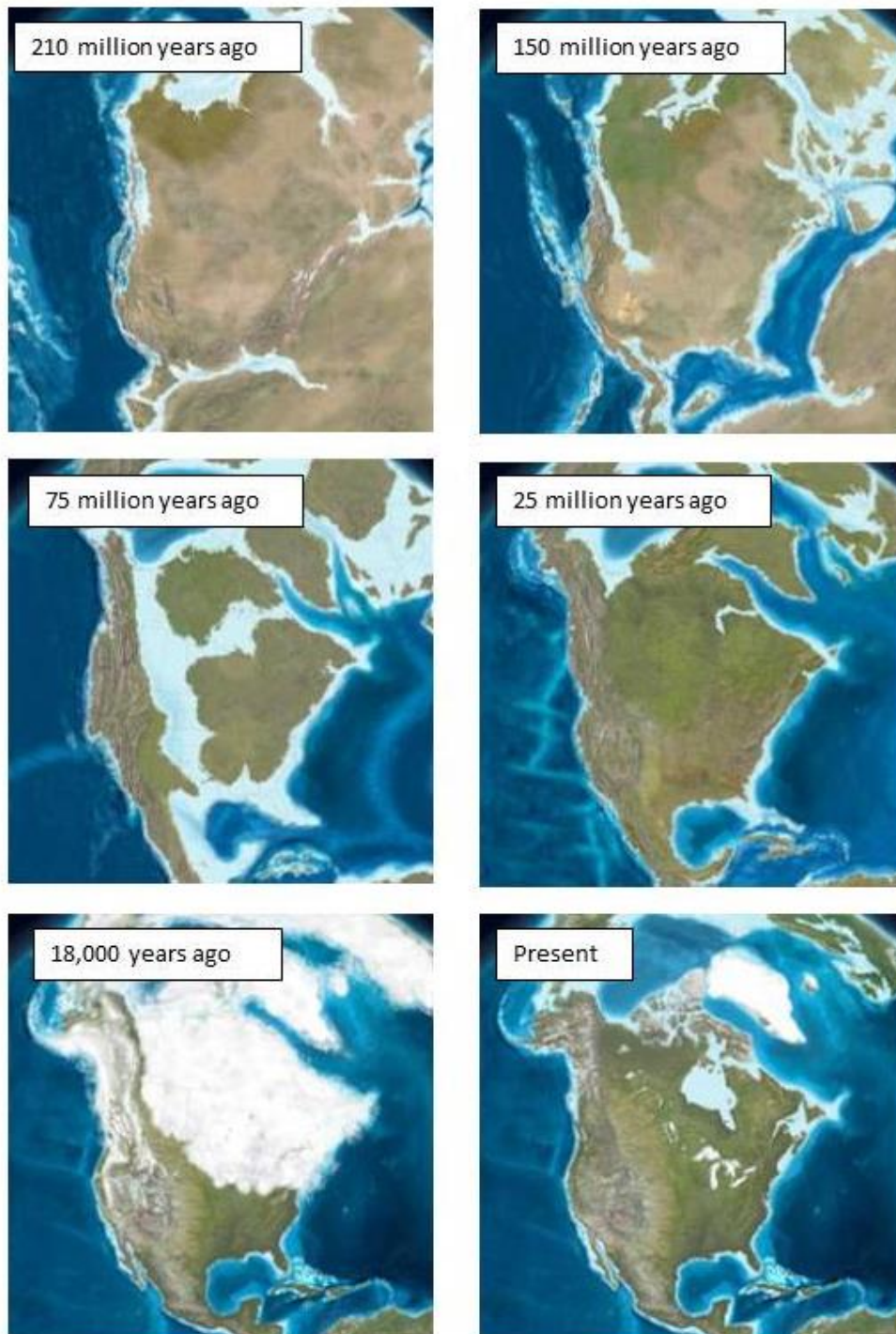


Figure 5. Geologic formation of the Atlantic Ocean, Floridan Plateau, and Florida Peninsula resulting from the breakup of the super continent Pangaea beginning approximately 210 million years ago. The last Quaternary Ice Age glacial retreat began about 18,000 years ago. (Images by Ron Blakey, Colorado Plateau Geosystems, Inc.)

As the plates continued to move apart the passive margin of the North America plate subsided and the Floridan Plateau began to form through deposition of thousands of meters of sediments. These sediments included materials eroded from the Appalachian Mountains and coastal lowlands of eastern North America, and deposition of marine carbonate materials in the form of coral reefs, shells, and limy muds (Hine, 2013).

The major driving force in the creation of the modern Florida landscape has been the influence of the last Ice Age and its repeating glacial and inter-glacial periods. Throughout Earth's 4.6 billion year history geologists have identified five significant Ice Ages or periods lasting a total of approximately 500 million years (Table 4).

Table 4. Known ice ages and associated geologic time periods. Throughout the history of the Earth, ice has been present only 10-12 % of the time. Warmer climate periods with higher sea levels are the norm.

Name	Period (mya)	Period	Era
Quaternary	2.58 – present	Neogene	Cenozoic
Karoo	360 – 260	Carboniferous and Permian	Paleozoic
Andean-Saharan	450 – 420	Ordovician and Silurian	Paleozoic
Cryogenian	800-635	Cryogenian	Neoproterozoic
Huronian	2400-2100	Siderian and Rhyacian	Paleoproterozoic

During the Quaternary ice age, repeated glacial and interglacial periods of the northern hemisphere produced dramatic fluctuations in sea level (Bowen, 1978). At the maximum of the Wisconsin glaciation (ca. 18,000 years B.P.), sea levels were on the order of 100 m lower than at present, and substantial additional areas of Florida were exposed along the Atlantic and Gulf coasts (Field and Duane, 1974; Delcourt and Delcourt, 1981).

The outer barrier island and Cape Canaveral formed after sea levels rose as the Wisconsin glaciers retreated (Davis, 1997). Cape Canaveral is mapped as Holocene in age suggesting that formation of the barrier island complex began about 7,000 years ago (Brooks, 1972, 1981). Cape Canaveral is part of a prograding barrier island complex, the result of southward growth of an original cape at the site of the present False Cape (White, 1958, 1970). Multiple dune ridges on Merritt Island and Cape Canaveral indicate periods of deposition and erosion alternating as sea level varied in height (Chaki, 1974). The barrier island separating Mosquito Lagoon from the Atlantic Ocean also originated about 7,000 years ago (Mehta and Brooks, 1973). However, its history has been marked by erosion, overwash, and landward migration rather than progradation (Mehta and Brooks, 1973).

The western portion of Merritt Island is substantially older than the eastern portion (Clapp, 1987). Erosion has reduced the western side to a nearly level plain (Brown et al., 1962) with elevations generally below 0.7 m. Regional elevation data are presented in Figure 6. These elevation data are useful in discerning the pattern of barrier island formation described above; and elevation is one controlling factor in other ecosystem characteristics and processes such as soil type formation, sub-surface and surface water flow patterns, evapotranspiration rates, primary production rates, and vegetation community structure and distribution across the landscape. Figure 7 shows the relative density distribution functions comparing elevations on KSC with CCAFS. These differences are in part related to age and weathering and in part to the geo-hydraulic conditions at the time of land feature formation.

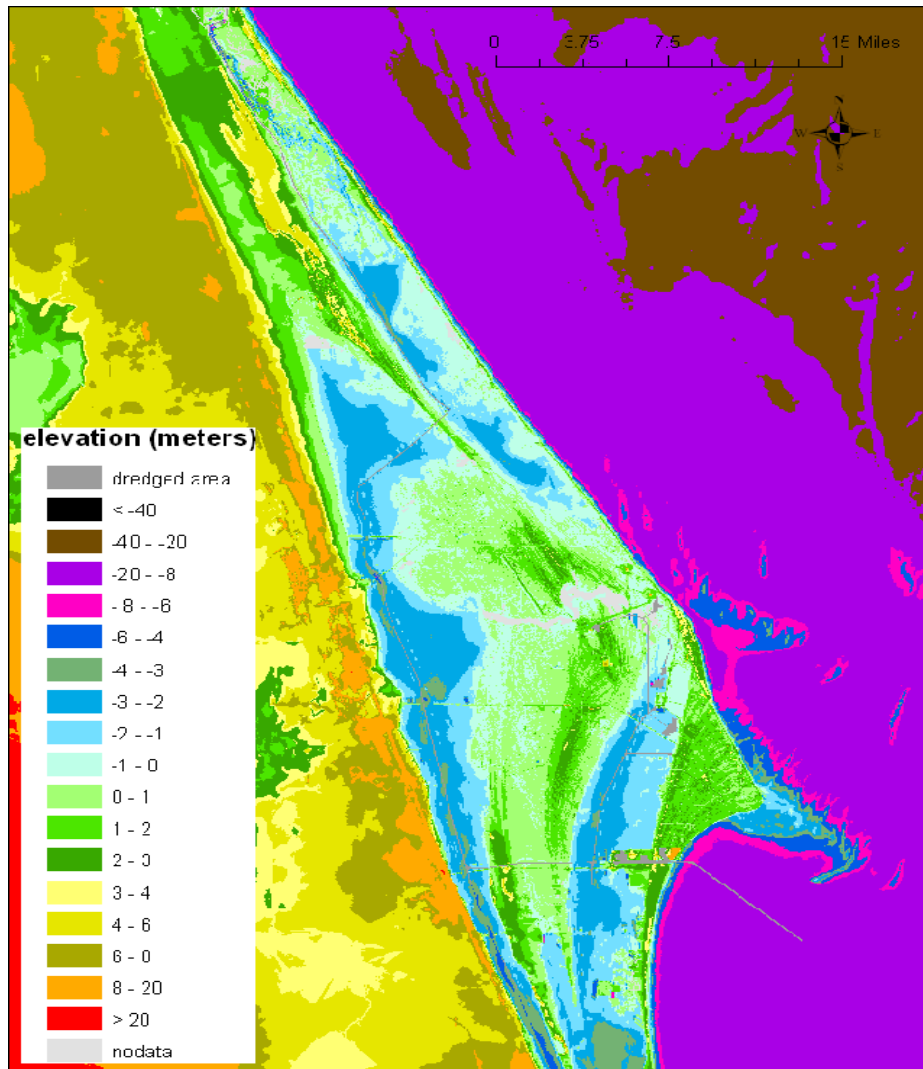


Figure 6. Regional elevation and bathymetry data for the Cape Canaveral Barrier Island ecosystem and the near-shore Atlantic Ocean.

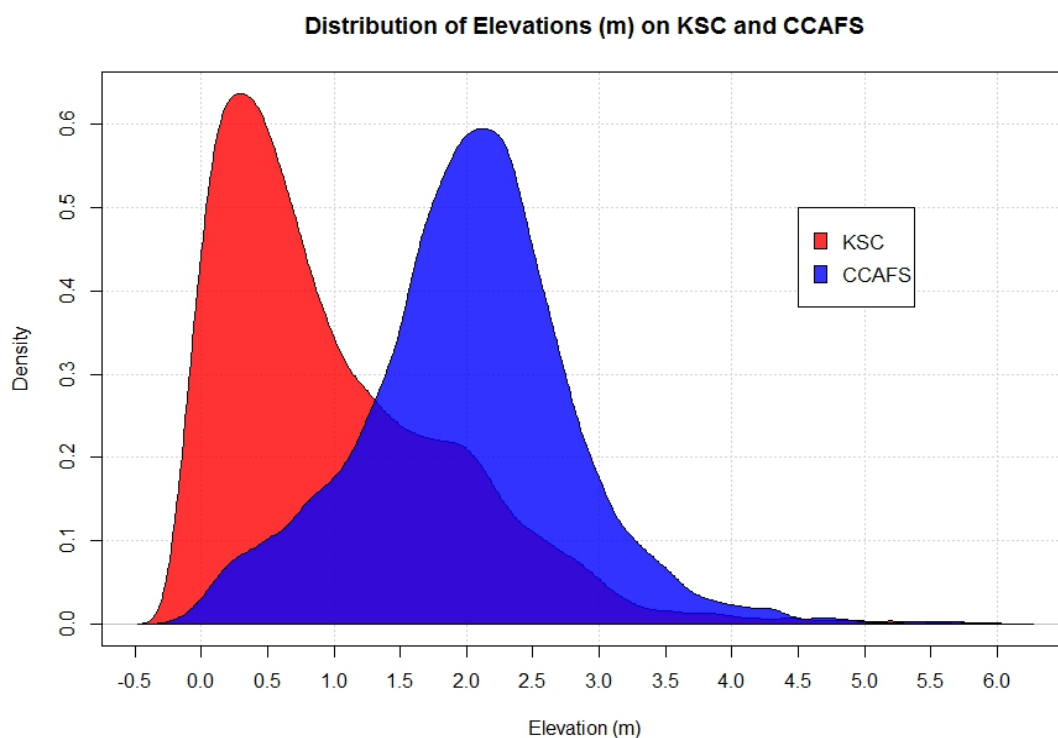


Figure 7. Kernel density plots of land elevation for KSC and CCAFS based on 2007 LIDAR data collected by the Florida Department of Emergency Management. Mean elevation for KSC is 0.7 m and CCAFS is 2.1 m.

3.3 Soils

Soils differ through the interaction of several factors including climate, parent material, topography, organisms, and time (Jenny, 1941, 1980); and the resulting soil pattern is highly complex. Detailed soil maps for KSC and the surrounding area are shown in the soil surveys for Brevard County (Huckle et al., 1974) and Volusia County (Baldwin et al., 1980). Numerous soil series and land types are represented even though Merritt Island is a relatively young landscape and one formed from coastal plain deposits. Some differences in soil parent material do occur. In particular, soils that formed in deposits over limestone, coquina, or other alkaline material differ greatly in properties from those formed in sand. Textural differences in parent material such as that between loam or clay material and sand also influence soil properties.

The primary source of parent material for KSC soils is sands of mixed terrestrial and biogenic origin. The terrestrial material originated from southern rivers carrying sediments eroded from highly weathered Coastal Plain and Piedmont soils. These sediments are quartzose with low feldspar content (Milliman, 1972), moved south through long-shore transport, and may have been reworked repeatedly. The biogenic carbonate fraction of

the sand is primarily of mollusk or barnacle origin with lesser contributions of coralline algae and lithoclasts; some may be reworked from offshore deposits of coquina and oolitic limestone (Milliman, 1972).

The Cape Canaveral-Merritt Island complex is not all of the same age. Soils on Cape Canaveral, False Cape, and the barrier island section on the east side of Mosquito Lagoon are younger than those of Merritt Island and therefore have had less time to weather. Well-drained soil series (e.g., Palm Beach, Canaveral) in these areas still retain shell fragments in the upper layers, while those inland on Merritt Island (e.g., Paola, Pomello) do not. The presence of shell fragments influences soil nutrient levels, particularly calcium and magnesium, and pH. The eastern and western sections of Merritt Island differ in age. The eastern section of Merritt Island inland including Pads 39A and 39B to about State Route 3 has a marked ridge-swale topography presumably retained from its formation as a barrier island. West of State Route 3, the island is flatter, without obvious ridges and swales, probably due to the greater age of this topography.

Differences in age and parent material account for some soil differences, but on landscapes of Merritt Island with similar age, topography has a dramatic effect on soil formation. Relatively small elevation changes cause dramatic differences in the position of the water table that, in turn affect leaching, accumulation of organic matter, and formation of soil horizons. In addition, proximity to the lagoon systems influences soil salinity. As part of a baseline characterization of soil, groundwater, surface water, and sediment of KSC, ten soil classes were identified (Schmalzer et al., 2000, 2001). Soils were divided into four groups: Upland, Wetland, Agricultural, and Disturbed. Upland soils are not flooded for substantial periods, while Wetland soils have standing water for substantial periods. Flooding affects organic matter accumulation, oxidation-reduction conditions, and other chemical properties of soils (Ponnamperuma, 1972). Upland soils were then further divided into well-drained and poorly drained categories. Poorly-drained soils accumulate more organic matter, which forms the cation exchange capacity in these soils, retaining nutrients and metals (Schmalzer et al., 2000, 2001; Schmalzer and Hinkle, 1996). Well-drained, upland soils were divided into three classes: 1) geologically recent, alkaline, sandy soils of coastal dunes where the vegetation is coastal dunes, coastal strand, or coastal scrub; 2) old, inland, leached, acid, sandy soils where the vegetation is oak-saw palmetto scrub or scrubby flatwoods; and 3) inland, circum-neutral soils formed over coquina where the vegetation is oak-saw palmetto scrub or xeric hammock. Poorly-drained, upland soils were divided into two classes: 1) acid, sandy soils with flatwoods vegetation; and 2) circum-neutral to alkaline soils formed over coquina or limestone where the vegetation is mesic hammock (Table 5).

The primary division of wetland soils was between: 1) inland, freshwater wetlands where the vegetation was freshwater marshes or hardwood swamps; and 2) coastal, brackish to saline wetlands where the vegetation was salt marshes or mangroves (Table 5).

Agricultural soils were of two types: 1) active or abandoned citrus on scrub soils; and 2) active or abandoned citrus on hammock soils (Table 5). Disturbed soils included various types modified by construction. There are clear landscape patterns to these soil classes (Figure 8). Flatwoods, Salt Water Wetlands, and Freshwater Wetlands were the largest categories (Table 5). These soil classes were shown to be significantly different for many chemical and physical parameters (Milliman, 1972; Schmalzer et al., 2000).

Table 5. Summary of major soil types and extents found at KSC. In the area of Pads 39A and B soils are geologically recent, alkaline, sandy soils of coastal dunes.

Soil Class	Area (hectares)	Percent of Soil Area
Coastal	1098.3	3.30
Acid Scrub	1556.9	4.76
Coquina Scrub	270.4	0.81
Flatwoods	10432.6	31.32
Hammocks	1990.1	5.97
Freshwater Wetlands	6154.3	18.48
Saltwater Wetlands	9626.2	28.90
Citrus Scrub	349.3	1.05
Citrus Hammock	640.0	1.92
Disturbed	1192.4	3.58

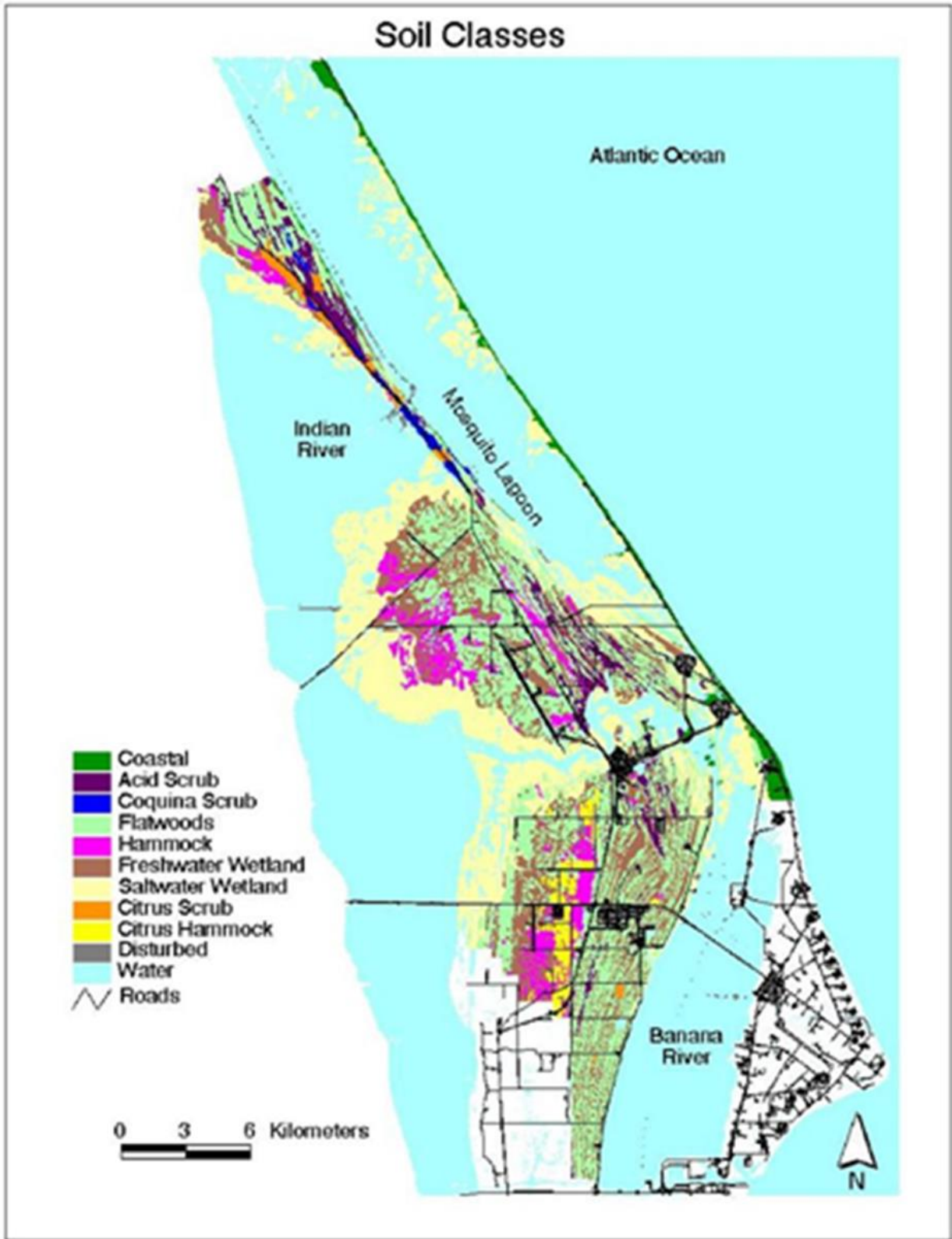


Figure 8. Distribution of major soil types on KSC (Schmalzer et al., 2000, 2001).

3.4 Climate and Weather

The climate and weather of east central Florida is subtropical with short, mild winters and hot, humid summers, with no recognizable spring or fall seasons (NASA, 2010). Warm weather, usually beginning in late April, prevails for about 9 months of the year. Typically, dawns are slightly cloudy or hazy, with little wind, and temperatures near 70 degrees Fahrenheit (°F). During the day the temperature rises into the 80s and 90s °F. Occasional cool days occur in November, but winter weather starts in January and extends through February and March. These last two months are usually windy and temperatures range from about 40 °F at night to 75 °F during the daytime (Mailander, 1990). Figure 9 displays the long term temperature trend for east central Florida. This upward trend in temperature is attributed primarily to increasing emissions of greenhouse gasses and manmade changes in global carbon pools.

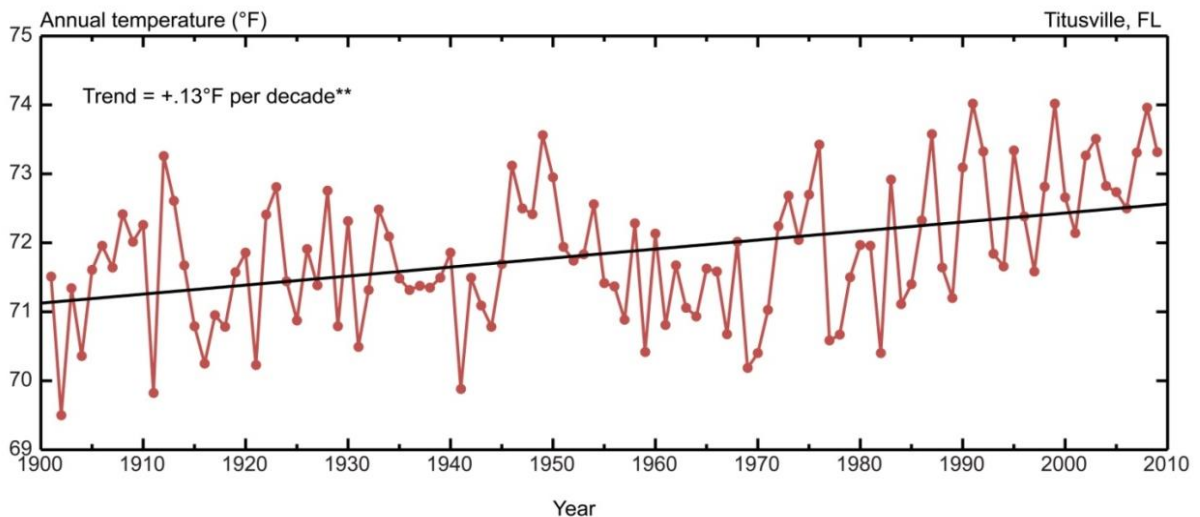


Figure 9. Long-term annual average temperature trend for Titusville Florida. The rising temperatures correlate with increasing global population growth, urbanization, rising atmospheric CO₂ levels, and other factors altering long-term global carbon budgets (National Climate Data Center).

The dominant weather pattern (May to October) is characterized by southeast winds, which travel clockwise around the Bermuda High. This pattern, in addition to almost daily sea breezes, brings moisture over the warmer land mass. As the air warms it rises producing almost daily thundershowers thus creating the summer wet season. Approximately 70 percent of the average annual rainfall occurs during this period. Weather patterns in the dry season (November to April) are influenced by cold continental air masses.

Rains occur when these masses move over the Florida peninsula and meet warmer air. In contrast to localized, heavy thundershowers in the wet season, rains are light and tend to be uniform in distribution during the dry season (Mailander, 1990).

The main factors influencing climate are latitude and proximity to the Atlantic Ocean and the Indian and Banana Rivers, which moderate temperature fluctuations (Mailander, 1990). Results of the Cape Atmospheric Boundary Layer Experiment show that wind direction, especially the sea breeze front, is controlled by thermal differences between the Atlantic Ocean, Banana River, Indian River, and Cape Canaveral land mass. Heat is gained and lost more rapidly from land than water. During a 24-hour period, water may be warmer and again cooler than adjacent land. Cool air replaces rising warm air creating offshore (from land to ocean) breezes in the night and onshore (from ocean to land) breezes in the day. These sea breezes have been recorded at altitudes of 1000 m (3,281 ft.) and higher, and reach further inland during the wet season. Seasonal wind directions are primarily influenced by continental temperature changes. In general, the fall winds occur predominantly from the east to northeast. Winter winds occur from the north to northwest shifting to the southeast in the spring and then to the south in the summer months (NASA, 2010).

3.5 Eco-hydrologic Setting

The Cape Canaveral Barrier Island complex, including KSC, is part of the Indian River Lagoon (IRL) ecosystem stretching 156 miles along Florida's east central coast from Ponce Inlet in the north to Jupiter Inlet in the south. This system is composed of three estuaries, the Mosquito Lagoon, Banana River Lagoon and Indian River Lagoon, and is adjacent to the western Atlantic Ocean (Figure 10). Both the land and water features have been defined by the historic rise and fall of sea level (Woodward-Clyde, 1994(a)). Periodically hurricanes and other forces can breach the barrier island, opening ephemeral inlets that close over time as a result of the long shore transport of sediments. The natural watershed of the lagoon has been estimated at roughly 226,016 hectares (ha) (558,500 acres (ac)). The area of each lagoon is estimated as:

- Mosquito Lagoon = 15,317 ha (37,850 ac)
- Banana River Lagoon = 19,327 ha (47,760 ac)
- Indian River Lagoon = 57,513 ha (142,120 ac)

The entire basin occupies approximately 318,175 ha (786,230 ac) of which 92,159 ha (227,730 ac) or 29 percent is open water lagoon (Woodward-Clyde, 1994(a)).

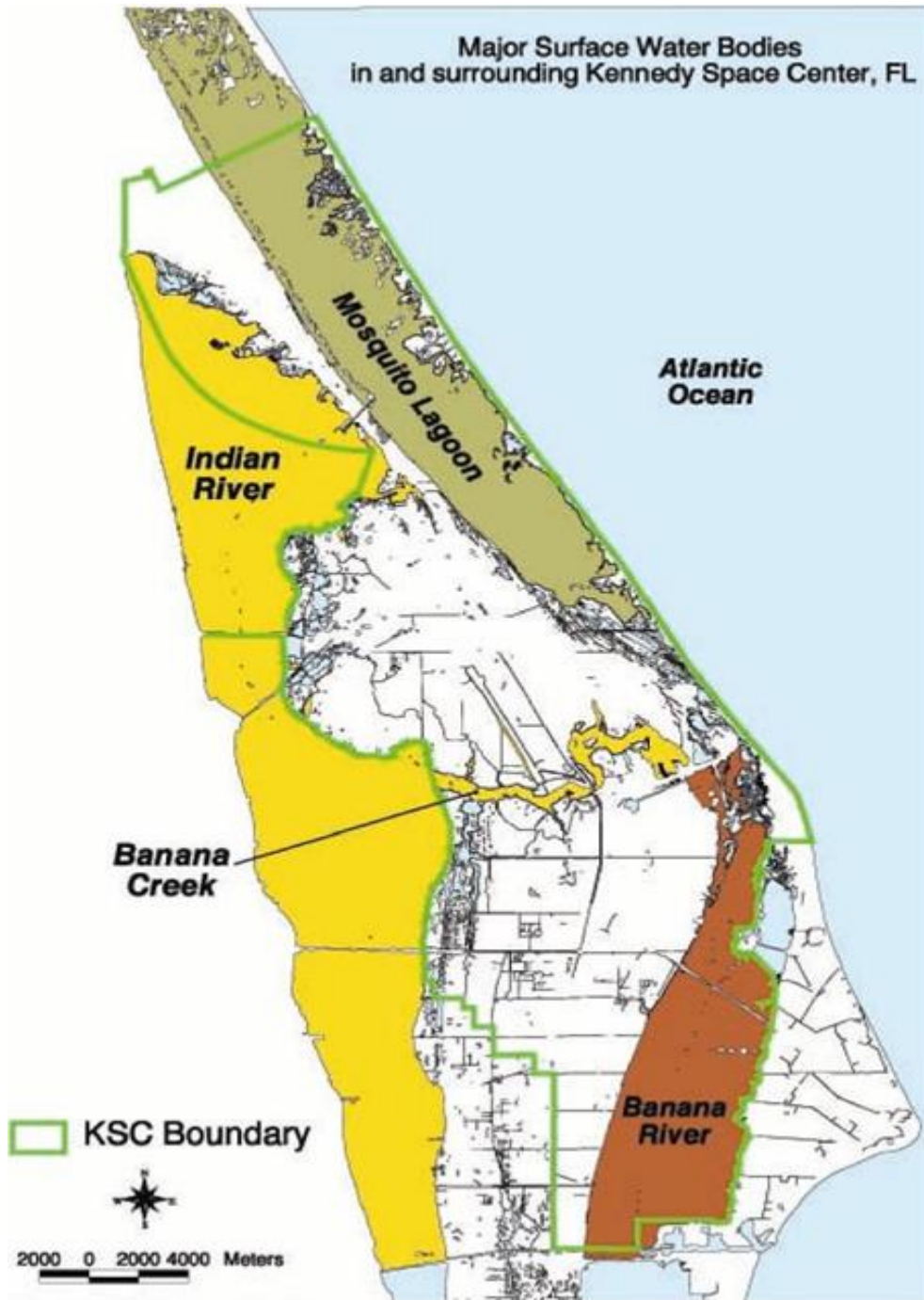


Figure 10. Relative locations of major water bodies in the vicinity of the Cape Canaveral Barrier Island Complex and KSC.

The current mean annual water level estimate for the Atlantic Ocean in the Cape Canaveral area, based on data from the Trident Pier tide gauge, is -0.29 m North American Vertical Datum of 1988 (NAVD88). Monthly average fluctuations are shown in Figure 11. There is an annual pattern in sea level with a fall peak and a winter minimum resulting primarily from the thermal expansion and contraction of the ocean surface due to annual heating and cooling.

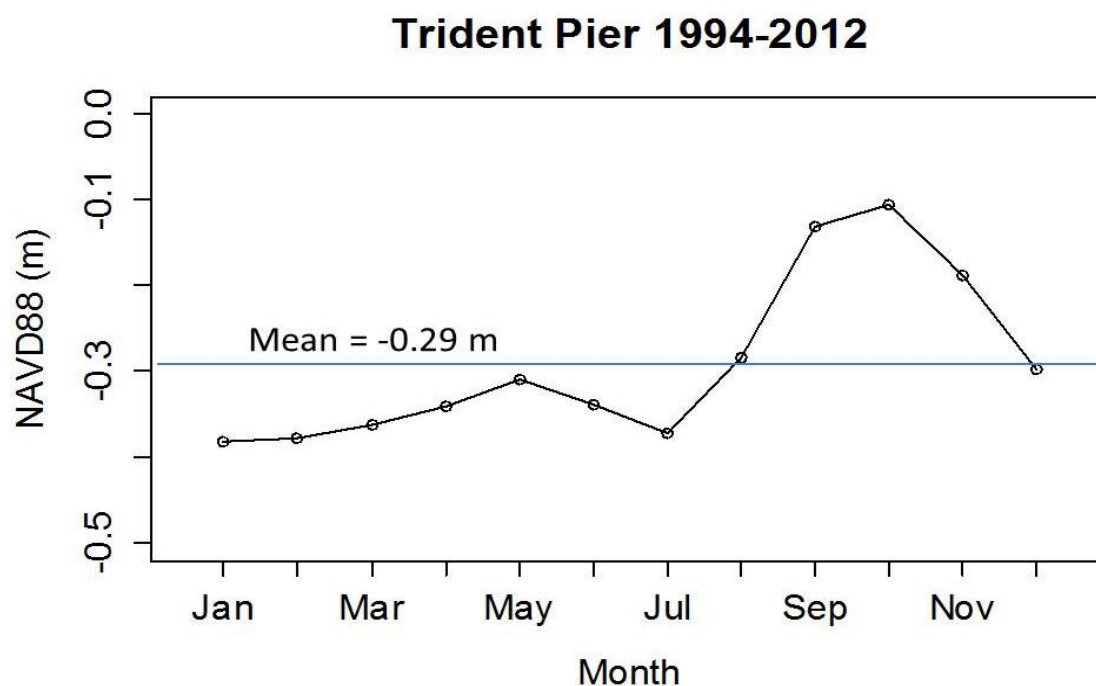


Figure 11. Monthly and annual mean water level for the Atlantic Ocean in the vicinity of Cape Canaveral based on 18 years of NOAA tide gauge data collected at the Trident Pier in Port Canaveral.

The long term trend in annual mean sea level based on the 100 year data set from the Key West tide gauge is shown in Figure 12. Sea levels along the east coast of Florida have been trending upward in a fashion similar to annual temperature. Results of monthly and annual average water level analyses for data collected at the USGS Haulover Canal tide gauge are shown in Figure 13. The annual average water level for the region is -0.20 m NAVD88. Monthly average water levels follow the trend observed for the Atlantic Ocean at the Trident Pier with a one month lag in the peak spring level from May to June. This lag may be a function of the summer onset of tropical rainfall and an increase in the sea breeze intensity pushing ocean water onshore.

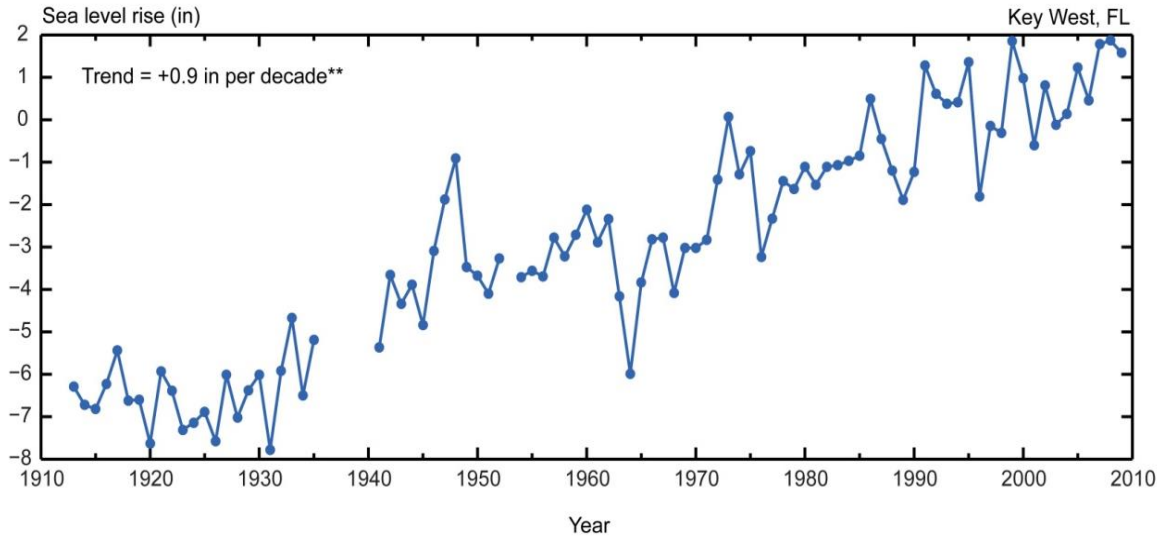


Figure 12. Long-term 100 year record of mean sea level deviation from the average value for the 30 year period between 1980 and 2010 based on records from the NOAA Key West tide gauge.

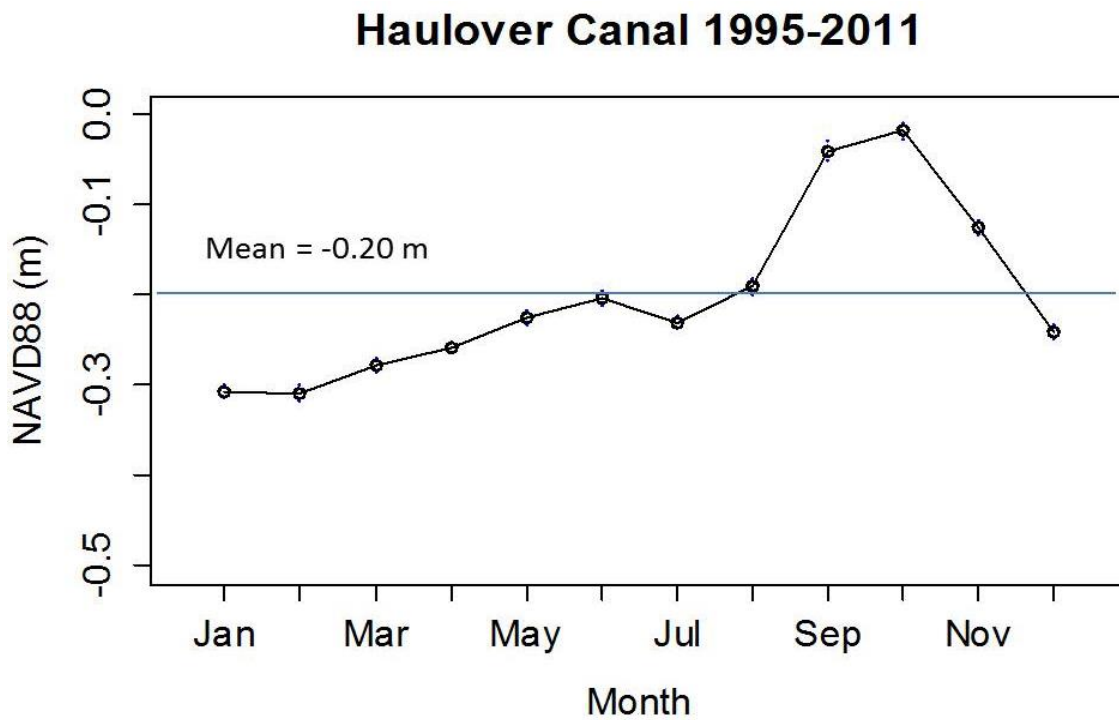


Figure 13. Monthly and annual mean water level for the Indian River Lagoon in the vicinity of KSC based on 16 years of data collected at the USGS Haulover Canal tide gauge on north Merritt Island.

Mean annual rainfall for Merritt Island and Titusville are 131.1 cm (51.6 in) and 136.7 cm (53.8 in), respectively (NASA, 2010). Annual rainfall varies widely; values for Merritt Island range from 77.5 cm (30.5 in) to 217.7 cm (85.7 in), and for Titusville range from 84.8 cm (33.4 in) to 207.5 cm (81.7 in). The long term annual rainfall data for Titusville is shown in Figure 14. No trend in annual rainfall is obvious through the 110 years of record. The monthly average rainfall pattern is shown in Figure 15. A small peak in rainfall in the winter is a result of passing cold fronts. There is a peak in rainfall in June with the onset of the summer thunderstorm season, and a second peak in August-September related to tropical storms and sea breeze derived thunderstorms.

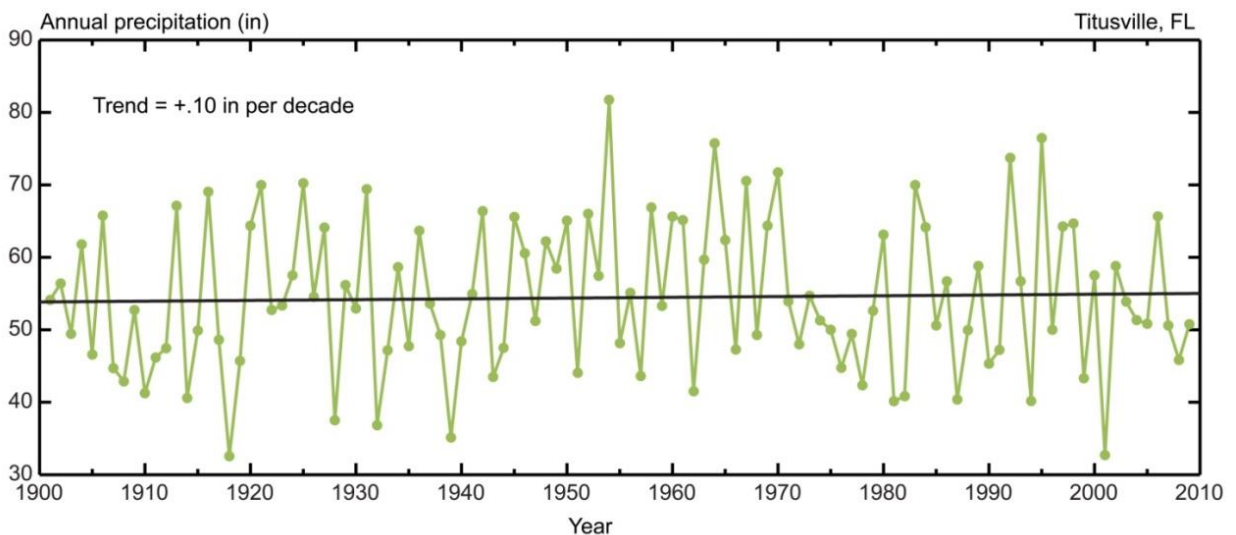


Figure 14. Long-term annual rainfall record for Titusville, Florida showing no increasing or decreasing trend. On an annual basis rainfall is highly variable, being influenced by the El Nino Southern Oscillation, the Atlantic Decadal Oscillation, and other global, regional and local processes (National Climate Data Center).

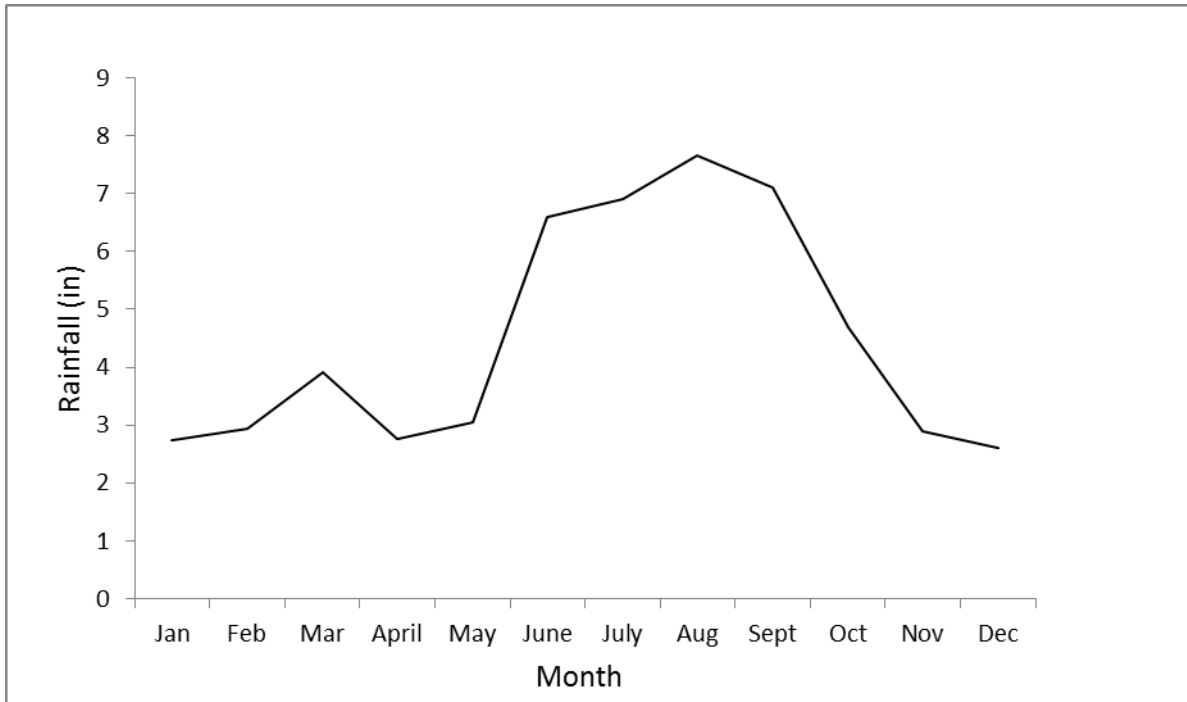


Figure 15. Monthly average rainfall (in) for Titusville, Florida showing a peak in the summer due to convective thunderstorms and tropical storms (National Climate Data Center).

Nearly all groundwater at KSC originates as precipitation that infiltrates through soil into flow systems in the underlying hydrogeologic units. Of the approximate 140 cm (53 in) of precipitation annually, approximately 75% is claimed by evapotranspiration. The remainder is accounted for by runoff, base flow, and recharge of the surficial aquifer. Recharge to the surficial aquifer system primarily comes from the direct infiltration of precipitation. Recharge potential differs across KSC with the greatest recharge potential in the ridges of eastern Merritt Island and north of Haulover Canal (Figure 16) (NASA, 2010; Edward E. Clark, 1987).

Groundwater mounds in the recharge areas creating a classic freshwater lens (Edward E. Clark, 1987). An example of the importance of these mounding phenomena is depicted in Figure 17 and Figure 18 which show an example of the relationship between land surface elevation, groundwater elevation, depth to water table, and vegetation community structure. Based on this short 2 year dataset, areas below 0.7 m (2.3 ft) elevation would on average be permanently flooded. Areas between 0.8 and 1.6 m (2.6 and 5.2 ft) would have seasonal standing water. In the region between about 1.6 and 2.0 m (5.2 and 6.6 ft), wetland vegetation is dominant with species being dependent on hydro period, soils, and other factors. Moving up slope, saw palmetto dominates between 2.0 and 2.4 m (6.6 and 7.9 ft), mixed

shrub and oak species dominate the region between 2.4 and 2.8 m (7.9 and 9.2 ft) transitioning to oak dominated cover above 2.8 m (9.2 ft) elevation.

Groundwater flows from these recharge areas east toward the Banana River, Mosquito Lagoon, and the Atlantic Ocean, and west toward the Indian River (NASA, 2010). In general, water in the surficial aquifer system near the groundwater divide of the island has potential gradients which tend to carry some of the water vertically downward to the deepest part of the surficial aquifer system and potentially to the upper units of the Intermediate aquifer system (Edward E. Clark, 1987). Major discharge points for the surficial aquifer system are the estuarine lagoons, shallow seepage occurring to troughs, ditches, and swales, and evapotranspiration (Edward E. Clark, 1987). Detailed descriptions of subsurface geology and hydrology can be found in the KSC Environmental Resources Document (NASA, 2010; Edward E. Clark, 1987).

Internal fresh surface waters are primarily derived from surficial groundwater; shallow groundwater supports freshwater wetlands; groundwater discharge to surrounding saltwater bodies contributes to the maintenance of lagoon salinity; and groundwater underflow is a major factor in establishing the equilibrium of the fresh-saltwater interface in the surficial aquifer system (Edward E. Clark, 1987).

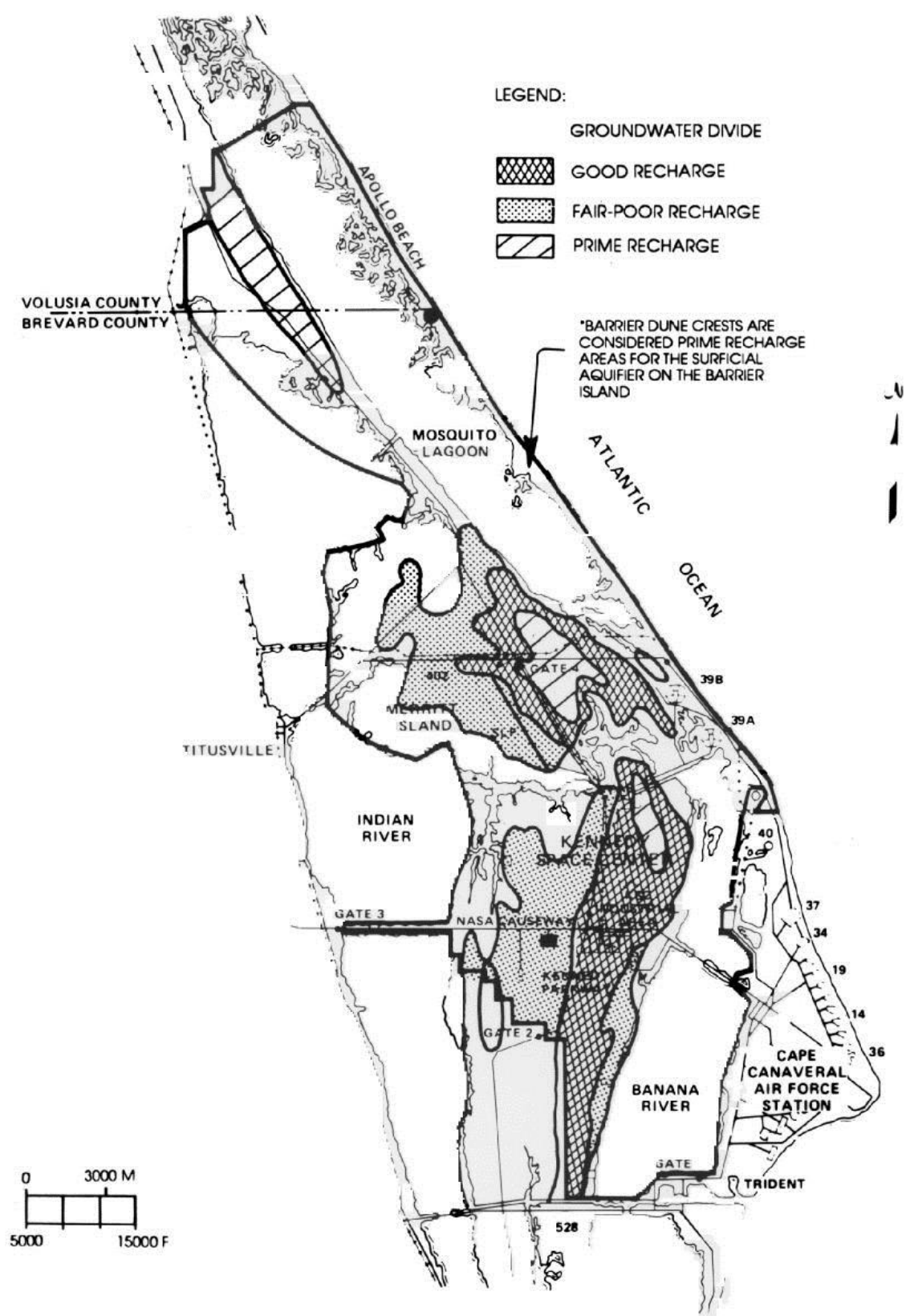


Figure 16. Potential for recharge of the surficial aquifer (Edward E. Clark, 1987).

KSC Surficial Aquifer Elevations (2010-2012) Tel-4

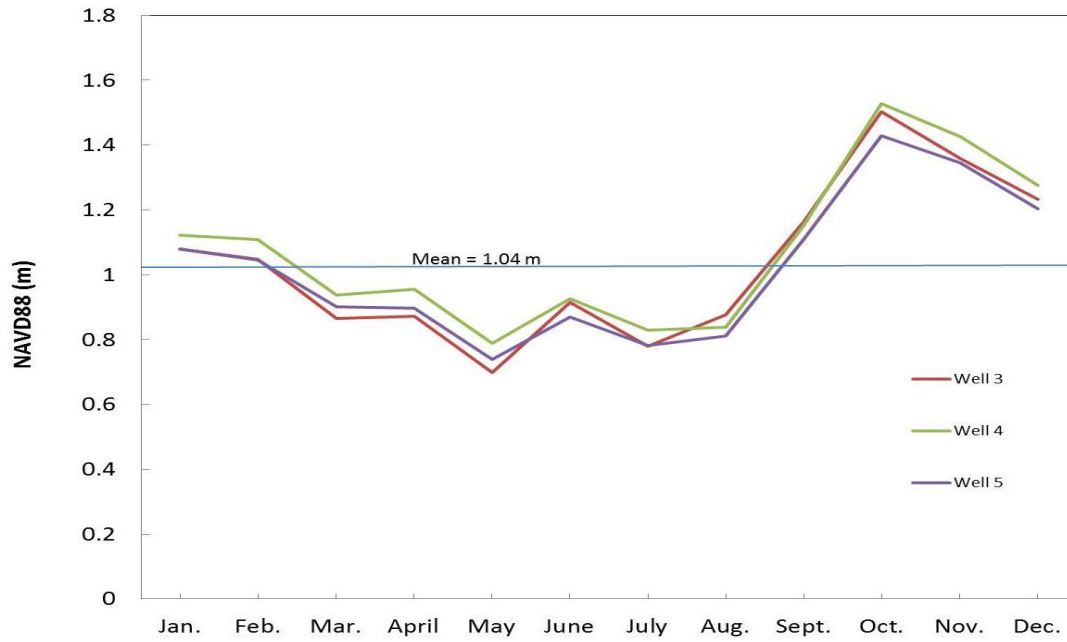


Figure 17. Average surficial aquifer elevation in the Tel-4 region of KSC based on two years of monitoring well data.

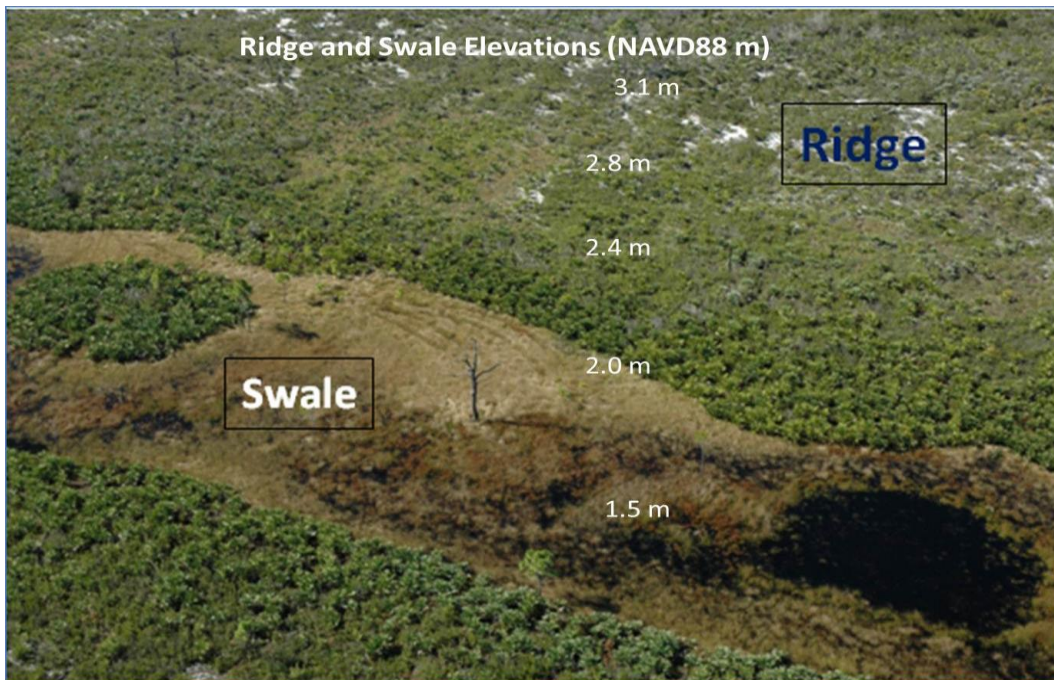


Figure 18. Example swale and ridge system with LIDAR elevations and vegetation community transitions from wetlands to saw palmetto to scrub oak.

3.6 Regional Biota

The Cape Canaveral Barrier Island Complex with the Indian River Lagoon stretches north to south along the climatic transition from the temperate Carolinian Province to the subtropical/tropical Caribbean or West Indian Province with species of fish and wildlife from both climate zones overlapping in and along the lagoon. This unique geographical feature contributes to the area being recognized as one of the most biologically diverse estuaries in North America with more than 2,200 different species of animals and 2,100 species of plants. Vegetation communities and the wildlife and fisheries that they support are directly and indirectly related to hydrology, water quality, soil/sediment type, elevation, fire, and anthropogenic activities (Hamilton et al., 1985). A comprehensive bibliography and assessment have been previously published (Morris, 1989). Of the 2200 different species of animals there are 700 saltwater and freshwater fish species and 310 bird species (EPA, 2007)).

Within the lagoon, submerged aquatic vegetation (SAV) beds were historically distributed throughout the region in most areas where light could penetrate to the bottom or approximately two m (6.6 ft) (Virnstein, 1995). Figure 19 shows the distribution of SAV in 2009 in the Cape Canaveral area. These extensive seagrass beds support the rich community of invertebrates, fishes, sea turtles, and marine mammals including the West Indian manatee.

There are seven species of seagrass with distributions that vary along the north-south axis of the lagoon. All seven species occur in the southern third of the lagoon (Dawes et al., 1995). Three of the seven (*Thalassia testudinum*, *Halophila johnsonii*, and *Halophila dicipiens*) are not currently found in the northern IRL where *Halodule wrightii*, *Syringodium filiforme*, *Ruppia maritima*, and *Halophila engelmannii* do occur. Areas that are not occupied by SAV beds generally have much less diverse and productive plant communities (Virnstein et al., 1983). Plant life is composed of phytoplankton, drift algae, and attached algae. Little is known about the drift and attached algae communities (Woodward-Clyde, 1994(d)). An example of a *Syringodium* bed with benthic algae is shown in Figure 20.

Phytoplankton represents a component of primary production that is key for many estuarine species and a sufficiently high density is a factor of estuarine productivity. Phytoplankton productivity in the IRL has been estimated at 2 to 7% of total primary production. Seagrass contributes roughly 50 to 85% with attached and drift algae contributing the remainder. Overabundance of phytoplankton can be problematic by altering water chemistry, contributing to fish kills, and decreasing light availability to SAV (Woodward-Clyde, 1994(d)).

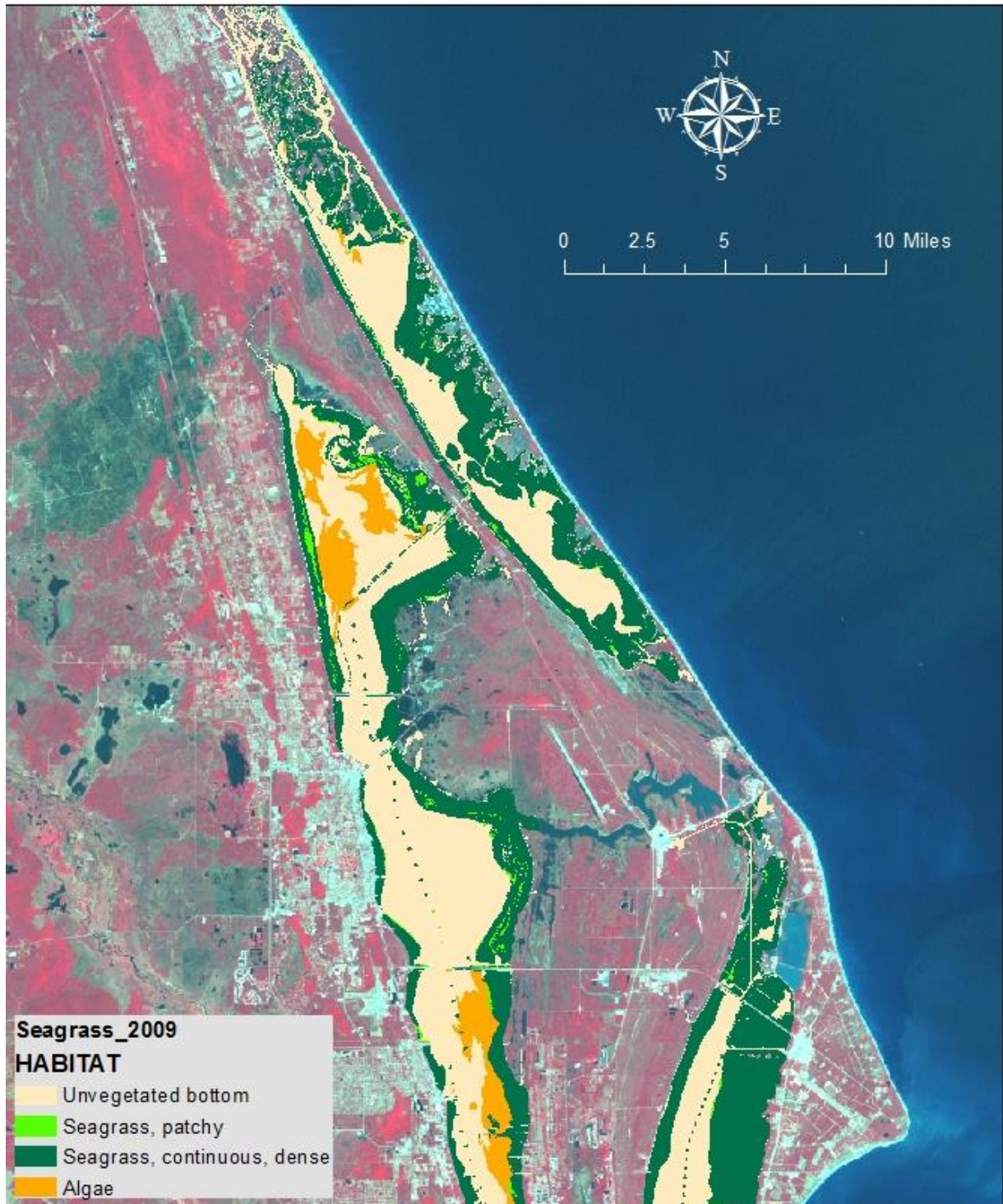


Figure 19. Distribution of submerged aquatic vegetation in the Indian River Lagoon around Cape Canaveral, Florida in 2009. Historic accounts suggest distributions were more extensive prior to development of the watershed for agriculture and urban use (St. Johns River Water Management District).



Figure 20. Example of a healthy seagrass bed in the Indian River Lagoon.

The historic landcover of the area representing conditions in 1920, 1943, and 1990 was mapped in 17 categories by Duncan et al., (2004). A description of the different landcover categories is shown in Table 6. Figure 21 shows examples of the marshes, pine flatwoods and scrub categories for reference. The distribution of each category across the regional landscape for 1920 is presented in Figure 22. Note the absence of bridges and causeways, Port Canaveral, and lack of significant fragmentation by roads or development which was limited along the western shoreline in the areas of Titusville, Cocoa, and Rockledge. This map is assumed to be fairly representative of historic conditions. A more detailed discussion of regional flora and fauna can be found in the KSC Environmental Resources Document (NASA, 2010).



Figure 21. Examples of scrub, pine flatwoods, salt marsh and freshwater marsh.

Table 6. Landcover classes used to map the Cape Region (Duncan et al., 2004)

Land Cover Class	Description
Urban/Development	Commercial, industrial, residential, and transportation.
Agriculture/Rangeland	Crops, groves, improved and unimproved pasture, rangeland, and conifer plantations.
Coastal Strand	Herbaceous, coastal dunes vegetation dominated by sea oats and shrub coastal strand vegetation with saw palmetto, sea grape and live oak.
Flatwoods	Scrubby, mesic and hydric flatwoods with longleaf, slash, or pond pine. Includes palmetto prairie with a saw palmetto-herb layer but no pine canopy. Also includes sand pine scrub.
Scrub	Xeric oak scrub vegetation with no or minimal pine canopy.
Hammocks	Temperate and tropical hardwoods, mixed hardwood-conifer, pine-mesic oak, and cabbage palm forests.
Disturbed Uplands	Wax myrtle, mixed and other hardwoods, oak-hickory-pine, shrub and brush and dead trees on upland sites.
Waterways/Reservoirs	Streams, drainage canals, lakes, reservoirs, and open water in freshwater marshes.
Estuarine Water	Water of the lagoon and salt-water ponds in salt marsh.
Forested Wetlands	Wetland hardwoods, cypress swamps, dwarf cypress, southern red cedar, bottomland swamps, and mixed wetland forests.
Mangrove	Black, white, and red mangroves with halophytes and salt marsh grasses.
Freshwater Marsh	Freshwater marsh, wet prairie, inland ponds and sloughs, and emergent aquatic vegetation.
Salt Marsh	Salt marsh and tidal flats including halophytes, saltgrass, sand cordgrass, and black rush.
Disturbed Estuarine Wetlands	Estuarine shrubs, wax myrtle, groundsel, and Brazilian pepper in former salt marsh.
Disturbed Freshwater Wetlands	Disturbed freshwater marshes, wet prairies, and wetland shrubs.
Sand/Barren Land	Shoreline, beaches, and other sand.
Spoil	Borrow and fill, spoil, dikes, and other disturbed areas.
Invasive/Exotic	Brazilian pepper, Australian pine, and melaleuca.

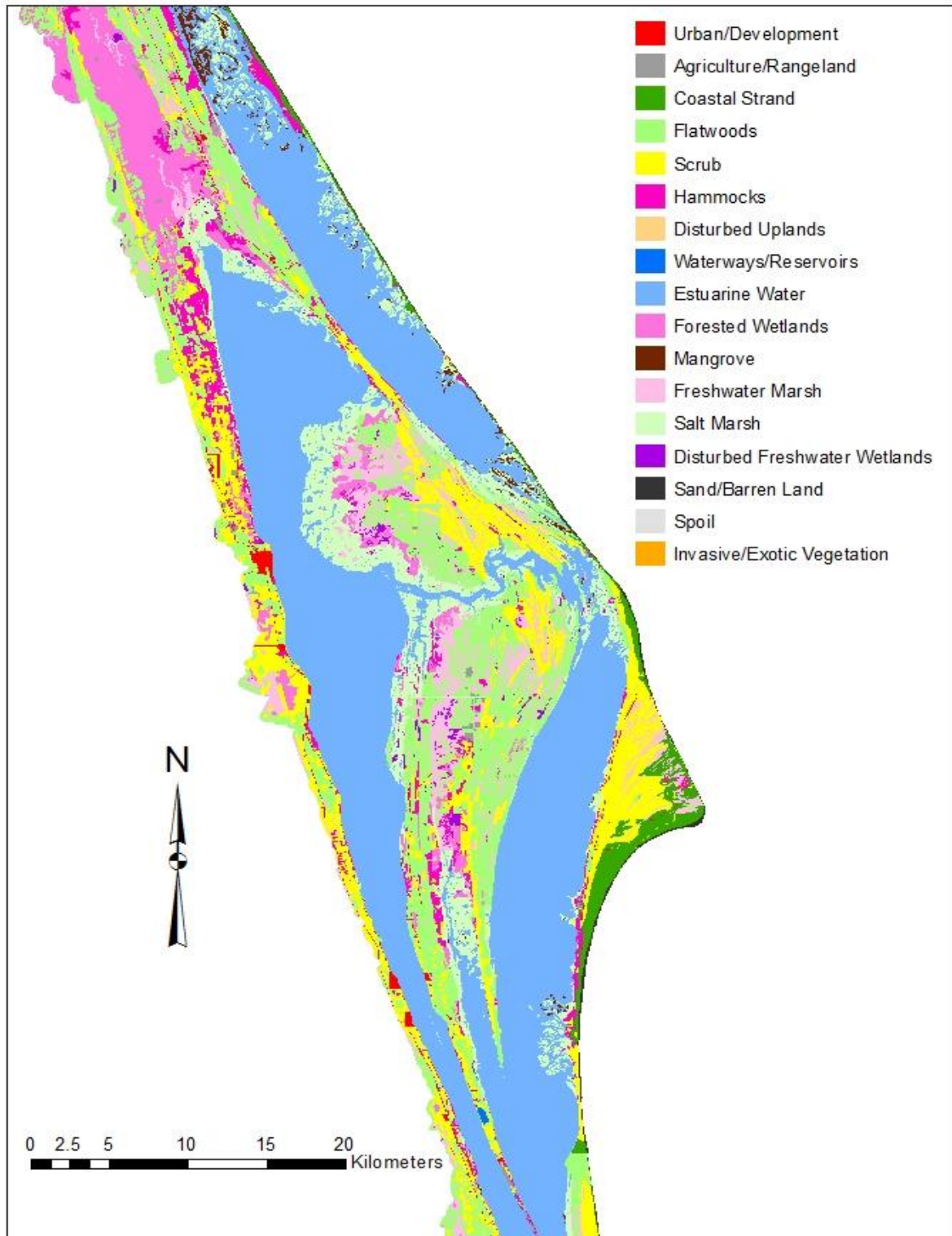


Figure 22. Distribution of 1920 landcover classes on the Cape Canaveral Barrier Island Complex. This distribution is believed to be similar to that present before major anthropogenic impacts.

Nearly 150 fish species have been identified in the lagoon system (SJRWMD, 1989). Species diversity is generally higher near inlets and toward the south end of the lagoon. For biological communities and fisheries, seagrass and mangrove habitats are extremely important (SJRWMD, 1989). Relative to the southern Indian River system, the northern area supports fewer tropical, oceanic, and freshwater species. Latitudinal temperature gradient, the absence of hard bottom and reef-like habitats, and reduced oceanic inlet influences are factors in limiting species diversity in the north. The absence of permanent freshwater habitats prior to the presence of man on Merritt Island is responsible for a limited freshwater fish fauna (Virnstein, 1990). Common fisheries resources in the lagoon include oyster, clams, scallops, shrimp, crab, mullet, red and black drum, sea trout, snook (Figure 23), tarpon, sawfish, and sea turtles.



Figure 23. Snook in the Indian River Lagoon in shallow water near a stand of mangroves.

Wetland areas support species that are well adapted physiologically to handle the wide variation in environmental conditions such as extremes in temperature, salinity, and dissolved oxygen. Typical species include sailfin molly (*Poecilia latipinna*), eastern mosquitofish (*Gambusia holbrooki*), and sheepshead minnow (*Cyprinodon variegatus*). Transient fish are species that utilize the marsh habitat during a portion of their life

cycle, usually the early stages. These fish may use this area for a source of forage or as a refuge from predators. Transient fish are not as well adapted physiologically to handle the harsh or extreme conditions that exist in the wetlands year-round (Peterson and Gilmore 1991). Examples of transient fish include striped mullet (*Mugil cephalus*), ladyfish (*Elops saurus*), and common snook (*Centropomus undecimalis*).

A summary of fish species, their general habitat requirements, and relative abundance is provided in the KSC ERD (NASA, 2010). Due to the shallow nature of the inshore water bodies, fish kills are not uncommon. Abrupt drops in temperature during the winter months with passage of strong cold fronts can lead to mortality in some of the fish species such as tarpon, snook, and permit (Provancha et al., 1986). During summer months, fish kills stem from low levels of dissolved oxygen as a result of high rates of respiration and decomposition during night and cloudy conditions.

Sixty-nine species of amphibians and reptiles are known from the region (NASA, 2010). These include alligators (Figure 24), sea turtles, gopher tortoises, diamond back terrapin, rattlesnakes, and others. The ocean beaches at KSC are important nesting areas for loggerhead, green, and leatherback sea turtles (Figure 25) (NASA, 2010; NPS, 1986).



Figure 24. Alligator in the Banana River Lagoon near KSC. Alligators are the top predators remaining at KSC and are a good sentinel species.



Figure 25. Sea turtle hatchlings making tracks for the ocean. Hatchling emergences during daylight hours are atypical.

Two hundred sixty-seven species of birds have been documented as occurring in the area, making it one of the top ten birding spots in the U.S. Ninety species nest here, 111 species are regular winter visitors, and 66 species are considered to be transients (Breininger et al., 1994).

The extensive wetlands on KSC provide habitat for many species of aquatic birds. The herons, egrets, ibises, and other birds in the order Ciconiiformes are collectively called wading birds. Thirteen species of wading birds are year-round residents, and due to the large numbers of waders using the habitats here for feeding and nesting, the region is crucial for the conservation of several species (Stolen et al., 2002). The impounded saltmarsh habitat and shallow areas along the estuarine shorelines are extensively used by wading birds (Stolen et al., 2002; Stolen, 2006). While the roadside ditches and natural freshwater swales are not used by as many wading birds as are the impoundments, they are also an important component of the overall feeding habitat. This is particularly true in the winter (October – January), when the number of waders feeding in roadside ditches increases. KSC is also important for breeding sites for several species of wading birds including White Ibis, Great Egret, Snowy Egret, and Tricolored Heron. Roseate Spoonbills (Figure 26) have nested at KSC during the life of the Space Shuttle Program.

KSC also supports a large wintering waterfowl population, and hunting takes place each year on a non-secure area of MINWR, from November through January, for 25 days. Twenty-nine species of waterfowl have been documented on KSC, with 23 species regularly occurring, and one, the mottled duck, a year-round resident. Mottled ducks inhabit estuarine edges, impoundments, freshwater wetlands, and occasionally roadside ditches. Important waterfowl species wintering on KSC include: Blue-wing Teal, American Wigeon, Northern Pintail, Lesser Scaup, Redhead, Red-breasted Mergansers, and Hooded Mergansers. KSC and the adjacent estuarine areas support up to 2/3 of the Lesser Scaup wintering along the Atlantic Flyway (Herring and Collazo, 2004). Other species of waterbirds, which are important components of the KSC avifauna, include the numerous shorebirds that migrate through and overwinter on KSC. These birds use the beaches (Stolen, 1999) and impounded wetland habitats. It has been estimated that as many as 5% of the Dunlin using the Atlantic flyway overwinter on KSC (Kelly, 2000). The Piping Plover, a federally threatened bird, is occasionally found using KSC beach habitat during migration. Least Terns and Black Skimmers are two state listed species of beach nesting birds that also nest on gravel rooftops; colonies of these birds exist on KSC. Much of the natural beach and sandbar habitat for these birds is no longer suitable, due to habitat alteration and introduced or natural predators. In recent years most nesting attempts on KSC have occurred on rooftops. However, changing roof construction practices are causing most of the gravel rooftops on KSC to be replaced with other materials, thus reducing the available nesting habitat for these species.



Figure 26. Roseate Spoonbills foraging in a KSC wetland area.

Thirty species of mammals have been documented on KSC in recent times (Table 7). This number includes five introduced species and does not include the numerous species of dolphins and whales that occur offshore and occasionally wash up dead on local beaches. Raccoons are a native that is common in most habitats and commonly observed near water sources of all kinds. Small mammal populations include the cotton rat, cotton mouse, Southeastern beach mouse and Florida mouse (Figure 27).

The largest mammalian predators remaining are the bobcat, river otter, and coyote. There are no population estimates available for these animals, and although they are commonly observed in many areas, the status of their populations is unknown. In data collected between 1992 and 1995, 31 bobcats and 17 river otters were documented road mortalities. Many of the bobcats were juveniles, but all of the otters were adults. Loss of large predator populations can lead to increased densities of prey populations and a proliferation of smaller predators, such as the raccoon. The archaeological record indicates mastodon, mammoths, giant armadillo, camels, bison, saber tooth tigers, and black bear were common prior to the arrival of man.

Table 7. List of mammal species currently occurring in the Cape Canaveral Barrier Island region of east central Florida.

Virginia opossum	<i>Didelphis virginiana</i>	commonly seen
least shrew	<i>Cryptotis parva</i>	rarely seen
eastern mole	<i>Scalopus aquaticus</i>	rarely seen
southeastern bat	<i>Myotis austroriparius</i>	occasionally seen
Brazilian free-tailed bat	<i>Tadarida brasiliensis</i>	occasionally seen
nine-banded armadillo (E)	<i>Dasypus novemcinctus</i>	commonly seen
eastern cottontail	<i>Sylvilagus floridanus</i>	commonly seen
marsh rabbit	<i>Sylvilagus palustris</i>	occasionally seen
gray squirrel	<i>Sciurus carolinensis</i>	rarely seen
hispid cotton rat	<i>Sigmodon hispidus</i>	occasionally seen
marsh rice rat	<i>Oryzomys palustris</i>	rarely seen
Florida mouse	<i>Podomys floridanus</i>	rarely seen
southeastern beach mouse	<i>Peromyscus polionotus</i>	rarely seen
cotton mouse	<i>Peromyscus gossypinus</i>	rarely seen
golden mouse	<i>Ochrotomys nuttalli</i>	rarely seen
round-tailed muskrat	<i>Neofiber alleni</i>	rarely seen
black rat (E)	<i>Rattus rattus</i>	rarely seen
raccoon	<i>Procyon lotor</i>	commonly seen
long-tailed weasel	<i>Mustela frenata</i>	rarely seen
eastern spotted skunk	<i>Spilogale putorius</i>	occasionally seen
river otter	<i>Lutra canadensis</i>	occasionally seen
gray fox	<i>Urocyon cinereoargenteus</i>	rarely seen
red fox (E)	<i>Vulpes vulpes</i>	rarely seen
coyote (E)	<i>Canis latrans</i>	rarely seen
bobcat	<i>Felis rufus</i>	occasionally seen
bottle-nosed dolphin	<i>Tursiops truncatus</i>	commonly seen
manatee	<i>Trichechus manatus</i>	commonly seen
wild hog (E)	<i>Sus scrofa</i>	commonly seen
white-tailed deer	<i>Odocoileus virginianus</i>	rarely seen



Figure 27. Examples of small mammals from the region. The Federally protected Southeastern beach mouse (left) and the State protected Florida mouse (right).

3.7 Man-made Influences

Prior to the arrival of man, the ecosystems of the Cape Canaveral Barrier Island Complex were controlled by regional climatic conditions that influenced hydrology and fire regimes. During the last 800,000 years of the current Quaternary Ice Age, glacial and inter-glacial cycles have had a frequency of approximately 100,000 years. During glacial periods when large ice sheets were present on the continents, sea levels were tens to a hundred meters lower than present. Climate of the area was cooler and much drier. These low water periods led to the development of Karst topography where groundwater flow leached carbonates and other minerals from the sedimentary rock formations. These periods of leaching created the underground caves and porous limestone that make up the Floridan Aquifer and other smaller aquifer systems (Hine, 2013). Summer thunderstorms with lightning, that formed when sea breezes carried moisture inland from the surrounding ocean, potentially ignited large wildfires that burned across an un-fragmented mostly xeric landscape.

During the interglacial periods when ice sheets retreated and sea levels rose, the climate of the region was warmer and more tropical. Seawater infiltrated the deeper aquifers near the coast and summer thunderstorms and tropical storms became more frequent and intense as the amount of energy and moisture stored in the atmosphere increased. Salt and freshwater marsh systems expanded in distribution and wildfire behavior changed in response to these conditions that fragmented and altered terrestrial fuel conditions such as species composition, biomass, and plant moisture content.

The first Paleo-Indians reached Florida about 12,000 years ago after crossing the Siberian land bridge and migrating across North America during the Wisconsin glacial period (Parker and Blyth, 2008) and archaeological evidence shows that Paleo-Indians would have shared Florida with large animals such as mastodon, giant armadillo, camel, bison, and mammoths. However, it is likely they consumed mostly plants, nuts, mammals such as rabbit, raccoon, opossum, squirrel, and deer along with fish and marine life (Parker and Blyth, 2008). Eventually, distinct tribes known today as Ais and Timucuan formed and lived along the shores of the Indian River and Atlantic Ocean, leaving behind evidence including huge mounds of discarded shellfish, animal bones, and fractured pottery. From these mounds, much has been learned about these peoples and their way of life (Parker and Blyth, 2008).

Europeans began visiting Florida in the 1500s. The first contact between the Ais Indians and Europeans was Juan Ponce de Leon's encounter with a village near Cape Canaveral in 1513. The first Spanish settlement was established at St. Augustine, north of the Cape, in 1565 (Parker and Blyth, 2008).

3.8 Rapid Local Economic and Ecosystem Change

For the next 300 years the population of Florida and the east central Florida area grew slowly as ranching, agriculture, and later tourism dominated the economy. Following the post-Civil War reconstruction period, northern businessmen with capital saw investment opportunities in Florida. In 1881 Hamilton Disston bought 4 million acres at 25 cents an acre helping the State clear its Civil War debt. Henry Plant and Henry Flagler invested heavily in railroads and hotels, connecting the northeast to Florida, stimulating both the agricultural, cattle ranching, and the tourist industries (Parker and Blyth, 2008).

Around 1830 Douglas Dummitt moved to the KSC area bringing the start of the Indian River Citrus industry and a growing agricultural revolution. Dummitt grafted cuttings from sweet orange trees, purportedly from groves planted by the Turnbull colonists at New Smyrna, to sour-orange root stock. These experimental trees survived the famous 1835 freeze and were transplanted to the Dummitt Grove that is located on the north end of Merritt Island. He increased the size of his grove over the years and by 1859 was producing an estimated 60,000 oranges a year. He sold bud wood to other growers in the region and the famous Indian River Citrus industry was born (Parker and Blyth, 2008). Over the next 150 years approximately 2500 acres of Merritt Island were converted to citrus.

In 1854, in an area near Dummitt Grove, a second event of major regional ecological significance took place. A part of the narrow relict barrier dune between the Indian River and Mosquito Lagoon that had been used as a “haul over” for centuries was officially dredged and improved, creating what is now Haulover Canal. This was one of the first major improvements to the inland waterway system that had served Florida travelers since pre-historic times (Parker and Blyth, 2008). At the time, the canal measured approximately one-third of a mile long, 10-12 feet wide, three feet deep, and was primarily used by shallow draft vessels. Further improvements to the canal began in 1885 and the work was completed by the U.S. Army Corps of Engineers in the 1930s. Today, Haulover Canal is a part of the Intracoastal Waterway and is used by thousands of vessels annually to travel between the Mosquito Lagoon and the Indian River. From an ecological impact view the canal stimulated fishing pressure, commercial and recreational boat traffic, and allowed mixing of fauna between water bodies.

Shortly after the completion of the Haulover Canal project, additional state and federal funds began to stimulate economic growth, watershed development, and rapid ecosystem change. In 1938, Congress authorized the Naval Expansion Act and by 1940 the Naval Air Station (NAS) Banana River located just south of Cocoa Beach on the barrier island, was commissioned. Initiation of World War II produced an increase in activity at the site. The Navy began anti-submarine patrols along the Florida coast using float planes from the

Banana River facility. Landing strips were constructed in 1943 for operation of shore based aircraft. Various military related activities took place at this site, including a blimp detachment, an Aviation Navigation Training School, and a major aircraft repair and maintenance facility. At its peak, the base complement included 278 aircraft, 587 civilian employees, and over 2800 officers and men (Euziere, 2003). The federal government paved roads, built bridges, and brought a new population seeking employment and opportunities to the new Naval Air Base.

Supplying the war ignited growth and expansion of the local economy (Faherty, 2005). NAS Banana River closed in September 1947 and was transferred to the U.S. Air Force in 1948 becoming Patrick Air Force Base (PAFB). The base is currently home to the Air Force Space Command. Major units assigned to PAFB include the 45th Space Wing, the Eastern Range, and the 920th Rescue Wing employing roughly 10,000 people. About this same time, President Truman established the Joint Long Range Proving Ground at Cape Canaveral to test missiles. From the 1950s through 2012 CCAFS continued to grow and expand its launch and range capabilities. Figure 28 shows CCAFS as it looked in 1964 with the VAB and Pads 39A and 39B under construction in the background.



Figure 28. Cape Canaveral Air Force Station and Missile Row. The view is looking north, with the NASA Vehicle Assembly Building (VAB), Crawlerway, and Pads 39A and B under construction, in the top of the 1964 NASA photo.

The Navy first asked Congress to approve construction of a deepwater port at Cape Canaveral in 1878, but Port Canaveral, the major deepwater point of entry for central Florida, was not dedicated until 1953 for military and commercial purposes. Commercial fishing was the first industry at the Port followed soon by cargo vessels carrying oil and newsprint; tanker vessels began carrying central Florida's orange juice from here to New York in 1958. By 1966, the cargo tonnage moving through the Port had reached one million tons per year and surpassed three million tons by 2010. In 1965, the Canaveral Lock, which connects Port Canaveral to the Banana River, and the Canaveral Barge Canal, that connects the Port to the Indian River and Intracoastal Waterway, were dedicated to support increasing demand for access and the growing regional Space Program. The lock is the largest navigation lock in Florida, designed to allow passage of the huge Saturn rocket boosters for the moon-bound Apollo program. For the past 30 years, the shuttle's external

tank from Louisiana and the retrieved solid rocket boosters passed through the locks on the way to KSC. Figure 29 shows the Port from the air as it currently looks. Since the 1970s the Port has continued to grow into one of most active on the east coast adding a Trident submarine base and several cruise terminals that supported more than 2.8 million multi-day passenger trips in 2010.

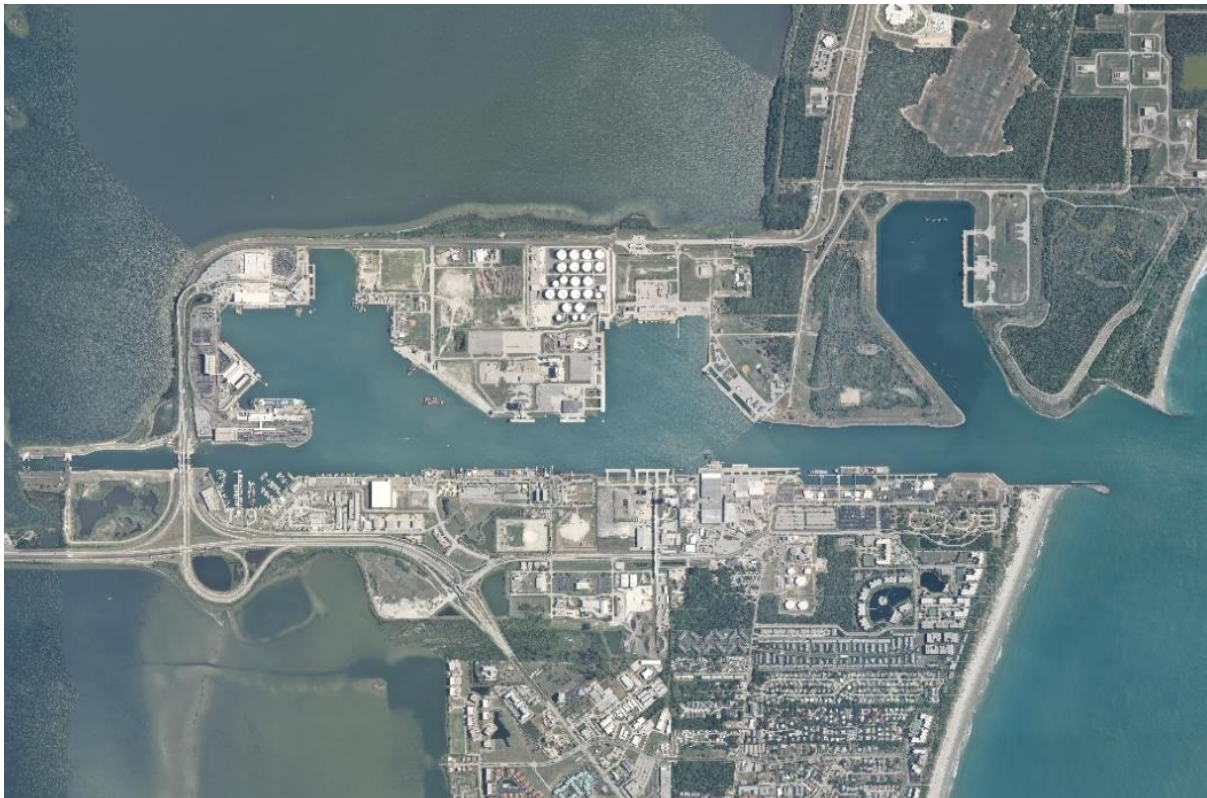


Figure 29. Aerial view of Port Canaveral with the Atlantic Ocean to the right, locks to Banana River on the left, CCAFS on the top and town of Cape Canaveral on the bottom of the image.

On July 29, 1958, President Dwight D. Eisenhower signed Public Law 85-568 that established the National Aeronautics and Space Administration (NASA). Dr. T. Keith Glennan was sworn in as the first administrator of NASA on Aug. 19, and on Oct. 1, the new agency began operation with the mission to perform civilian research related to space flight and aeronautics. On Sept. 1, 1961, NASA requested appropriations for initial land purchases on Merritt Island to support the Apollo Lunar Landing Program. Early in 1962,

NASA began acquiring property for a space center as a base for launch operations in support of the Manned Lunar Landing Program. Approximately 34,000 ha (84,000 ac) were purchased on Merritt Island in the northern part of Brevard County extending into the southernmost tip of Volusia County. An additional 22,660 ha (56,000 ac) of state-owned submerged land (Mosquito Lagoon and part of Indian River Lagoon) were negotiated with the State of Florida for exclusive rights dedicated to the United States. This total area of nearly 56,660 ha (140,000 ac), together with the adjoining water bodies, was considered extensive enough to provide adequate safety for the surrounding communities from the planned vehicle launches (NASA, 1971, 1979)

KSC first began making its mark on the Merritt Island side of the Banana River after acquiring property there in the early 1960s. Figure 30 is a mosaic of 1951 aerial photographs that show an example of what the area looked like prior to purchase and development. There were few roads, several hunting and fishing camps and limited ranching and agriculture; however, land developers had already initiated projects for residential development. Designers quickly began developing plans for Launch Complex 39 facilities which include the LCC, Pads 39A and 39B as well as the VAB. The NASA KSC Headquarters building, located in the Industrial Area, was formally opened on May 26, 1965. In February 1964, construction on the Central Instrumentation Facility (CIF) began. The CIF was the core of instrumentation and data processing operations at KSC, which included offices, laboratories, and test stations. Formerly known as the Manned Spacecraft Operations Building, the Operations and Checkout Building (O&C) was opened during the fall of 1964. It was used to test Apollo spacecraft, both the Command and Lunar Modules. Figure 31 shows the same area in 1969 after most facilities and infrastructure were completed for the Apollo Program.

Prior to 1930, Brevard's population, which depended mainly on fishing and agricultural resources, was less than 5,000. Figure 32 shows the population growth in Brevard County since 1860. By 1950 the population had increased to about 23,700 as a result of heavy federal spending associated with the war effort. When new government programs began developing missiles for defense, the 45th Space Wing and Eastern Range constructed needed facilities at PAFB and CCAFS, and with urging from the Navy and local developers the Corp of Engineers constructed Port Canaveral (Faherty, 2002).



Figure 30. Mosaic of 1951 aerial photographs showing the Merritt Island area purchased for development of future NASA facilities. Agriculture, ranching, and hunting and fishing were the primary land use activities in the area.

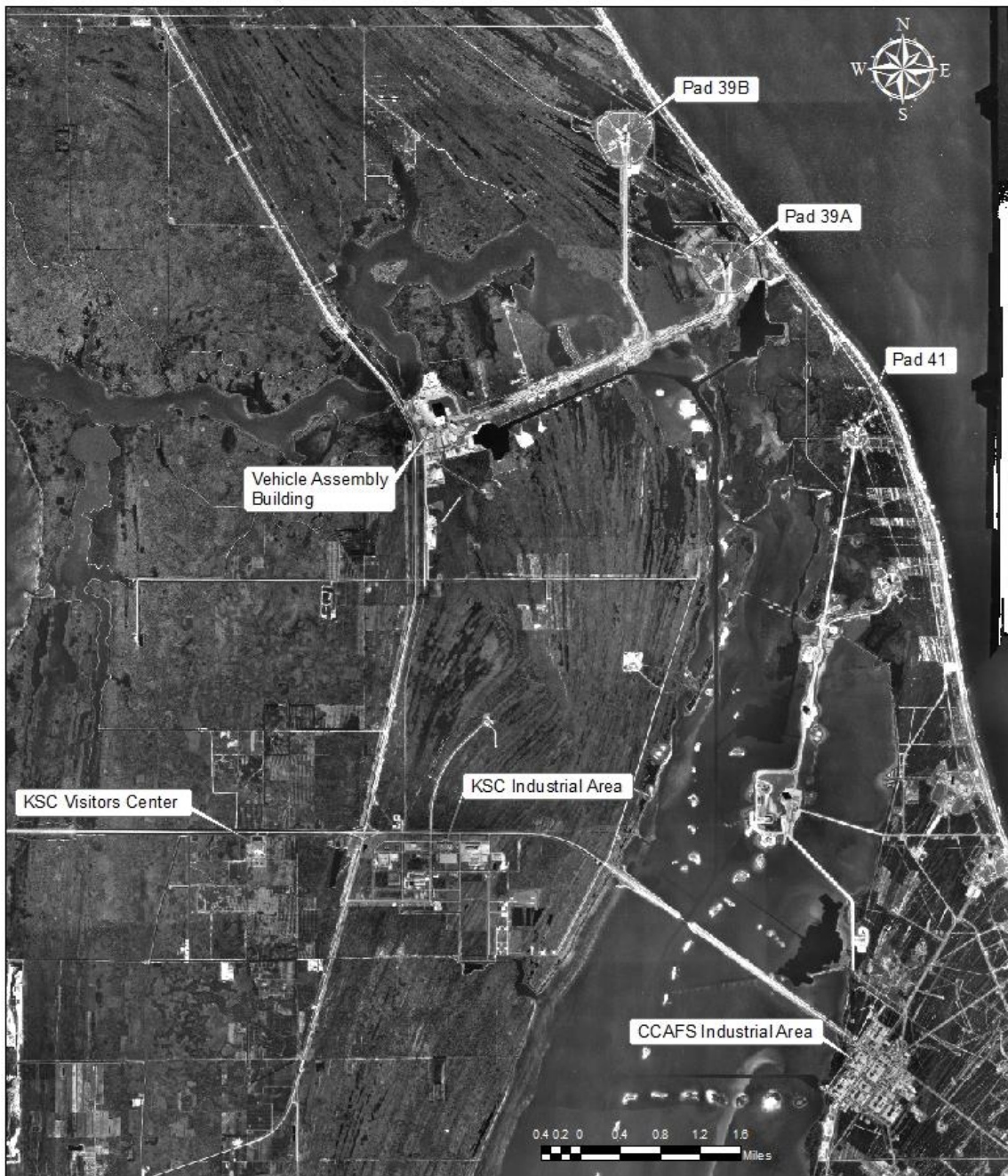


Figure 31. Mosaic of 1969 aerial imagery showing land use change and ecosystem fragmentation resulting from infrastructure and facilities construction by NASA on Merritt Island to support the Apollo Program and other unmanned missions. CCAFS is visible to the right of the photograph.

This explosive growth raised Brevard's population past the 100,000 mark in the early 1960s. With the decision to bring the Apollo Program to north Merritt Island came another large and relatively long-term injection of federal spending, and the population soared to more than 230,000 in 1970. Employment at KSC peaked in 1968, with 26,500 people working on the Apollo Program but was reduced to about 8,000 following the Skylab mission and decision to stop lunar exploration (Faherty, 2002). Effects on population growth can be seen as a dip in the line in Figure 32. Population growth and associated environmental and ecological issues continued to trend upward with the onset of the active Space Shuttle Program between 1981 and 2011. Employment at KSC fluctuated between 12,000 and 17,000 depending on mission schedules and demand. Other industries such as tourism, real estate development, aerospace, and light manufacturing all continued to expand, putting increasing demands on local ecosystems.

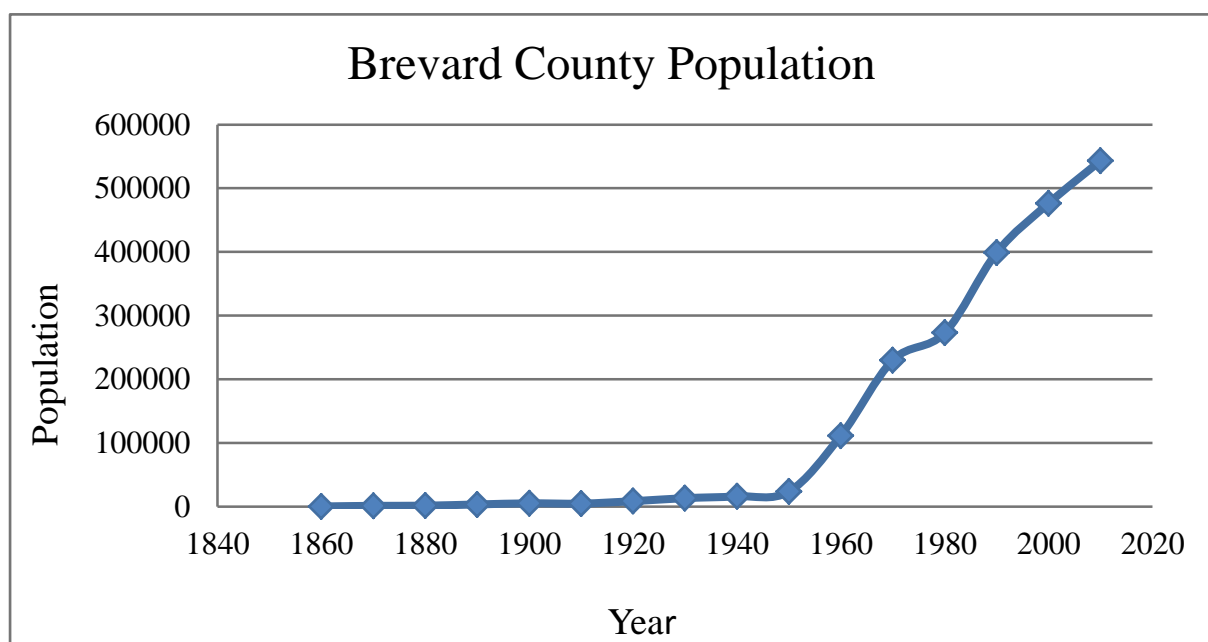


Figure 32. Rapid population growth of Brevard County resulting from the infusion of federal and state resources post World War II. Note the growth rate change associated with the period between the Saturn V Program ending in the early 1970s and the Space Shuttle flights starting in the early 1980s (Brevard County Census).

3.9 Environmental Regulations and Land Management

During the period of rapid population growth prior to 1970 there were few laws or regulations to stem pollution or coordinate planning to optimize creation of quality living conditions that include preservation of ecosystems and the valuable services they provide to society. Around the world citizens were becoming concerned by the loss of environmental quality and increased risk of disease and cancer associated with air, water, and soil pollution. Federal, state, and county governments responded with a variety of laws, regulations, and processes to gain control over the deteriorating conditions of local ecosystems. Laws like the National Environmental Policy Act, the Endangered Species Act, the Clean Air Act, and the Clean Water Act were promulgated and in some cases delegated to state and local governments for implementation (see Table 1). NASA and KSC established policies and procedures to ensure compliance with all federal, state, and local environmental requirements. These are described in detail in the KSC ERD (NASA, 2010).

3.10 Regional Water Quality

A study of watershed alteration for the entire Indian River Lagoon was performed by the KSC Ecological Program (Duncan et al., 2004) in support of water quality monitoring, modeling, and management activities being conducted by the SJRWMD as required by FDEP and EPA. Land use change results for the period between 1943 and 1990 are shown graphically in Figure 33 and Figure 34. Large areas of the central and southern Indian River Lagoon and Banana River watersheds have become urbanized as a result of rapid and continued population growth.

Major problems resulting from this conversion include the loss or alteration of the Lagoon's salt marsh and mangrove wetlands, excessive freshwater nutrient laden discharges into the lagoon due to drainage improvements, and discharges of pollutant-laden wastewater and stormwater (FDEP, 2009). Excessive freshwater and pollutants in the form of nutrients, suspended sediments, metals, pesticides, and herbicides degraded pelagic and benthic habitats; seagrass coverage densities decline, and contaminants enter the food chain, including human consumers of fisheries products (FDEP, 2009). In 2011 and 2012 extensive algae blooms in the north Indian River Lagoon and Banana River greatly reduced light penetration, eliminating seagrass beds completely in many areas.

In 1991, the IRL became a part of the U.S. EPA National Estuary Program (NEP). Efforts under the IRL Program at the SJRWMD focus on improving water and sediment quality to restore or enhance seagrass, and rehabilitating impacted wetlands to recover as many of their natural functions as possible. Figure 35 shows the northern Indian River Lagoon and Banana River as they currently exist. These lagoons have impaired water quality based on

years of monitoring (FDEP, 2009). This poor water quality is a result of long water retention times due to distances from ocean passes, and the degree of watershed development and associated point and non-point discharges.

Table 8 and Table 9 show acreages and percent of the current watershed by broad landcover classes. Lagoon waters were verified as impaired due to excessive amounts of phosphorus and nitrogen in the system, based on evidence of a decrease in seagrass distribution provided by the SJRWMD and low dissolved oxygen (DO), as verified through water quality assessments. These waters were added to the Verified List of impaired waters for the IRL Basin by Secretarial Order on December 12, 2007. The FDEP and SJRWMD are developing a target based water quality discharge program that limits total maximum daily loads (TMDL) of nutrients to the lagoon through point and non-point source discharges. A TMDL represents the maximum amount of a given pollutant that a water body can assimilate and still meet water quality standards, including its applicable water quality criteria and its designated uses. TMDLs are developed for water bodies that are verified as not meeting their water quality standards, and provide important water quality restoration goals that will guide future land use restoration activities (FDEP, 2009).

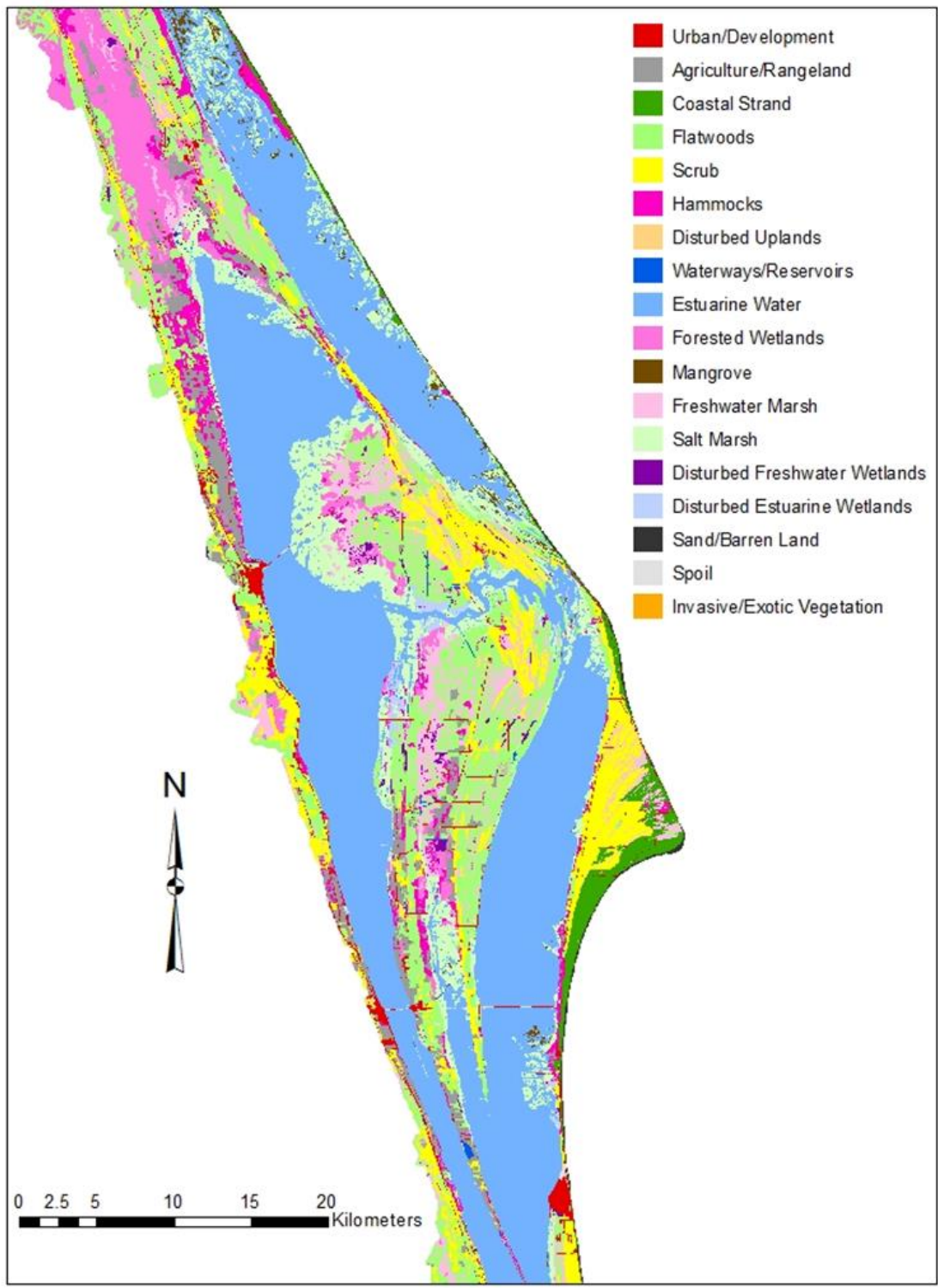


Figure 33. Distribution of landcover categories in the Indian River Lagoon Watershed based on analysis of 1943 aerial photography. Red represents urbanization. Causeways have been constructed across the lagoon.

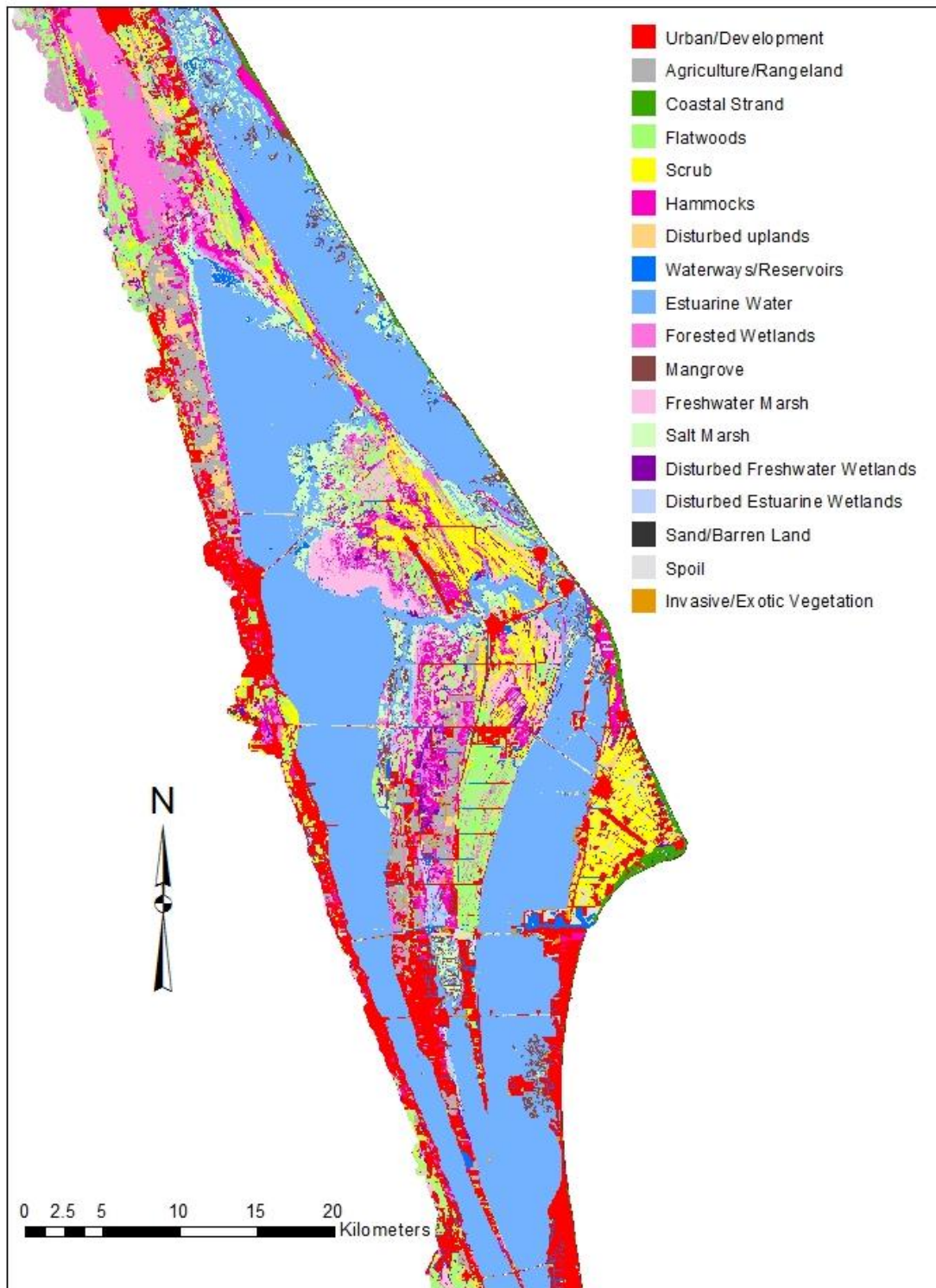


Figure 34. Distribution of landcover categories in the Indian River Lagoon Watershed based on analysis of 1990 aerial photography. Red represents urbanization. Urban sprawl covers most of the Atlantic Beach Ridge south of Cape Canaveral, south Merritt Island and most of the Atlantic Coastal Ridge west of the Indian River. NASA and CCAFS properties represent the least developed areas in the region.



Figure 35. Current distribution of urban and industrial activities in the northern Indian River, Banana River, and southern Mosquito Lagoon systems.

Table 8. Acreages of different landcover classes identified by FDEP and SJRWMD during development of TMDLs for the different watersheds (FDEP 2009).

Sublagoon	Lagoon Segment	Urban and Built-Up	Low-Density Residential	Medium-Density Residential	High-Density Residential	Agriculture	Rangeland	Upland Forest	Water	Wetland	Barren Land	Transportation, Communication, and Utilities	Subtotal
North IRL	IR1-3	247	1,894	570	137	7,129	6,120	6,533	494	27,776	545	564	52,009
	IR4	351	264	66	384	274	68	199	5	334	36	246	2,227
	IR5	2,312	150	479	1,115	662	6,621	2,024	349	18,428	465	749	33,353
	IR6-7	1,297	1,679	1,862	982	3,407	1,666	1,240	830	7,928	90	911	21,892
	IR8	550	505	694	238	88	178	185	50	132	15	109	2,744
	IR9-11	4,028	1,106	4,667	3,593	175	1,178	1,624	848	1,477	84	1,131	19,910
	Subtotal	8,784	5,597	8,338	6,449	11,735	15,831	11,805	2,576	56,074	1,234	3,710	132,135
Banana River Lagoon	BR1-2	3,880	139	0.0	0.1	105	9,148	9,281	2,036	7,846	188	473	33,095
	BR3-5	2,633	102	1,182	1,433	8	356	278	217	1,047	38	300	7,593
	BR6	720	110	802	1,244	108	156	186	1,153	1,602	39	194	6,314
	BR7	592	88	2,433	601	11	262	73	243	13	34	71	4,420
	Subtotal	7,825	439	4,416	3,278	231	9,921	9,818	3,649	10,507	299	1,038	51,423
Total		43,965	21,980	52,380	17,624	88,124	58,936	60,416	12,352	96,085	4,301	11,003	467,167

Table 9. Percent of different land cover classes identified by the FDEP and SJRWMD during development of TMDLs for the different watersheds (FDEP 2009).

Sublagoon	Lagoon Segment	Urban and Built-Up	Low-Density Residential	Medium-Density Residential	High-Density Residential	Agriculture	Rangeland	Upland Forest	Water	Wetland	Barren Land	Transportation, Communication, and Utilities	Subtotal
North IRL	IR1-3	0.5%	3.6%	1.1%	0.3%	13.7%	11.8%	12.6%	0.9%	53.4%	1.0%	1.1%	100.0%
	IR4	15.7%	11.9%	3.0%	17.3%	12.3%	3.0%	8.9%	0.2%	15.0%	1.6%	11.0%	100.0%
	IR5	6.9%	0.4%	1.4%	3.3%	2.0%	19.9%	6.1%	1.0%	55.3%	1.4%	2.2%	100.0%
	IR6-7	5.9%	7.7%	8.5%	4.5%	15.6%	7.6%	5.7%	3.8%	36.2%	0.4%	4.2%	100.0%
	IR8	20.0%	18.4%	25.3%	8.7%	3.2%	6.5%	6.7%	1.8%	4.8%	0.6%	4.0%	100.0%
	IR9-11	20.2%	5.6%	23.4%	18.0%	0.9%	5.9%	8.2%	4.3%	7.4%	0.4%	5.7%	100.0%
	Subtotal	6.6%	4.2%	6.3%	4.9%	8.9%	12.0%	8.9%	1.9%	42.4%	0.9%	2.8%	100.0%
Banana River Lagoon	BR1-2	12.4%	0.4%	0.0%	0.0%	0.3%	29.2%	29.6%	0.9%	25.0%	0.6%	1.5%	100.0%
	BR3-5	34.9%	1.4%	15.7%	19.0%	0.1%	4.7%	3.7%	2.1%	13.9%	0.5%	4.0%	100.0%
	BR6	12.1%	1.9%	13.4%	20.9%	1.8%	2.6%	3.1%	13.5%	26.8%	0.6%	3.3%	100.0%
	BR7	13.4%	2.0%	55.0%	13.6%	0.2%	5.9%	1.7%	5.5%	0.3%	0.8%	1.6%	100.0%
	Subtotal	15.9%	0.9%	9.0%	6.7%	0.5%	20.1%	19.9%	3.0%	21.3%	0.6%	2.1%	100.0%
Total		9.5%	4.7%	11.3%	3.8%	19.0%	12.7%	13.0%	2.2%	20.7%	0.9%	2.4%	100.0%

3.11 Impoundments and Mosquito Control

Along the Indian River Lagoon the majority of the estuarine wetlands were impounded for mosquito control and isolated from the estuary in the late 1950s and 1960s (Figure 36). Salt marsh mosquitoes (*Aedes* sp.) need moist exposed substrate for egg laying sites, and then flooding to produce a brood. The shorelines, wetlands, and marshes along the Indian River Lagoon system (including the Banana River and Mosquito Lagoon) are ideal for mosquito production during the summer and fall period of high rainfall and rising lagoon levels (see Figure 13 and Figure 15) (Provost 1967; Rey and Kain 1989).

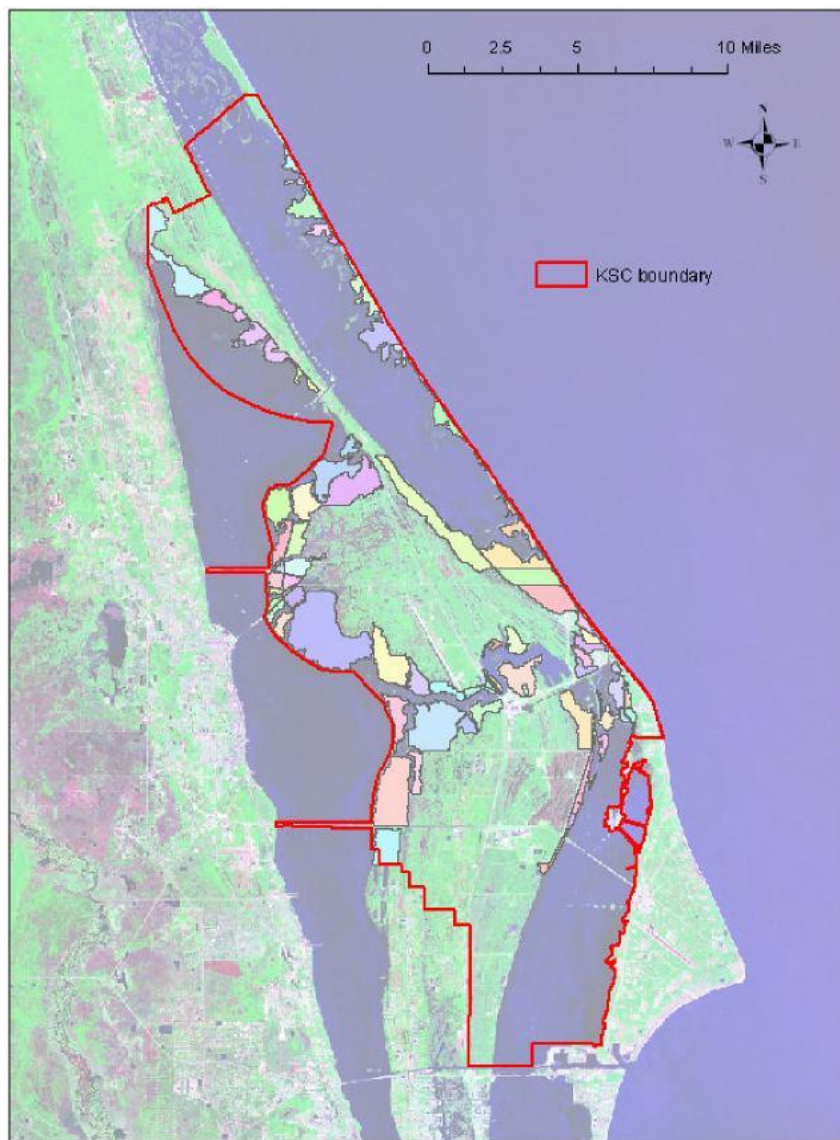


Figure 36. Distribution of mosquito control dikes and impoundments on KSC. Control of mosquitoes was critical to the economic development of the region.

To control the salt marsh mosquitoes, managers can use chemical agents (pesticides) or use a biological control to interrupt part of the mosquito's life cycle. The portion of the life cycle easiest to interrupt is the egg laying stage. This can be accomplished by either drying out the exposed moist substrate needed for egg laying or by keeping this substrate flooded.

In the 1950-1960s, the Brevard County Mosquito Control District set about to control mosquitoes by interrupting the egg laying portion of the life cycle. Wetlands and other low lying areas adjacent to the Indian River Lagoon were impounded. This was done by digging steep ditches and using the excavated soil to build earthen dikes around the marshes. Examples of the diking activity are shown in Figure 37 in the area of Banana Creek and the south end of the SLF. These areas were impounded and then flooded. This worked well for controlling mosquitoes (Provost 1967; Rey and Kain 1989); however, it removed not only tidal access, but any type of water connection between the estuary and the wetlands. These habitats that were once accessible to fish and macro-crustaceans were removed from the ecosystem which was changed dramatically during this period of rapid land and economic development (Harrington and Harrington 1961, 1982; Gilmore et al., 1982, 1987; Rey et al., 1990a, 1990b).

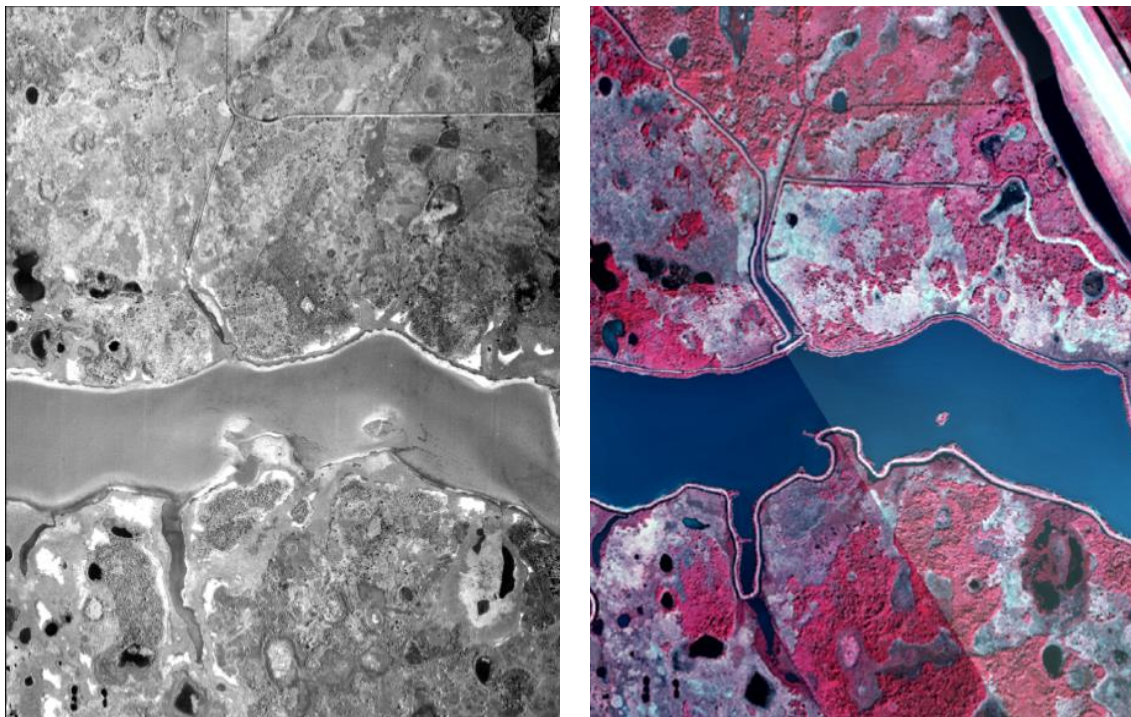


Figure 37. Aerial photos showing pre- and post- dike construction for impoundment creation along the Banana Creek area. Dike roads replace the small low water beaches along the lower end of the high marsh.

3.12 Fire Ecology and the Controlled Burn Program

The terrestrial and wetland communities of the Cape Canaveral barrier island ecosystem evolved in the presence of fire (Figure 38). The sandy soils with typically low carbon content hold little moisture, and evapotranspiration rates are high during the hot long summers. Afternoon sea breezes produce almost daily thunderstorms with a high frequency of lightning strikes in June, July, and August (Figure 39).

Results of fire regime modeling suggest lightning strike fires behaved in two unique ways. In areas with high fuel loads that have gone long periods without burning, large catastrophic fires could burn across the un-fragmented landscape. In areas that had recently burned or had discontinuous fuel loads, smaller fires would be the norm making for a more diverse habitat structure. As the area became more populated and developed between the 1950s and 1980s fire suppression was common and large fuel loads began to develop in the region increasing the chances of catastrophic fires.



Figure 38. Fire burning through xeric scrub community on KSC. Fire has become one of the primary habitat enhancement tools for managing scrub and the associated wildlife of special concern.

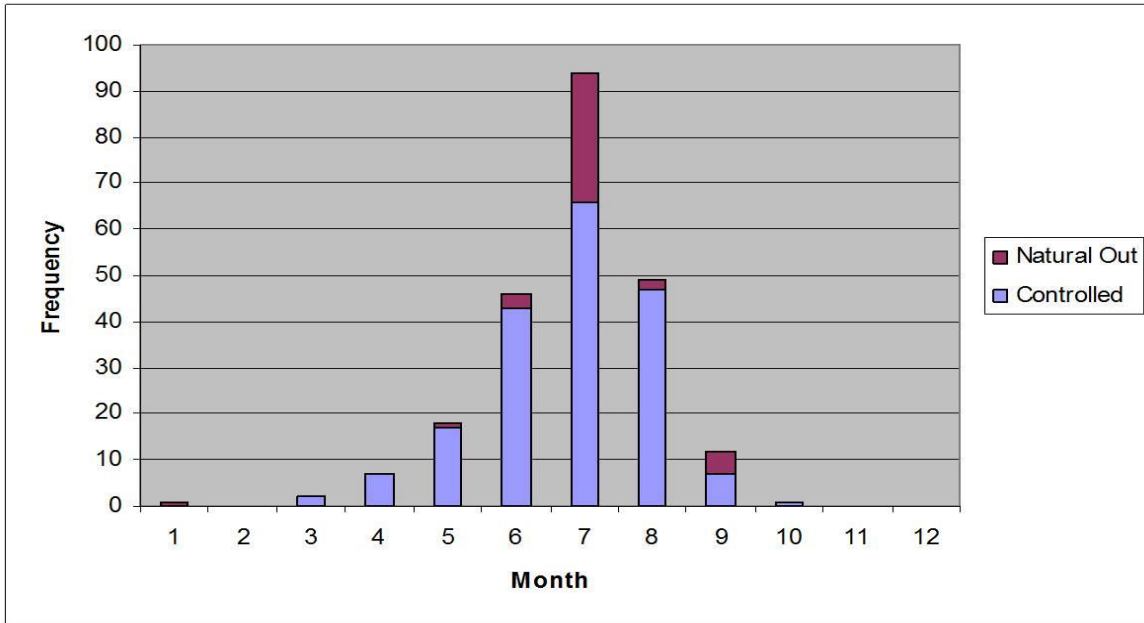


Figure 39. Pattern of lightning strike initiated fires over the last 20 years on MINWR. Many fires are controlled and put out while some go out naturally.

3.13 Species of Special Concern

The Endangered Species Act of 1973 (PL-93-205) provides guidance regarding the management and protection of certain species based on determinations made regarding their relative ability to survive. The USFWS is responsible for determining which species are listed as either Threatened or Endangered and for maintaining this listing. In addition, Section 7 of the statute provides for a consultation process between the Service and any federal agency that may, through one of its proposed actions, impact one of these species or their critical habitat (NASA, 2010).

The State of Florida also develops and maintains its own list of species suffering threats to populations and habitats. The FFWCC (Florida Fish and Wildlife Conservation Commission) Endangered Species Coordinator is responsible for the review of species, designating their status and formally listing them in the State's Official List of Endangered and Potentially Endangered Fauna and Flora in Florida. This official list provides a comprehensive directory of the biota requiring special consideration in the State of Florida (NASA 2010). A list of the 33 federally and state-protected animals known to occur at KSC and MINWR is given in Table 10.

Table 10. A list of the 33 federally and state-protected animals known to occur at KSC .

SCIENTIFIC NAME	COMMON NAME	LEVEL OF PROTECTION	
		STATE	FEDERAL
Amphibians and Reptiles			
<i>Lithobates capito</i>	Florida gopher frog	SSC	
<i>Alligator mississippiensis</i>	American alligator	SSC	T(S/A)
<i>Caretta caretta</i>	Loggerhead		T
<i>Chelonia mydas</i>	Atlantic green turtle		E
<i>Dermochelys coriacea</i>	Leatherback sea turtle		E
<i>Gopherus polyphemus</i>	Gopher tortoise	T	
<i>Drymarchon couperi</i>	Eastern indigo snake		T
<i>Pituophis melanoleucus mugitus</i>	Florida pine snake	SSC	
Birds			
<i>Egretta thula</i>	Snowy egret	SSC	
<i>Egretta caerulea</i>	Little blue heron	SSC	
<i>Egretta tricolor</i>	Tricolored heron	SSC	
<i>Egretta rufescens</i>	Reddish egret	SSC	
<i>Eudocimus albus</i>	White ibis	SSC	
<i>Ajaia ajaja</i>	Roseate spoonbill	SSC	
<i>Mycteria Americana</i>	Wood stork		E
<i>Haliaeetus leucocephalus</i>	Bald eagle		P
<i>Pelecanus occidentalis</i>	Brown Pelican	SSC	
<i>Falco sparverius paulus</i>	Southeastern American kestrel	T	
<i>Sterna antillarum</i>	Least tern	T	
<i>Rynchops niger</i>	Black skimmer	SSC	
<i>Aphelocoma coerulescens</i>	Florida Scrub-jay		T
<i>Polyborus plancus audubonii</i>	Crested caracara	T	
<i>Aramus guarauna</i>	Limpkin	SSC	
<i>Grus canadensis pratensis</i>	Florida sandhill crane	T	
<i>Charadrius melodus</i>	Piping plover	T	T
<i>Charadrius alexandrinus</i>	Snowy plover	T	
<i>Haematopus palliatus</i>	American oystercatcher	SSC	
Mammals			
<i>Peromyscus polionotus niveiventris</i>	Southeastern beach mouse		T
<i>Podomys floridanus</i>	Florida mouse	SSC	
<i>Trichechus manatus</i>	West Indian manatee		E
Key: SSC = Species of Special Concern; T(S/A) = threatened because of similarity of appearance to another protected species; T = threatened; E = endangered.			

During the last 50 years urbanization and expansion of agriculture has continued to reduce the availability and quality of habitats in the east central Florida region. This unique geographical feature contributes to the area being recognized as one of the most biologically diverse estuaries in North America with more than 2,200 different species of animals and 2,100 species of plants. Vegetation communities and the wildlife and fisheries that they support are directly and indirectly related to hydrology, water quality, soil/sediment type, elevation, fire, and anthropogenic activities (Hamilton et al., 1985). A comprehensive bibliography and assessment have been previously published (Morris, 1989). Of the 2,200 different species of animals there are 700 saltwater and freshwater fish species and 310 bird species (EPA, 2007).

4.0 Shuttle Launch Monitoring

This section builds on information identified in the Shuttle Programmatic EIS of 1978 (NASA 1978), information provided by the American Institute of Biological Sciences (AIBS. 1982), and the Space Shuttle Environmental Effects: the First Five Flights (NASA 1983). These documents identified the areas of potential launch concern that warranted continued monitoring and evaluation that were incorporated into activities of the KSC Ecological Monitoring Program. These include:

- Nearfield launch deposition characterization and impacts to soils, water quality, and biota.
- Farfield launch deposition patterns and impacts
- Noise impacts

4.1 Launch Characterization

Through the 30 year flight history of the Space Shuttle Program there were 135 launches, 82 from Pad 39A and 53 from Pad 39B (see [Appendix A](#)). The shuttle SRBs are the largest solid rocket motors ever built and flown. Each contained 498,950 kg of propellant. The propellant consisted of an aluminum (Al) powder fuel (16%), ammonium perchlorate as an oxidizer (69.9%), a catalyst of iron oxidizer powder (0.07%), a rubber-based binder of polybutadiene acrylic acid acrylonitrile (12.04%), and an epoxy curing agent (1.96%). Each SRB produced approximately 2,650,000 pounds of thrust at sea level. The exhaust from the SRBs was directed northward from the launch pads by the split flame trench (Anderson and Keller 1983). The exhaust was composed primarily of aluminum, hydrogen, nitrogen, carbon, oxygen, and chloride compounds (Table 11).

At each launch pad, a sound suppression water system was utilized to protect the shuttle and payloads from damage by acoustical energy reflected from the mobile launch platform during launch. The system consisted of an elevated 2,006,050 l (530,000 gal) tank and associated plumbing that included a system of six large rainbirds and 16 nozzles above the flame deflectors. At approximately 12 seconds prior to launch, the system was activated, initiating a 25 to 30 second dump of the entire water system (NASA 1978; NASA 1983). The system also contained an overpressure suppression system consisting of two compartments. A water spray system provided a cushion of water that was routed directly into the flame hole beneath each booster. This was supplemented by a series of water hammocks stretched across each hole in the mobile launch platform. This dual system provided a 26,495 l (7,000 gal) water mass to dampen the pressure pulse resulting from ignition of the SRBs. At launch minus 12 seconds, the sound suppression system was activated, starting flow of water onto the launch pad and structure. At minus nine seconds,

the three shuttle main engines were ignited and throttled toward full power. At zero the two SRBs were ignited. The initial blast hit the sound suppression hammocks and water that had been pouring onto the pad, instantly vaporizing and atomizing it. The resulting mixture of deluge water, debris, and exhaust chemicals exploded from the flame trench at a velocity of approximately 85-100 meters per second. As the shuttle rose from the launch pad, the exit velocity and percent of SRB exhaust exiting the flame trench decayed to zero. At that point, the exhaust ground cloud formation ceased and column cloud formation predominated.

Table 11. List of major chemicals in exhaust of solid rocket motors used on the Space Transportation System. Weights estimated from the amount of fuel expended during the first ten seconds of flight (Dreschel and Hall 1990).

Exhaust Product	Weight (kg)	Percent
AlCl	6.3	0.0068
AlClO	7.3	0.0079
AlCl ₂	29.9	0.032
AlCl ₃	4.6	0.0049
H	17.3	0.0186
H ₂	18 x10 ³	1.8829
HO	30	0.0323
H ₂ O	9.8 x10 ³	10.487
N ₂	8.2 x 10 ³	8.7728
NO	2.0	0.0022
HCl	1.7 x 10 ⁴	21.6872
CO	2.1 x10 ⁴	22.8433
CO ₂	3.7 x 10 ³	4.0188
Al ₂ O ₃	2.8 10 ⁴	30.2046

Modified from NASA (1978, 1979) and information provided by Morton Thiokol, Inc.

During the first 10-12 seconds of a launch, a ground cloud forms that is approximately 1.4x10⁶ m³ in volume. This cloud is composed of the complex mixture of gases and dissolved and particulate exhaust products formed by SRB fuels, sound suppression water, and materials ablated from the physical surfaces on and around the launch pad (Figure 40).



Figure 40. During the first 10-12 seconds of the launch event the Space Transportation System produced a ground cloud consisting primarily of water vapor, HCl, and aluminum oxide particulates.

The shuttle main engine exhaust was directed to the south (left of photo) of the pad and the SRM exhaust was directed north (right side of photo). As horizontal velocities in the cloud decreased, the cloud rose, cooled, and began to move away from the launch site with prevailing winds. Launches produced acid and particulate deposition (NASA, 1983, Dreschel and Hall, 1990). Anderson and Keller (1983) described the mechanisms producing acidic deposition as follows: 1) acidic deposition results from the atomization of deluge water by the turbulence of the vehicle exhausts; 2) large liquid drops produced by this atomization become the core of the deposition; 3) these drops rapidly coagulate with aluminum oxide (Al_2O_3) particles and condensed water in the cloud and scavenge hydrogen chloride (HCl) gas. Since the mechanism producing acid deposition depended on the interaction of the rocket exhausts with the deluge water and not specific meteorological conditions, it was to be expected with each launch. Figure 41, Figure 42 and Figure 43 show the evolution of the ground cloud as it rose, cooled, and drifted away from the pad on prevailing winds, and rains out HCl and Al_2O_3 particulates.



Figure 41. VAB roof top view of a shuttle launch from Pad 39B. Fifteen seconds after liftoff the ground cloud has formed and the shuttle column cloud is beginning to grow as the vehicle travels skyward. The column cloud has much less water than the ground cloud enhancing the tan color of the Al_2O_3 particulates.



Figure 42. VAB roof top view of a shuttle launch from Pad 39B. Fifty seconds after liftoff the ground cloud is beginning to rise and drift to the southwest of the launch pad that can be seen in the right of the photograph. Heavy rainout is seen beneath the cloud.



Figure 43. VAB roof top view of a shuttle launch from Pad 39B. One minute 26 seconds after liftoff the ground cloud continues to rise and drift to the southwest of the launch pad. Light rainout is still visible beneath the cloud.

4.2 Rocket Exhaust Effluent Diffusion Modeling and Verification

Direction and amount of deposition were predicted for each launch by the Rocket Exhaust Effluent Diffusion Model (REEDM) (Bjorklund, et al., 1982; Bowman et al., 1984). Predictions were made based on inputs of meteorological data from rawinsonde readings of vertical profiles of wind direction, wind speed, air temperature, atmospheric pressure, and relative humidity from the surface to 3048 m (10000 ft). Early versions of this model (Bjorklund, et al., 1982) predicted gaseous HCl concentrations and Al₂O₃ deposition. The model was modified to predict gravitational hydrochloric acid deposition (Bowman et al., 1984). Comparisons of predictions of the revised REEDM (Figure 44) and mapped patterns of deposition (Figure 45) for the first 49 launches (Duncan and Schmalzer 1992, 1994) indicated that the model correctly predicted direction but over-predicted the total area that received deposition, and the maximum distance that deposition occurred away from the launch pad. For most launches, mapped far-field deposition generally corresponded to the greater than 250 mg/m² isopleth.

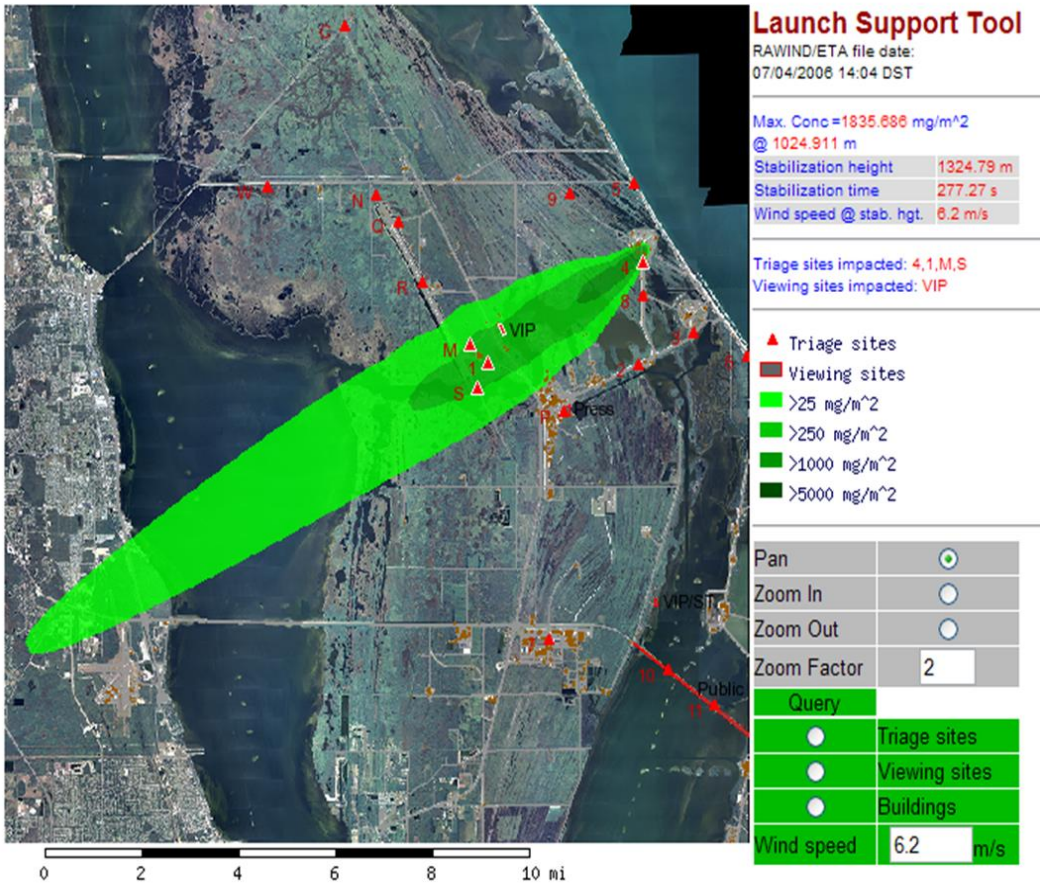


Figure 44. Example of the web based Launch Support Tool utilizing output from the REEDM. The model predicts the cloud will pass north of the VAB, and then cross over the Banana Creek viewing site and the south end of the SLF.

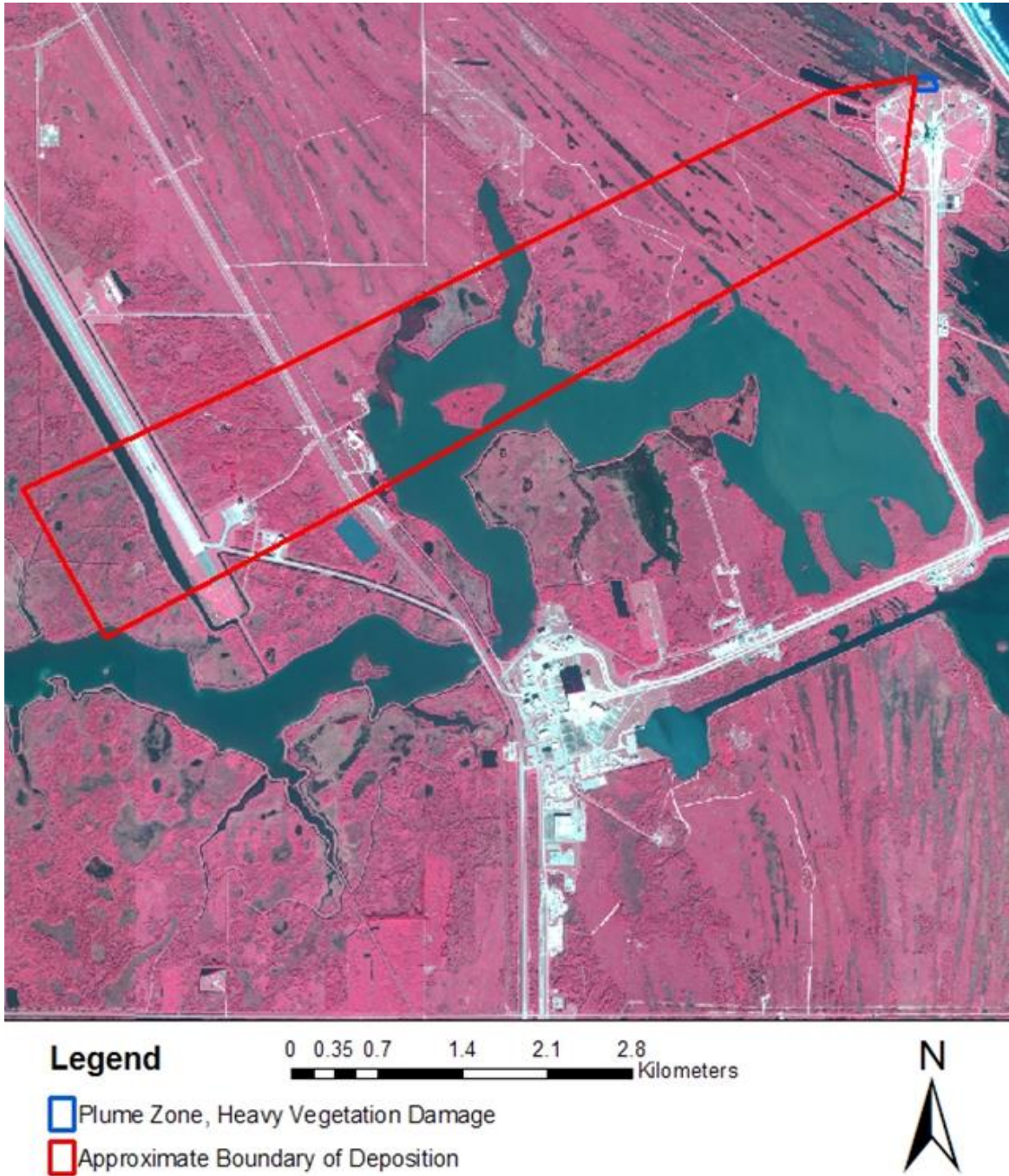


Figure 45. Mapped footprint of deposition resulting from exhaust product rainout. The pattern was developed by collecting GPS points from structures and vegetation where exhaust deposition was observed. These data are then entered into ArcGIS to create the deposition polygon.

4.3 Launch Cloud Deposition Characterization

4.3.1 Near-field

Near-field deposition was created by the ground cloud sweeping turbulently across the ground, vegetation, and lagoon waters primarily to the north of the launch pads in line with the SRB flame trench. For each launch, the area impacted by near-field deposition was mapped based on the visible effects on vegetation and structures. Cumulative maps have been prepared (Schmalzer et al., 1985; Duncan and Schmalzer 1992, 1994; Duncan et al., 2002) and a web based database was created. Near-field deposition was concentrated north of each launch complex (Figure 46 and Figure 47). After 82 launches the area of cumulative near-field impacts at Pad 39A was about 90 ha (221 ac), and the area of cumulative near-field impacts at Pad 39B after 53 launches is 62 ha (154 ac). After the first 49 launches the near-field Pad 39A area was 87 ha (214 ac) and the Pad B area was 53 ha (130 ac) (Duncan and Schmalzer 1994). Figure 48 is an example of vegetation that has been impacted by the near-field exhaust deposition. Leaf coverage was nearly complete and the HCl and Al₂O₃ has turned the vegetation a tan color.

Figure 49 and Figure 50 show examples of the mass deposition surface for chloride and particulate loading as measured for STS-11. Deposition of chlorides in the near-field recorded for launches ranged from 0.0-125.0 g/m² when winds were from the south; particulate deposition ranged from 0.0->200 g/m² (Dreschel and Hall 1985, 1990). Total chloride deposition in the near-field per launch was estimated at 3.4 x 10³ kg and particulate deposition at 7.1 x 10³ kg. Particulate deposition collected in the near-field ranged in size from submicron particulates to debris several centimeters in diameter. Materials identified included Al₂O₃, sand, shell, paint, vegetation, firebrick, iron fragments from railroad tracks, and other debris dislodged by the SRB ignition blast.

Examples of near-field deposition particulates, separated by size class, are shown in Figure 51 and a comparison of the cumulative particle size distributions between background soils and launch deposition is shown in Figure 52. The solid rocket motors produced a fine particulate mixture of aluminum compounds that were generally less than 63 μ in diameter (Anderson and Keller, 1983). These fine particulates made up roughly 40% of the deposition found in the near-field area, but in background soils only about two or three percent of particles occur in this silt and clay fraction. Near-field deposition greater than 63 μ was composed in large part of fine silica sand, shell fragments, and other debris entrained in the exhaust cloud from the pad surface north of the flame trench.

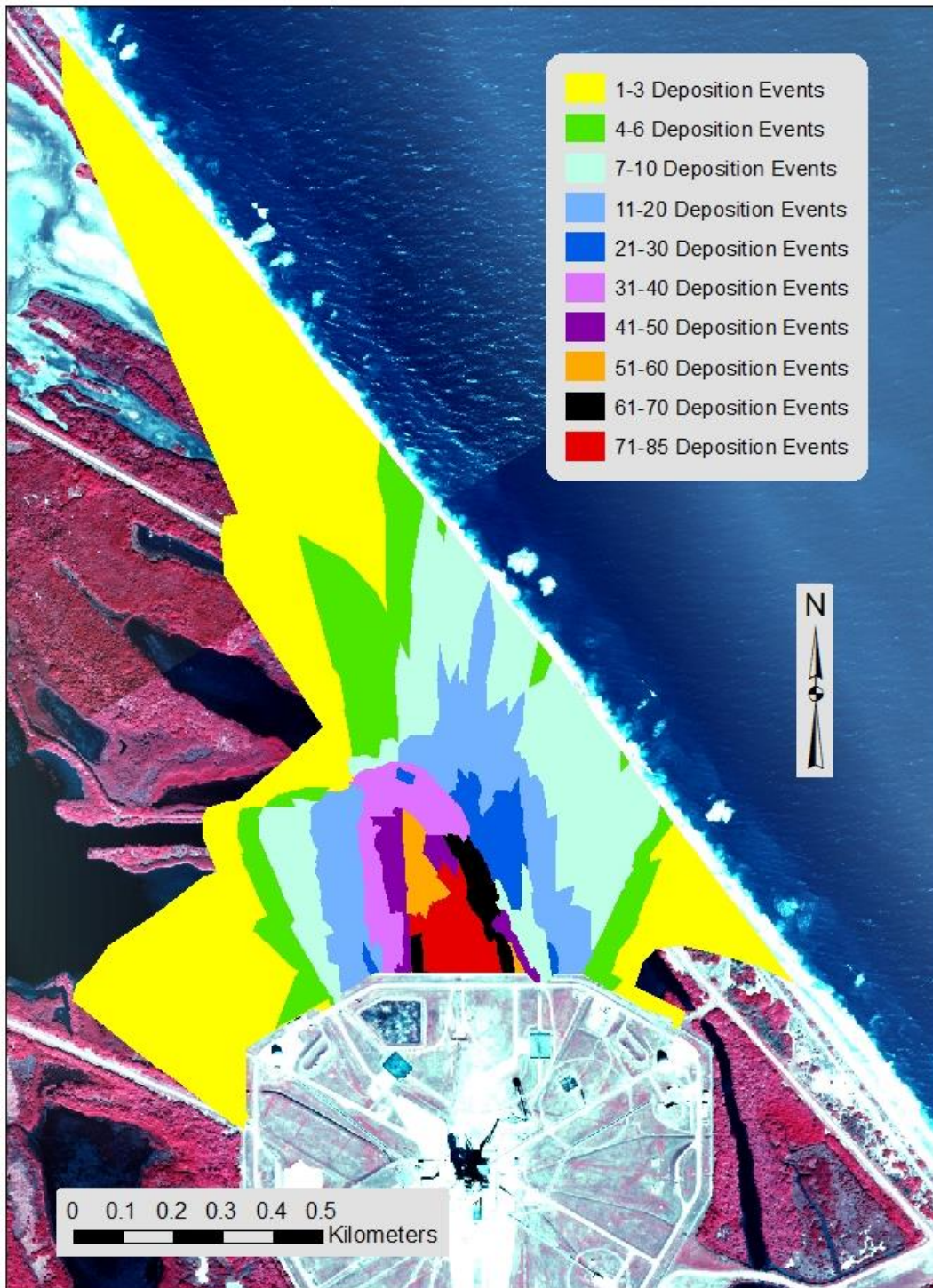


Figure 46. Cumulative near-field exhaust deposition pattern at Launch Pad 39A resulting from the solid rocket motor exhaust mixing with the deluge water ($n = 82$). Direction and distance of travel is controlled by surface wind speed and direction.



Figure 47. Cumulative near-field exhaust deposition pattern at Launch Pad 39B resulting from the solid rocket motor exhaust mixing with the deluge water (n = 53). Direction and distance of travel is controlled by surface wind speed and direction.



Figure 48. Example of vegetation impacted by near-field exhaust deposition from a shuttle launch.

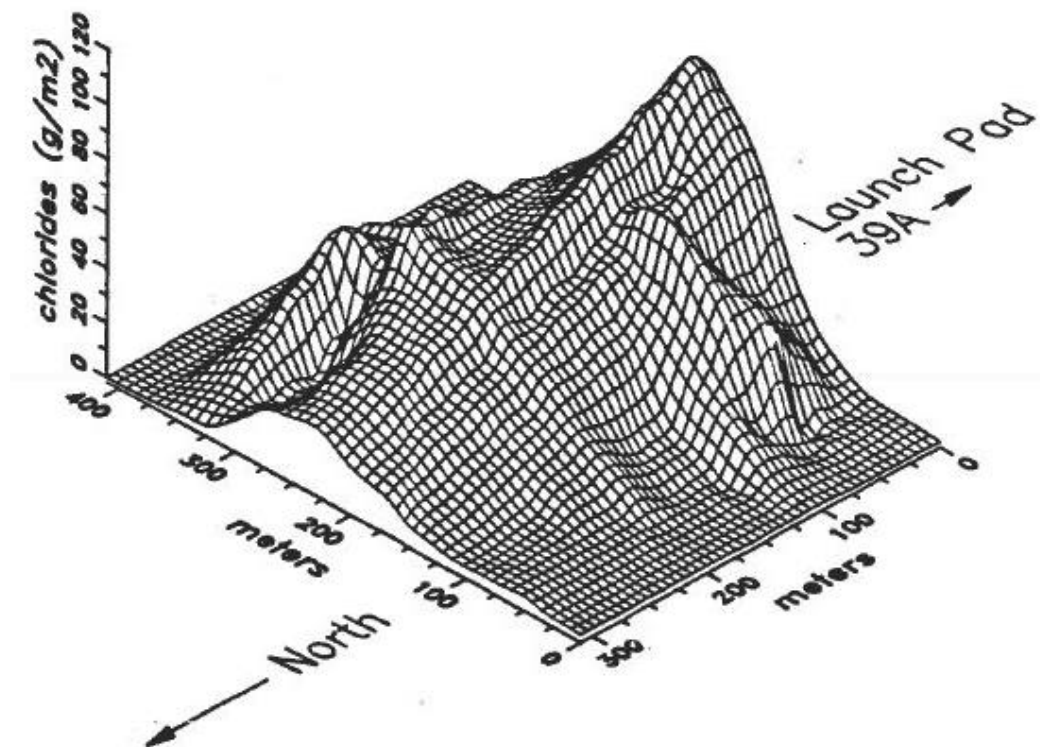


Figure 49. Trend surface plot of chloride deposition (g/m²) in the near-field area resulting from launch of STS-11 at Pad 39A. Wind was from the south.

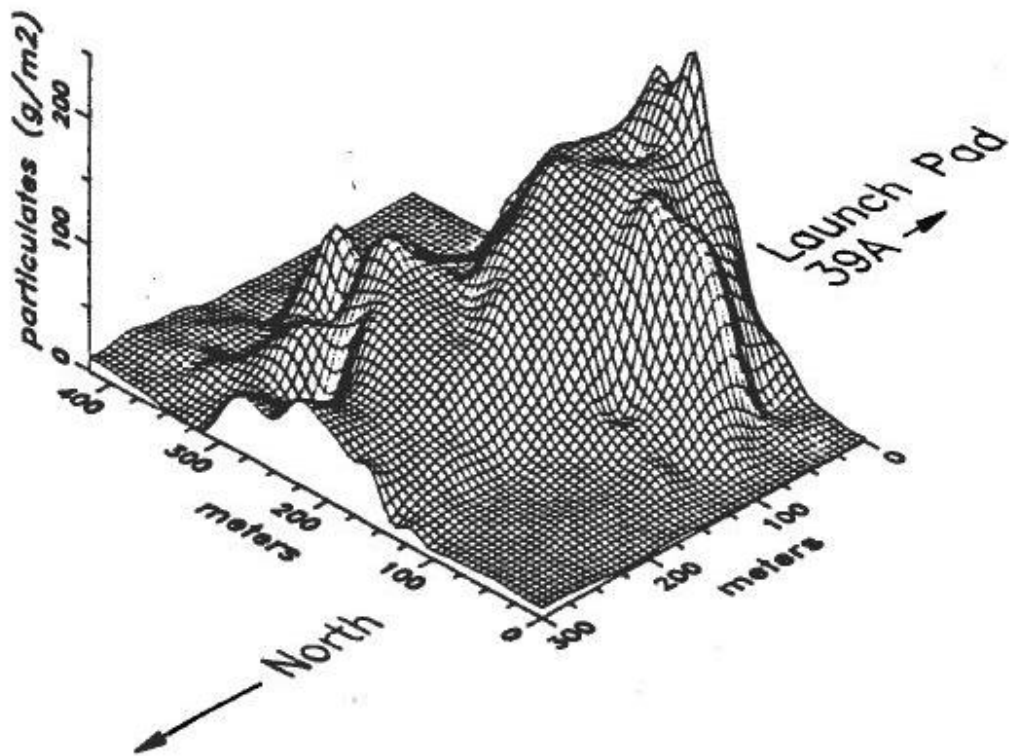


Figure 50. Trend surface plot of particulate deposition (g/m²) in the near-field area resulting from launch of STS-11 at Pad 39A. Wind was from the south.

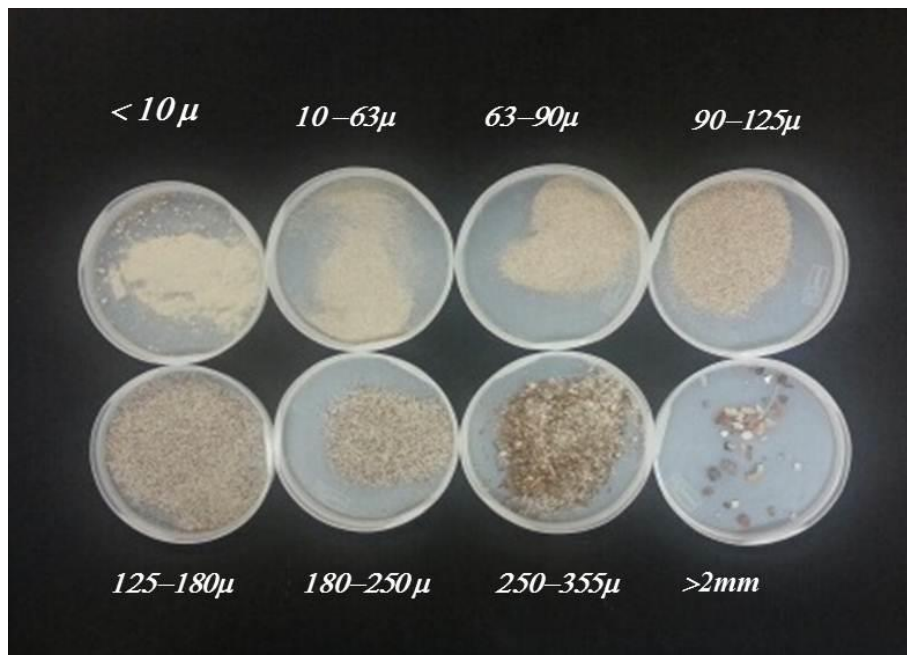


Figure 51. Image of near-field deposition after sieving into eight different size classes for chemical analyses.

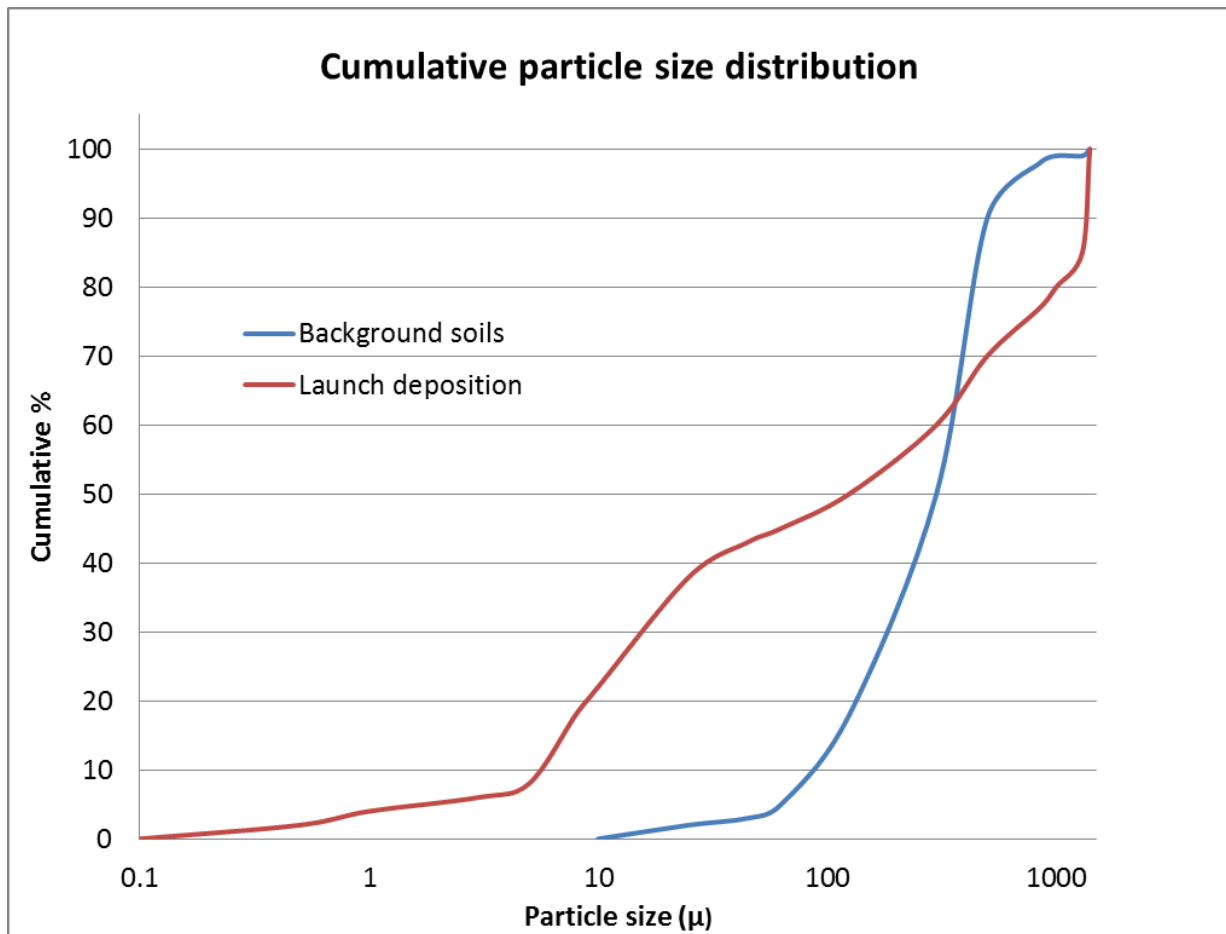


Figure 52. Comparison of cumulative particle size distributions for shuttle launch deposition and background soils collected for STS-11.

Results of metals analyses for the different particle size classes are shown graphically in Figure 53, Figure 54, Figure 55, Figure 56, Figure 57, and Figure 58 for aluminum (Al), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), and zinc (Zn), respectively. As expected, Al concentrations were highest in the launch derived fine fraction of the deposition while larger size classes displayed values similar to background soils. Cu deposition displayed a peak in the 63-125 μ size class but the source was not readily apparent. Two metals, Fe and Mn, were observed well above background levels, primarily in the largest particle size class. These two metals are associated with steel manufacturing. Examination with a microscope revealed the presence of numerous metal flakes in this fraction and exposure to a magnet indicated they contained iron. These metal flakes were blown off of Apollo era railroad tracks that were used to position the flame splitter beneath the mobile launch platform inside each launch pad flame trench. These railroad tracks were removed from the pad surfaces during renovations and upgrades. Pb levels were consistently low but were higher than background soils in the 63-250 μ range. Zn concentrations were above

background levels and the source was believed to be the large amount used in corrosion control on the pad and mobile launch platform surfaces. SRB exhaust blasts were known to strip the coating off of these exposed surfaces.

Fish exposed to high levels of heavy metals can suffer from reduced enzyme activity, structural protein rearrangement, bone and nervous system disorders, and reproductive problems. Rydene (1988) examined levels of Al, Cd, Pb, V and Zn in both sediments and marsh fish near Pad 39A and a control site. He found Al and Zn were elevated in sediments near Pad 39A and Al concentrations in sailfin mollies and sheepshead minnow were higher than generally reported in the literature. A comprehensive ecological risk assessment has been initiated to define potential fate and effects of metals in the launch deposition.

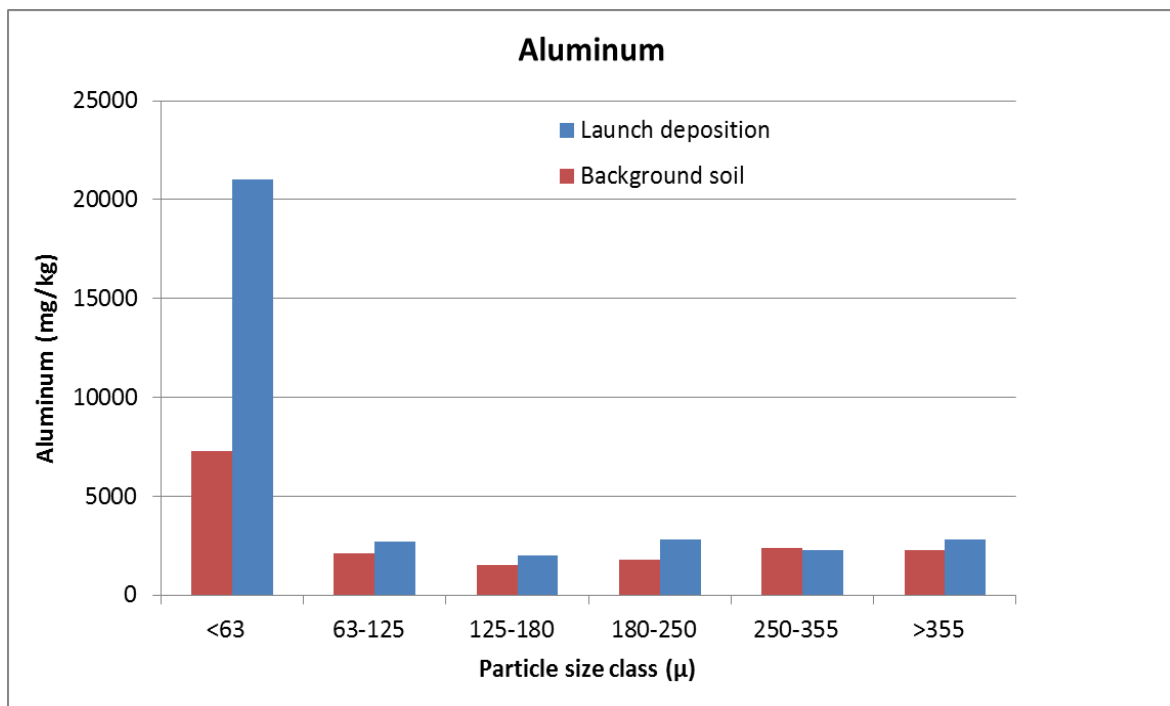


Figure 53. Results of total aluminum analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

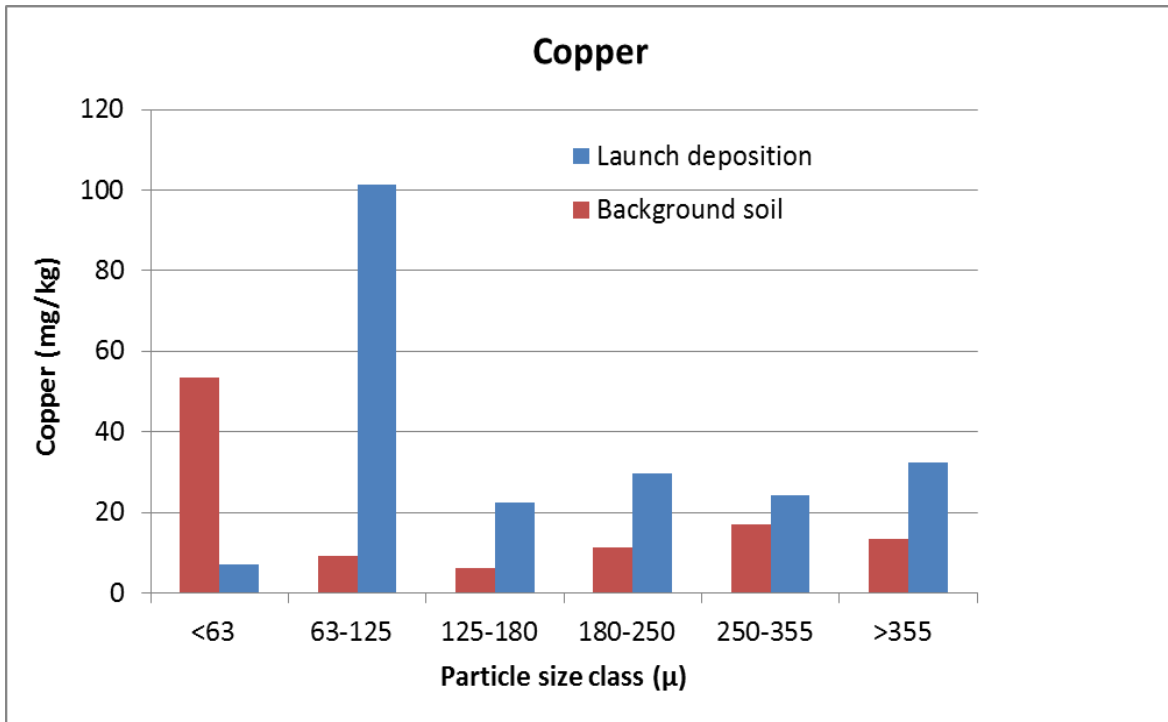


Figure 54. Results of total copper analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

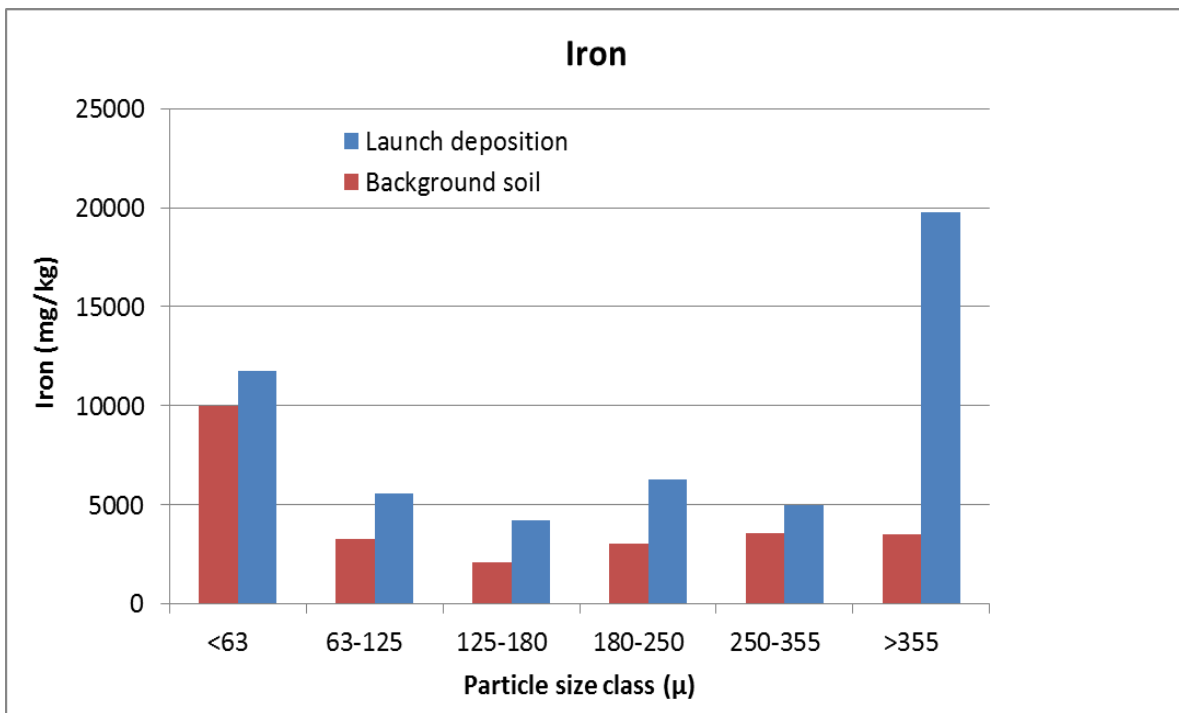


Figure 55. Results of total iron analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

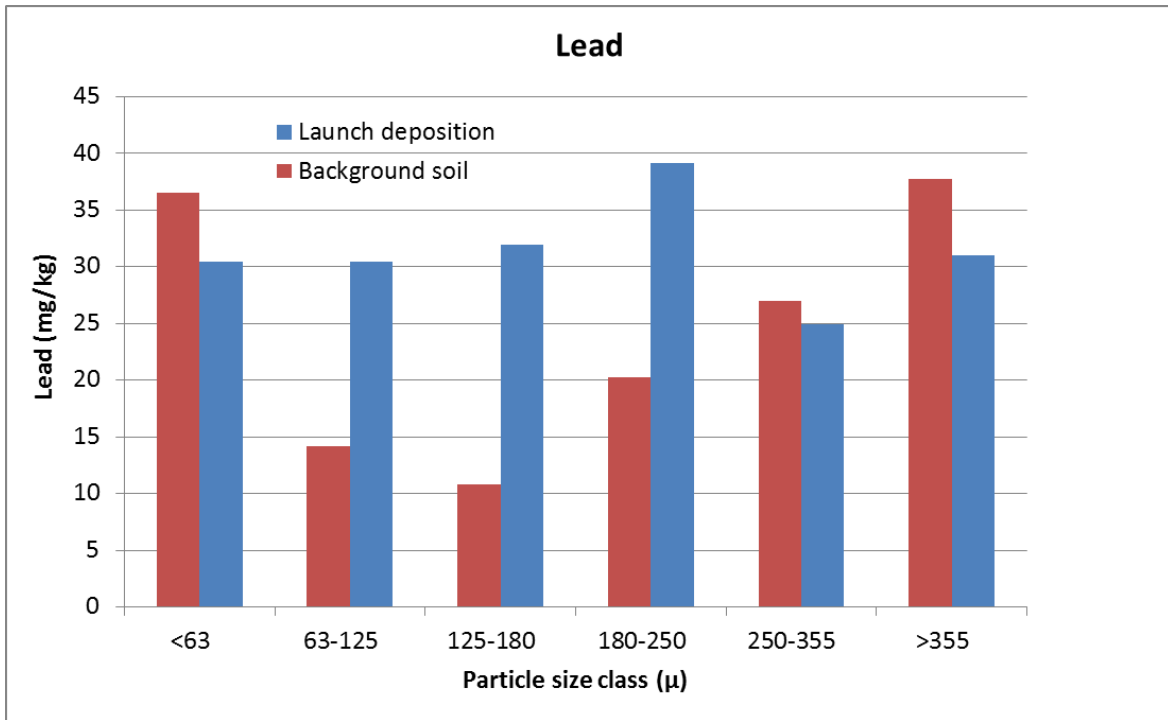


Figure 56. Results of total lead analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

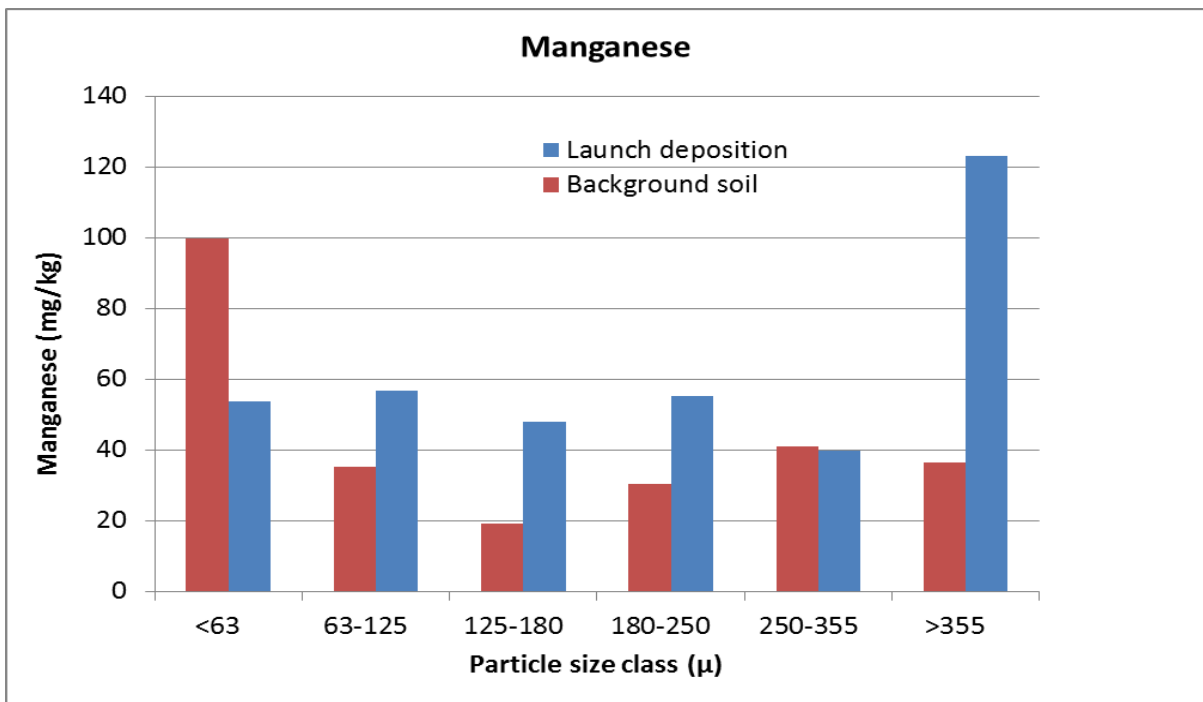


Figure 57. Results of total manganese analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

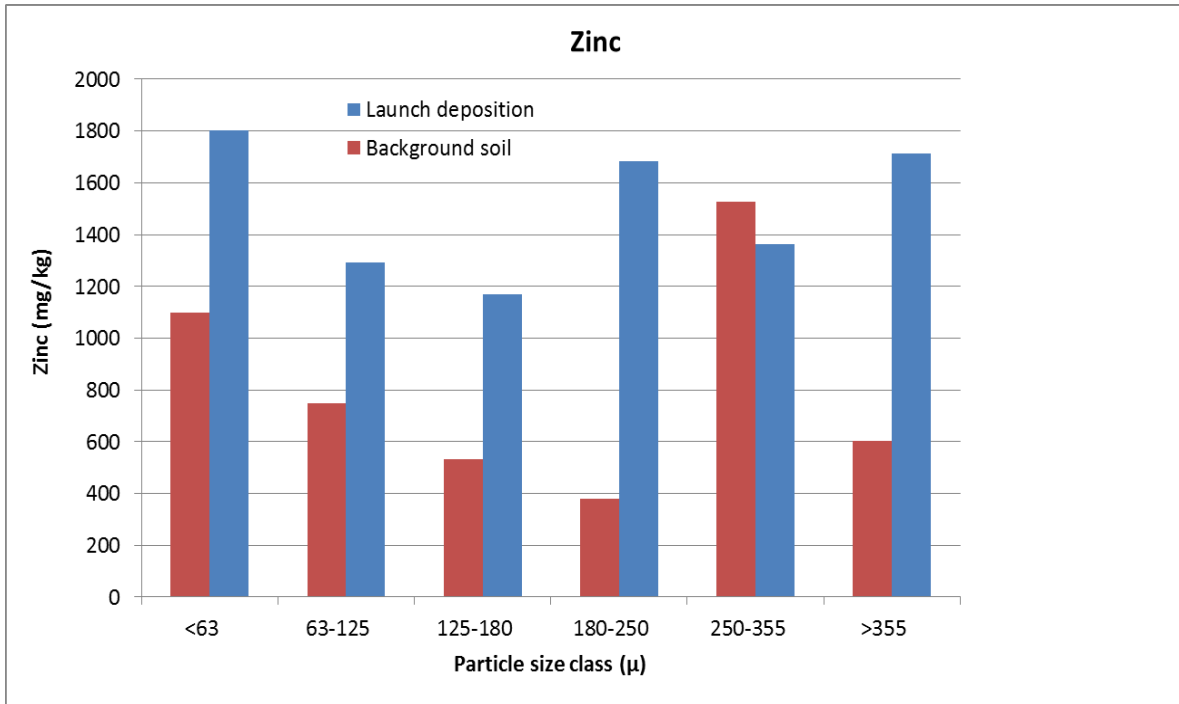


Figure 58. Results of total zinc analysis on six different size classes of near-field exhaust deposition and background soil samples collected during STS-11.

4.3.2 Far-field

Far-field deposition patterns are shown in Figure 59 and Figure 60. This deposition occurred outside of the near-field plume zone, as a result of movement of the launch cloud with prevailing meteorological conditions at cloud stabilization height (see Figure 43 for an example of this behavior). The ground tracks of deposition from every launch were mapped for each pad and a cumulative far-field map was prepared for all areas of KSC receiving deposition (Figure 61) (Schmalzer et al., 1985; Duncan and Schmalzer, 1992, 1994; Duncan et al., 2002). Spots of acid or dry deposition on leaves of plants or on structures indicated that the area received far-field deposition (Figure 62). The geographic distribution of far-field deposition was far more variable than that of near-field deposition, and much of KSC received deposition from at least one launch. After 135 launches, 23,124.7 ha (57,142.2 ac) had received far-field deposition at least once, but 14,065 ha (34,755.2 ac) were impacted no more than two times. The area of cumulative far-field deposition increased from 19,396 ha (47,928 ac) after the first 49 launches (Duncan and Schmalzer 1994) to 23,124.7 ha after 124 launches. Chloride deposition was measured for several launches and ranged from 25-5,300 mg/m² (Schmalzer et al., 1986).

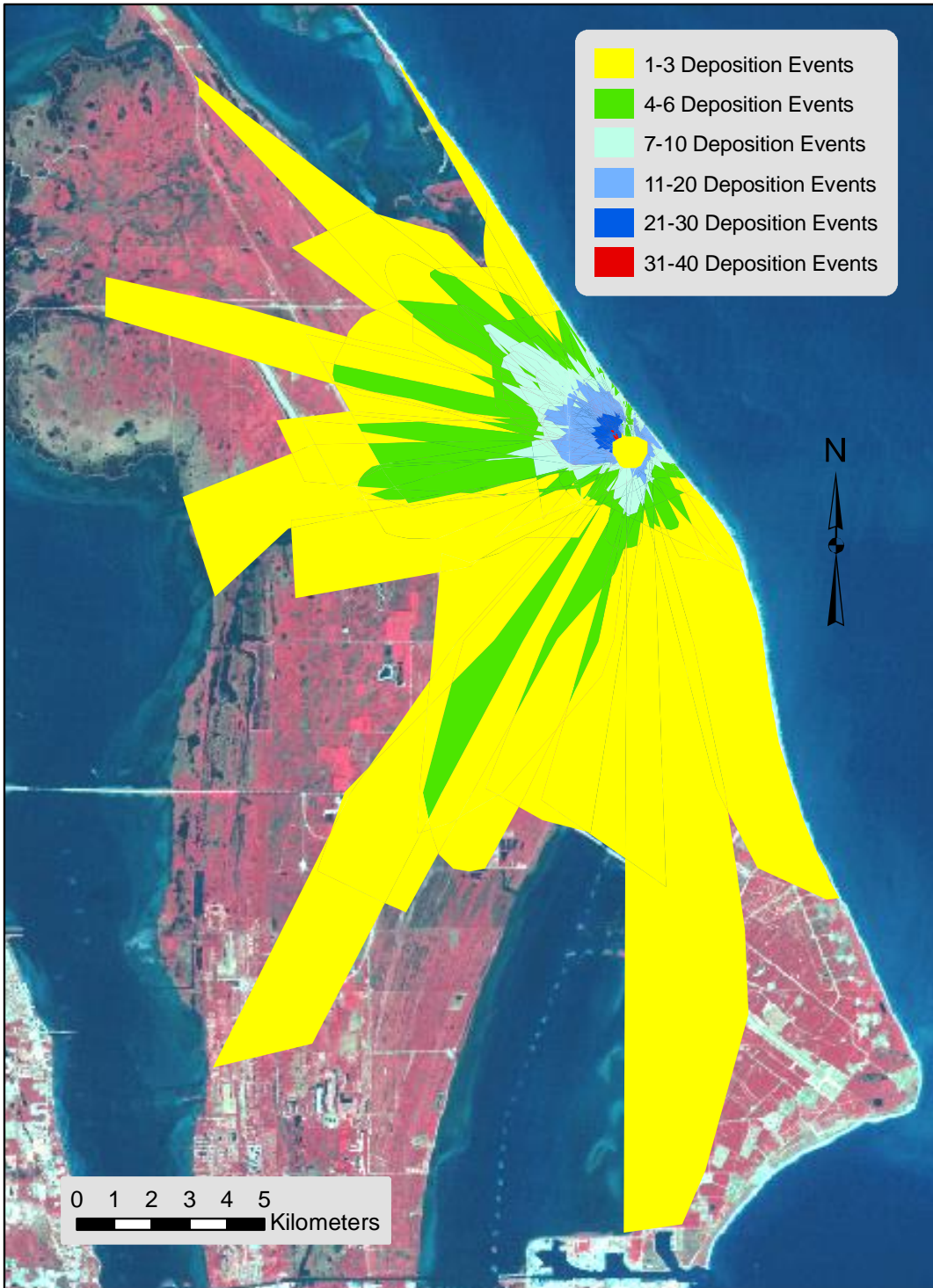


Figure 59. Far-field exhaust deposition pattern from shuttle launches at Pad 39A. Deposition results from the solid rocket motor exhaust mixing with the deluge water. Direction and distance of travel is controlled by wind speed and direction at cloud stabilization height.

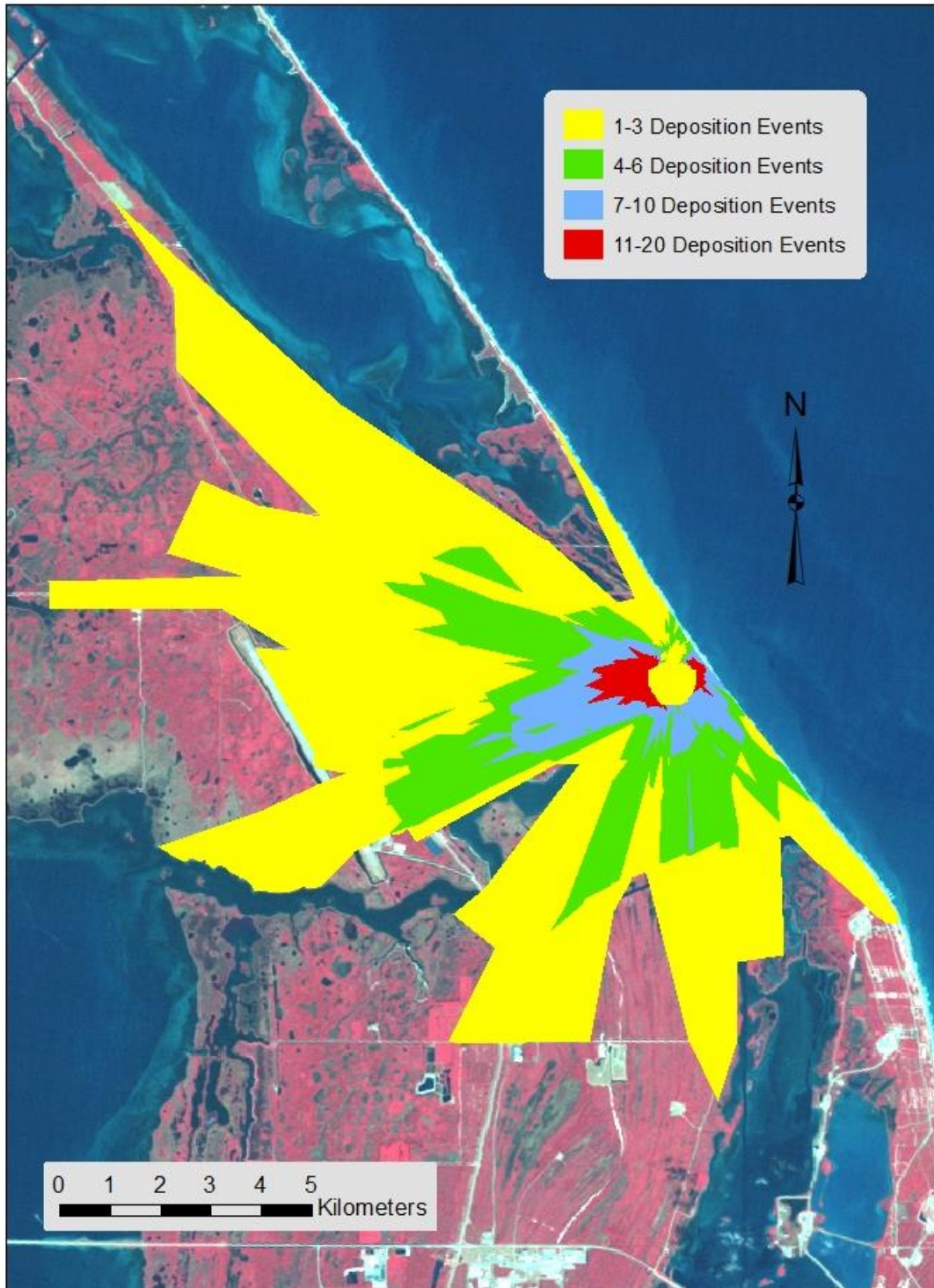


Figure 60. Far-field exhaust deposition pattern from shuttle launches at Pad 39B. Deposition results from the solid rocket motor exhaust mixing with the deluge water. Direction and distance of travel is controlled by wind speed and direction at cloud stabilization height.

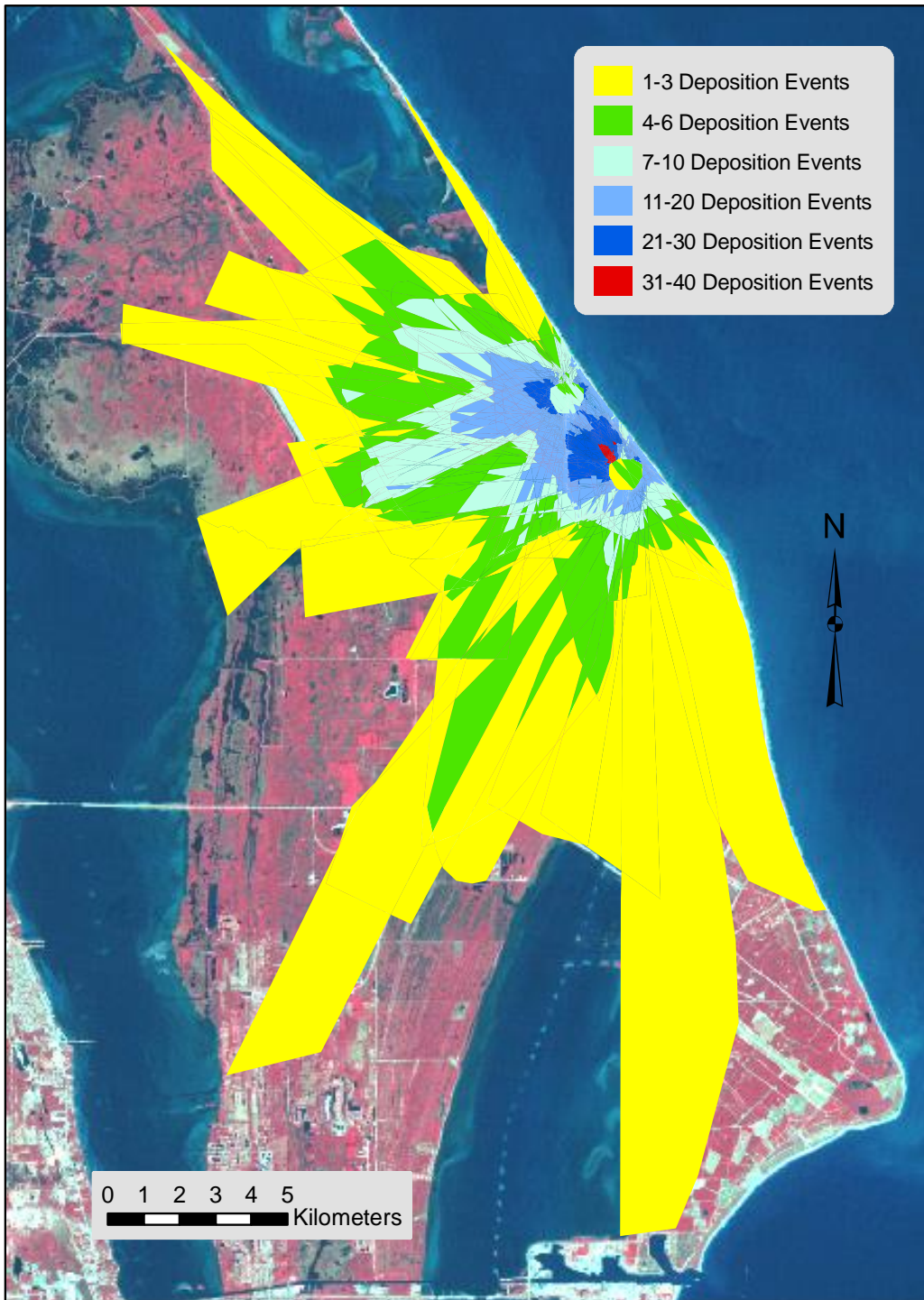


Figure 61. Total cumulative far-field deposition pattern resulting from all shuttle launches at KSC.

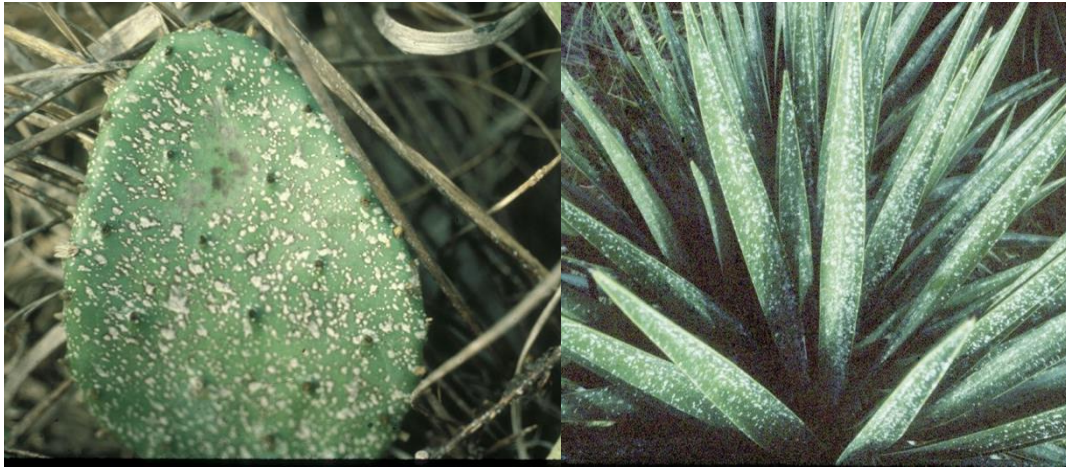


Figure 62. Examples of vegetation impacted by far-field deposition from a shuttle launch.

4.4 Soils

Soil studies completed previous to STS-1 indicated that strong solutions of hydrochloric acid would leach the cations sodium (Na), calcium (Ca), and magnesium (Mg), and certain metals including aluminum (Al), iron (Fe), manganese (Mn), nickel (Ni), zinc (Zn), and cobalt (Co) from KSC soils (Madsen, 1980).

Soil microcosm studies were conducted at Pad 39A between January 1984 and November 1985 (Schmalzer et al., 1993). The pH of leachate from microcosms exposed to near-field deposition decreased immediately post-launch. During any one event, leachate pH recovered to pre-launch values within seven days. Over the course of the studies, a cumulative decline of 0.35 pH units in the background soil pH was noted in the highly exposed soils. With each loading of HCl by the shuttle exhaust cloud, metal concentrations (e.g., Al, Cu, Fe, Zn) increased in soil leachates due to increased metal solubility at lower pH. Between launches, as leachate pH recovered to near background levels, metal concentrations in the leachate declined, probably due to the formation of less soluble metal oxides and hydroxides, at circumneutral pH. Cation concentrations, particularly Ca^{2+} and Mg^{2+} , were elevated immediately post-launch and between launches probably due in part to dissolution of shell fragments prevalent in these coastal soils.

Soils in the most frequently impacted area north of Pad 39A were sampled after nine launches and again after 24 launches from the same sites (Schmalzer et al., 1993). These soils near the launch complexes are heterogeneous but can be divided into saline and non-saline groups. Within these groups, changes between conditions after nine launches and after 24 launches differed. In the non-saline soils, there were increases in conductivity, Ca, potassium (K), Na, and Zn and decreases in phosphorus (P), nitrate nitrogen ($\text{NO}_3\text{-N}$), and ammonium as N ($\text{NH}_4\text{-N}$). In the saline soils, there were increases in Ca, K, Na, Zn, and P

but not conductivity, and decreases in $\text{NH}_4\text{-N}$ but not $\text{NO}_3\text{-N}$ (Schmalzer et al., 1993). Increases in conductivity, Ca, K, and Na between nine and 24 launches may be due to leaching of soil material including shell fragments. Increases in zinc could be from soil leaching or from deposition of material derived from paint or plating on pad structures. Soils in the impact area remained well buffered; even after 24 launches, soil pH was still alkaline. A Land Use Control Implementation Plan (LUCIP) was developed to prohibit residential exposure to soil and swale soil (NASA, 2004). In addition to the LUCIP, sediment blocks were installed in the ditches and swales with outfalls outside the Pad 39A perimeter fence to prevent off-site migration of swale soils containing elevated metal (primarily Zn) concentrations (NASA 2009). After 24 launches, monitoring of soil and sediment at Pad 39A and Pad 39B became part of the RCRA Facility Investigation (RFI) process.

During the RFI, Zn and Cu were identified above their respective FDEP Residential Soil Cleanup Levels (R-SCTLs) (NASA 2003). Cu was identified in sediment samples collected in the Environmental Control System (ECS) area and Zn was identified in the swales and ditches within the Pad 39A fence line. It appears the source of the Cu was cooling water discharge prior to 1995. Zn is used to coat the launch structures and mobile launch platform for cathodic protection. Due to ongoing shuttle operations and limited ecological impacts identified at Pad 39A, no additional investigations were warranted.

During the RFI performed at Pad 39B, benzo(a)pyrene (BaP), arsenic (As), nickel (Ni), and Zn were identified above the FDEP R-SCTLs in site soils (NASA 2003). The BaP and As impacts were identified in the Heating, Ventilation and Air Conditioning (HVAC) area; the Ni impacts were identified in the Compressed Air Building area; and the Zn impacts were identified in the swales and ditches within the Pad 39B fence line. Due to ongoing shuttle operations and limited ecological impacts identified at Pad 39B, no additional investigations were planned until the end of the Space Shuttle Program.

4.5 Water Quality

Background pH in the estuarine system generally ranges between 7.8 and 8.8 units. At launch, the surface layer of the lagoon water in line with the flame trench received up to 1,700 kg (3,748 lbs) of HCl from deposition (Dreschel and Hall, 1985, 1990). This acid mixed downward into the water column through advection and diffusion eventually impacting approximately the upper 1.5 m (4.9 ft). Figure 63 shows a time series recording of pH in the lagoon north of Pad 39B pre- and post- launch of STS 95. The rate of mixing was driven primarily by wind speed and direction. Levels of impact were highly variable spatially and temporally depending on meteorological conditions at the time of launch. Maximum pH reductions (about six to seven units) were found at the surface and in the area adjacent to the storm water drainage ditch in line with the flame trench at each pad. In these areas, pH

depression could be acute and lethal to organisms utilizing gills for respiration. Minimal effects were observed around the edges of the near-field ground cloud footprint and at depth where buffering and dilution minimized chemical impacts (Schmalzer et al., 1993).

Surface and ground waters in the region around the launch pads are highly buffered, as a result of local soils and geological conditions, with total alkalinity values typically ranging between 120 and 200 mg/l as calcium carbonate (CaCO_3). This aquatic buffering system reacted readily with the exhausted HCl to produce calcium chloride (CaCl_2), carbon dioxide (CO_2), and water (H_2O) (Dreschel and Hinkle 1984). Advective and diffusive mixing during the 48 to 72 hours post-launch were found to return pH readings and alkalinity measurements in the lagoon to pre-launch levels (Schmalzer et al., 1993).

Figure 64 shows the pre-and post-launch concentrations of total Zn in the water column. Concentration was generally below one mg/l but rise to near five mg/l post launch.

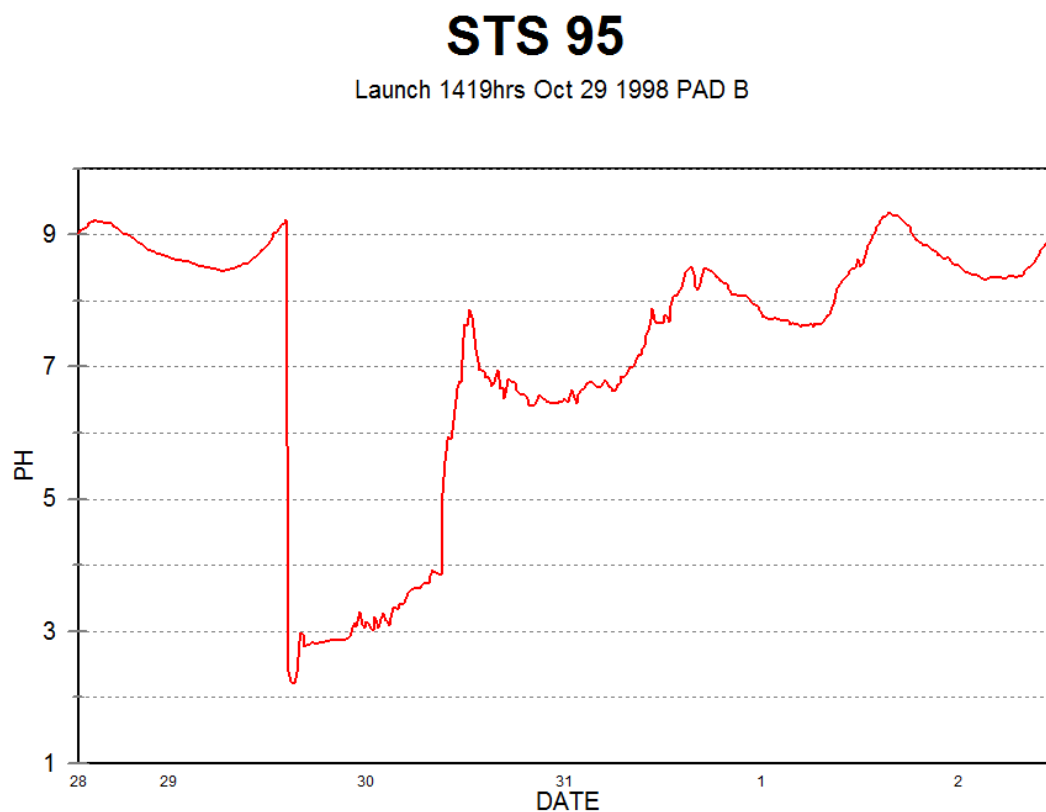


Figure 63. Example of STS near-field HCl launch deposition effects on surface water pH in the area north of Pad 39B.

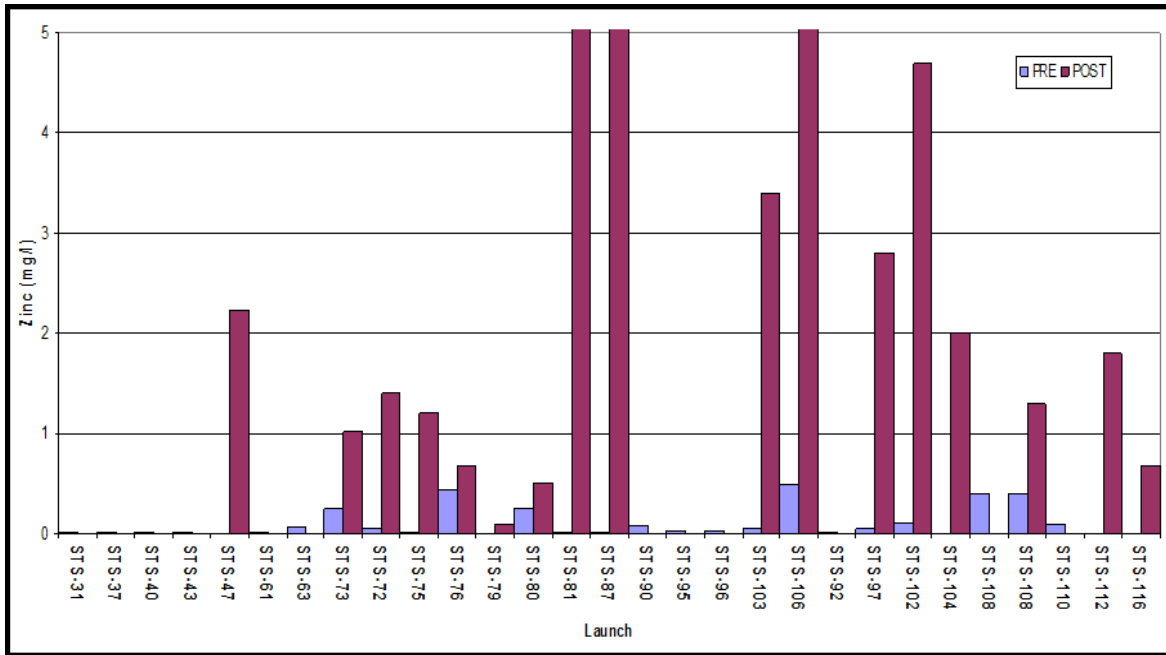


Figure 64. Example of STS near-field zinc launch deposition on lagoon water quality in the area north of Pad 39A.

4.6 Vegetation

Cumulative impacts in the most frequently exposed area north of Pad 39A through STS-9 included reduction in the number of plant species present, and reduction in total cover. The reduction in total species number included both loss of sensitive species and invasion of more weedy ones, but losses exceeded new invasion (Schmalzer et al., 1985). Vegetation effects differed by strata; shrubs and small trees were eliminated by repeated defoliation more rapidly than forbs and graminoids. The community level effects consisted of retrogressive changes. These changes continued until the cessation of launches in 1986 with an increasing amount of bare ground in the most severely impacted area. Considerable regrowth occurred in the period without launches. Resumption of launches in September 1988 initiated another retrogressive sequence. Launch rates were lower in the post-Challenger period, and this limited the extent of bare ground in the impacted area. Similar changes occurred at Pad 39B (Schmalzer et al., 1993).

Some launches resulted in damage to the coastal dune community when the near-field zone extended across the dunes (Schmalzer et al., 1985, 1993) (see Figure 46 and Figure 47). Thin leaved herbaceous species, and shrubs with succulent leaves were more sensitive to launch cloud deposits than are typical dune grasses (Schmalzer et.al., 1985). Dune community species exhibiting sensitivity to launch cloud effects included camphorweed (*Heterotheca subaxillaris*), inkberry (*Scaevola plumieri*), beach sunflower (*Helianthus debilis*), and marsh elder (*Iva imbricata*). Dune species exhibiting resistance to launch cloud

effects included sea oats (*Uniola paniculata*), beach grass (*Panicum amarum*), slender cordgrass (*Spartina patens*), and sea grape (*Coccoloba unifera*). Within six months, vegetation recovery was nearly complete (Schmalzer et al., 1985). Impacts to the dunes were infrequent and cumulative changes in vegetation have not occurred.

Aerial photography was collected before and throughout the Space Shuttle Program to document vegetation community changes that might result from launch impacts as recommended by AIBS (1982). Figure 65 and Figure 66 show the areas around Pads 39A and 39B as they existed in 1979 and 2012. At Pad 39A the general pattern has been an expansion of disturbance tolerant wax myrtle (*Myrica cerifera*), Brazilian pepper (*Schinus terebinthifolius*), and mangroves filling bare ground and some areas of wetland and herbaceous cover. At Pad 39B mangroves have increased in abundance in the impounded areas northwest of the pad, and wax myrtle, Brazilian pepper and other disturbance tolerant taxa have expanded in coverage. At both pads the amount of bright reflective bare ground has been greatly reduced by expansion of vegetation communities. Mangroves and Brazilian pepper were significantly impacted by freezing temperatures in 1989 and 1990 with total top kill in some areas. They have since recovered.



Figure 65. Aerial color infrared photographs of the Pad 39A area showing vegetation changes over a 32 year period between 1979 (left) and 2012 (right). Note the reduction in open space and increase in vegetation mass.

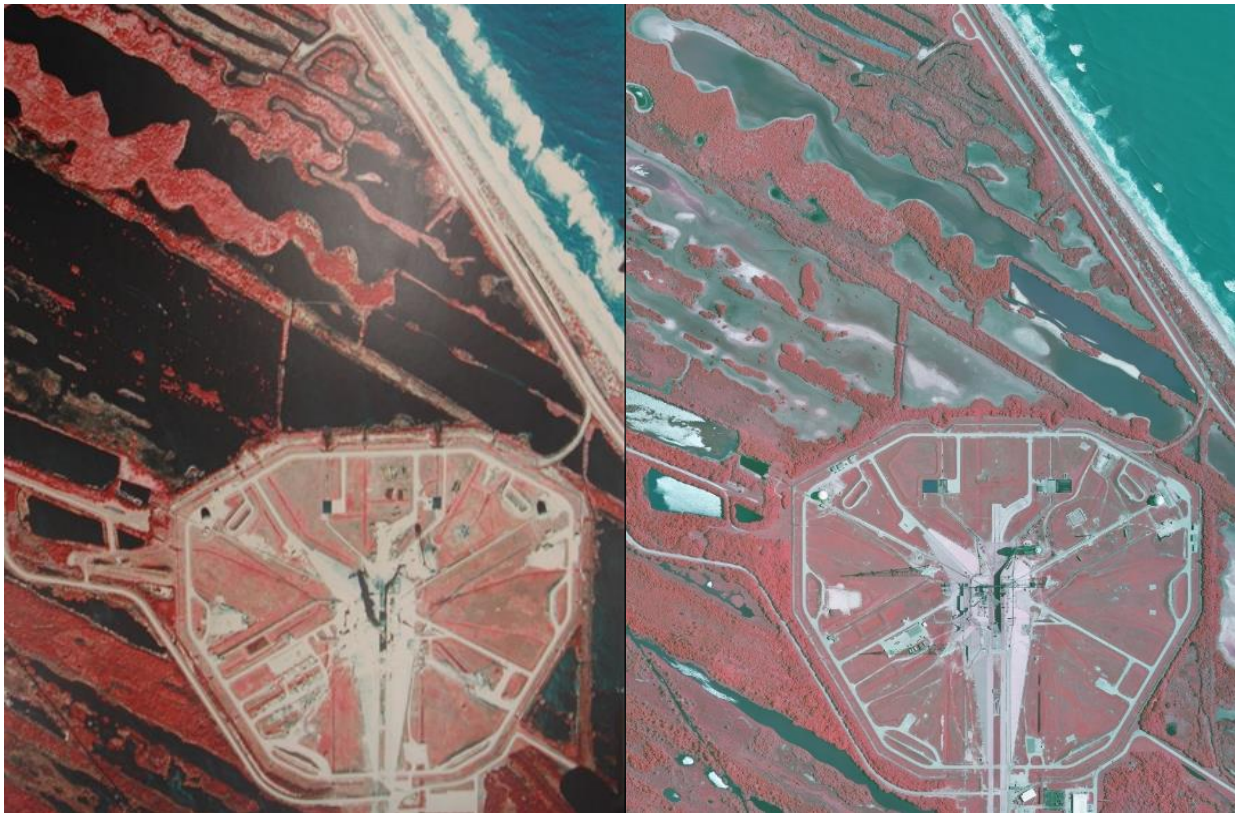


Figure 66. Aerial color infrared photographs of the Pad 39B area showing vegetation changes over a 32 year period between 1979 (left) and 2012 (right). Note the reduction in open space and increase in vegetation mass.

Far-field deposition from individual launches could produce damage to foliage of vegetation. Areas receiving $1,000 \text{ mg/m}^2$ chlorides experienced damage from acid etching of the leaves; sensitive species were damaged by 100 mg/m^2 chlorides (Schmalzer et al., 1986). Far-field deposition was sufficiently dispersed and variable launch-to-launch that successive launches seldom affected the same areas (see Figure 61). No changes in plant community composition or structure due to cumulative effects of far-field deposition were seen (Schmalzer et al., 1993).

4.7 Fish

For many launches, a fish kill occurred in the shallow surface waters of the lagoon (Pad 39A) or impoundment (Pad 39B) immediately north of each launch complex in line with the SRB flame trench (Figure 67). This fish kill was the direct result of the surface water acidification that often drops five pH units. Hawkins et al., (Hawkins et al., 1984) found that the rapid drop in pH produced severe damage to the gill lamella of fish exposed to the near-field

launch deposition. Field surveys conducted after each launch have indicated that this event was generally limited to the shallow shoreline closest to the pad and the stormwater ditches leading away from the north side of the pad surface. At Pad 39A the fish kill appeared limited to a band of shallow water approximately ten m (33 ft) wide (the 0.5 m (1.6 ft) depth contour). In deeper, open water, fish apparently dive below the area of acidification avoiding the rapid drop in pH. At Pad 39B, the fish kill could cover a larger area and involve a larger number of individuals, because the impoundment water depth was generally less than 0.5 m (1.6 ft) year round, and the fish were not able to avoid the rapid drop in pH. In every event, the fish kill occurred in direct relation to the spatial pattern of the near-field deposition footprint (Schmalzer et al., 1993).



Figure 67. Photo documentation of a fish kill associated with launch of the space shuttle from Pad 39A. Numbers impacted depend on path of exhaust cloud, water depth, and seasonal reproductive patterns.

Species observed after almost every launch included small resident species such as the rainwater killifish (*Lucania parva*), mosquito fish (*Gambusia holbrooki*), sheepshead minnow (*Cyprinodon variegatus*), and sailfin molly (*Poecilia latipinna*). The numbers of individuals observed after each launch were highly variable, ranging between zero and > 5,000, depending on such factors as deposition pattern, seasonal water depths, and seasonal

reproductive activity (presence of large numbers of juveniles). These species are found in virtually every fresh and brackish water habitat with densities ranging between ten and 100 individuals per m². Populations are aggressive invaders of open habitats and begin to recolonize the area within several days after each launch. This rapid immigration is possible because only a small portion of the larger contiguous population is actually impacted. Also, these species are tolerant of a wide range of environmental conditions and are extremely prolific, making them ideally suited for life in the shallow brackish waters around the pads. Other taxa that have been observed less frequently included mullet (*Mugil cephalus*), sheepshead (*Archosargus probatocephalus*), black drum (*Pogonias cromis*), needle fish (*Strongylura spp.*), lady fish, (*Elops saurus*) and red drum (*Sciaenops ocellatus*).

4.8 Noise Measurements

The highest acoustic noise levels generated by the STS were recorded within the first two minutes of launch. In the launch pad vicinity (within ca. 400 m), noise levels could exceed 160 dBA. Noise levels recorded at the Launch Impact Line near the VAB area did not exceed the 115 dBA maximum level established for short exposure by the Department of Labor Standards. For maximum protection, observer areas and security zones were set at distances beyond which the 115 dBA sound level was not exceeded.

All STS launches from KSC generated sonic booms with focal zones over uninhabited ocean waters. Clearance zones established by the launch trajectory and SRB retrieval areas essentially preclude significant adverse impacts to human populations. Three sonic booms were generated during the launch of the STS. The first sonic boom was generated by the shuttle system upon ascent. This was the largest sonic boom of the mission with a maximum overpressure of 3.66 psf (25.2 kPa) (Garcia 1983). The sonic boom focal zone was typically located approximately 64 km (40 miles) offshore of the launch site, in the Atlantic Ocean (Garcia 1983).

Following separation of the SRBs from the orbiter and external tank, the SRBs re-entered the atmosphere. This re-entry generated a sonic boom with a focal zone approximately 242-320 km (150-200 mi) down range of the launch site and a projected maximum overpressure of two to three psf (13.8-20.7 kPa) (NASA, 1978).

The third sonic boom was generated by the reentry of the jettisoned external tank. The sonic boom focal zone is located over the Indian Ocean with a maximum overpressure of two to four psf (13.8-27.6 kPa) (NASA, 1978).

Orbiter reentry through the atmosphere produced a sonic boom of varying intensities distributed along the ground track during the final descent and landing phase of a space

shuttle mission. The intensity and shape of the sonic boom pressure signature was a function of the vehicle shape, weight and volume, combined with the flight path and the prevailing atmospheric conditions (Stansbery and Stanley, 1984a). Sonic boom measurements from early landings at Edwards Air Force Base, California ranged from 0.7-2.4 psf (4.8-16.5 kPa) at different locations (Garcia 1983). Beginning with STS-38, the majority of space shuttle missions landed at KSC. Sonic boom measurements were recorded at various points in Florida along the descent and landing trajectory of these flights (Stansbery and Stanley, 1984a, 1984b, 1984c). A maximum measured overpressure of 2.2 psf (15.2 kPa) was recorded in Titusville during the landing of the STS-51D flight. All sonic boom measurements recorded in Florida during orbiter landings have been accurately predicted by computer model analyses. Noise was identified as a potential concern for wildlife during the NEPA documentation process (NASA, 1978). Sonic booms during landing had the potential to produce startle responses in individual wildlife but impacts to populations appeared to be non-existent.

4.9 Wildlife Impacts

Acute impacts of shuttle launches to wildlife populations at KSC appeared minimal with the majority of birds being able to flee the pad area in a fright response to the ignition of the shuttle main engines seven seconds prior to the ignition of the SRBs. On occasion some individuals were caught in the exhaust blast and were killed or injured. Species observed included armadillo, marsh rabbits, snowy egret, killdeer, frogs, and alligators. Because injured animals tend to hide in burrows or dense vegetation, the number may be greater than observed. No federally listed threatened or endangered species were directly identified as being killed as a result of the launch event (Schmalzer 1993).

Two taxa were given special consideration due to possible impacts that may result from the extreme noise levels near the pads at the time of launch. Low frequency noise levels in the 145- 160 dB range have been measured near the launch pads. The Florida Scrub-jay (*Aphelocoma coerulescens*) (Figure 68), a species listed as threatened by the USFWS in 1987, inhabits scrub vegetation between the two launch pads and scrub south of Pad 39A (Figure 69). After launch, observations were made of the behavior of individuals and their responses to alarm calls. No effects were documented.



Figure 68. The Florida Scrub-jay occupies the area between Pad 39A and Pad 39B and the area south of Pad 39A, linking the KSC population with the CCAFS population. The area between the pads is subject to near-field deposition given certain meteorological condition and high noise levels.

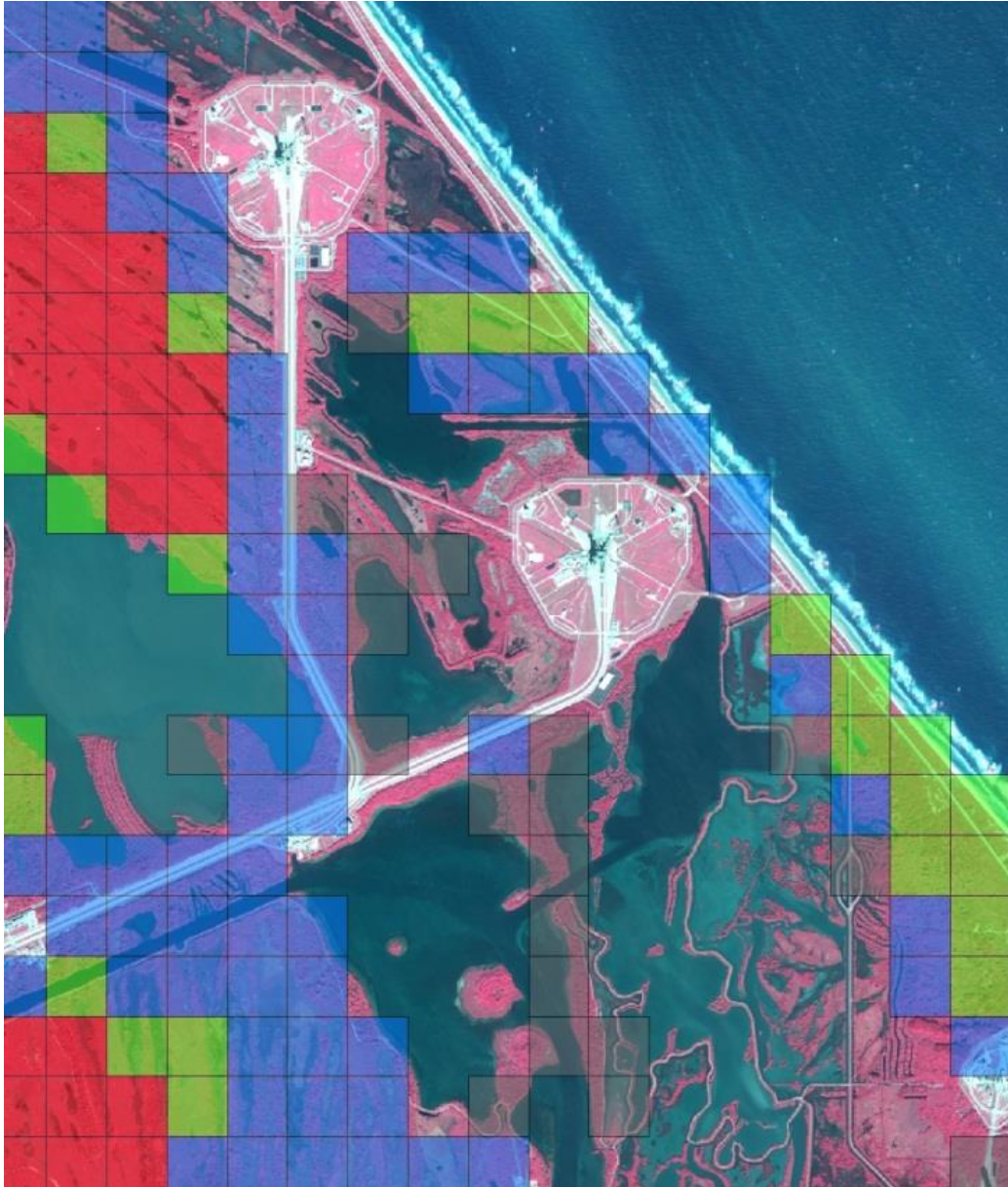


Figure 69. Map of Florida Scrub-jay habitat quality in the vicinity of the Pads 39A and 39B. Red represents primary or high quality habitat potential. Green represents medium potential. Blue represents areas of lower potential.

A second species of concern was the Wood Stork (*Mycteria americana*) (Figure 70) which nested at the Bluebill Creek Rookery approximately 750-800 m (0.47-0.50 mi) south of Pad 39A. During three nesting seasons, observations of nesting success were conducted at the colony to document possible adverse effects resulting from launch noise or acid deposition. It was speculated that the high noise levels, fright response, or acid deposition on eggs might interfere with some aspect of nesting success. Wood storks were flushed from their nests on several launches with most individuals returning within four minutes. Nests that

could be easily seen from boats showed production of two to three young and no evidence that launches reduce nest success. It is plausible that some egg or chick losses were undetected but these are unlikely to have been significant to the species. In December 1989, a severe freeze damaged the black mangroves (*Avicennia germinans*) in which the storks nested. These trees deteriorated in subsequent years and became unsuitable for stork nesting. During the period of observation, success of wood stork nesting at the Bluebill Creek site continually declined, with total failure during the 1992 nesting season. Given the loss of mangroves from the freeze, this decline in nesting could not be associated with launch (Schmalzer et al., 1993).



Figure 70. Wood storks occupied the Bluebill Creek rookery located approximately 700 m south of Pad 39A. Freezing temperatures in 1989 and 1990 killed the mangroves in the area and the rookery was abandoned.

4.10 Ongoing Work

Results of monitoring shuttle launch impacts have shown no macro-scale negative responses. Ecological communities have persisted through the duration of the program with no dramatic change in species composition or physical distribution. Ongoing assessments of potential launch impacts include a comprehensive Ecological Risk Assessment being conducted by the KSC Remediation Program Office in response to preliminary RFI findings (NASA, 2010). This project will evaluate the likelihood that adverse ecological effects are occurring or may potentially occur as a result of site-specific constituents including metals, semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides (OCPs), perchlorate, and total petroleum hydrocarbons (TRPH). Assessment endpoints include invertebrates, fish, mammals, birds, and amphibians. Potential risks to these receptors will be evaluated using a variety of approaches including chemical analysis of sediment, surface water, and biota, food web modeling, calculation of hazard quotients, sediment toxicity testing, and biological community assessments. Media include sediments, surface water, invertebrates, fish, amphibians, and birds. Data will be evaluated using a variety of approaches including sediment toxicity tests, calculation of hazard quotients, and food web modeling.

An assessment of potential endocrine system disruption in alligator populations in Florida and South Carolina, including the Pad 39 area at KSC, is being conducted with the Medical University of South Carolina. The alligator is recognized as a model sentinel species because it is continually exposed directly to the environment it occupies, it is long lived, it generally does not travel far, and it is a top predator in the food web. Although alligators continue to occupy the area around the launch pads there may be non-lethal issues associated with the endocrine system and damage to reproductive systems. A genotoxicity characterization utilizing alligators is also planned with the Wise Laboratory of Environmental and Genetic Toxicology at the University of Southern Maine. The goal is to assess the potential for genetic alterations resulting from exposure to metals in the region. Ongoing Ecological Program monitoring in the area includes sport and commercial fisheries, small mammal habitat occupancy, water bird use, vegetation transects, aerial photo-documentation and annual sea turtle nesting success.

4.11 Launch Effects Summary

Through the 30 year flight history of the Space Shuttle Program there were 135 launches, 82 from Pad 39A and 53 from Pad 39B. The shuttle SRBs were the largest solid rocket motors ever built and flown. Each contained 498,950 kg of propellant. The propellant consisted of an aluminum (Al) powder fuel (16%), ammonium perchlorate as an oxidizer (69.9%), a

catalyst of iron oxidizer powder (0.07%), a rubber-based binder of polybutadiene acrylic acid acrylonitrile (12.04%), and an epoxy curing agent (1.96%). Each SRB produced approximately 2,650,000 pounds of thrust at sea level. The exhaust from the SRBs was directed northward from the launch pads by the split flame trench (Anderson and Keller 1983). The exhaust was composed primarily of aluminum, hydrogen, nitrogen, carbon, oxygen, and chloride compounds (see Table 11).

At each launch pad, a sound suppression water system was utilized to protect the shuttle and payloads from damage by acoustical energy reflected from the mobile launch platform during launch. The system consisted of an elevated 2,006,050 l (530,000 gal) tank and associated plumbing that includes a system of six large rain birds and 16 nozzles above the flame deflectors. At approximately 12 seconds prior to launch, the system was activated, initiating a 25 to 30 second dump of the entire water system (NASA, 1978; NASA, 1983). The system also contained an overpressure suppression system consisting of two compartments. A water spray system provided a cushion of water that is routed directly into the flame hole beneath each booster. This was supplemented by a series of water hammocks stretched across each hole in the mobile launch platform. This dual system provided a 26,495 l (7,000 gal) water mass to dampen the pressure pulse resulting from ignition of the SRBs. At launch minus 12 seconds, the sound suppression system was activated, starting flow of water onto the launch pad and structure. At minus nine seconds, the three shuttle main engines were ignited and throttled toward full power. At zero the two SRBs were ignited. The initial blast hit the sound suppression hammocks and water that had been pouring onto the pad, instantly vaporizing and atomizing it. The resulting mixture of deluge water, debris, and exhaust chemicals exploded from the flame trench at a velocity of approximately 85-100 meters per second. As the shuttle rose from the launch pad, the exit velocity and percent of SRB exhaust exiting the flame trench decayed to zero. At this point, the exhaust ground cloud formation ceased and column cloud formation predominated. Exhaust effluent can follow three paths:

- **Near-field** wet exhaust deposited north of the flame trench resulting from the SRM ignition and initial blast,
- **Far-field** wet deposition that “rains out” of the ground cloud as it rises, cools and drifts from the pad on prevailing winds,
- **Column-cloud** dry particulate and HCl gas that did not entrain water from the deluge and sound suppression system that disperses with prevailing winds

The near-field deposition consisted primarily of the Al_2O_3 particulates, HCl liquid, H_2O , and sand, shell fragments and other materials such as metals entrained into the exhaust cloud from the pad surface by the SRB blast. HCl deposition was heavy in the near-field zone

causing small fish kills in shallow water areas and vegetation damage as a result of the low pH. Cumulative vegetation damage from repeated launches included loss of woody species, loss of sensitive species, and increased bare ground. During times of no launches recovery of vegetation occurred. Soil surface chemistry was altered by the HCl neutralization process that dissolved calcium and magnesium carbonates. Waters and soils in the area have high buffering capacity and typically returned to pre-launch pH levels within 96 hours. Fish repopulated the area from adjacent areas of no impact and vegetation resprouts if the launch frequency was low enough to allow for it. Launch frequencies as high as 40 per year were projected (NASA, 1978, 1979). If these had been achieved, there would have been a reduction in soil buffering capacity, plants would not have time to resprout or recolonize the area and impacts would have been more severe. This would result in loss of vegetation cover, exposing bare soil. Far-field deposition displayed no impacts other than periodic spotting on plant leaves. There is much uncertainty associated with projecting impacts from higher launch rates. Current data and observations indicate the shuttle launch rate that was achieved had no substantial ecosystem impacts. An ongoing ecological risk assessment is being conducted to quantify possible metals impacts to the local food chain. Alligators, sea turtles, gopher tortoises, sport fish, manatees, southeastern beach mice, and other species continue to utilize the area.

5.0 Area Wide Monitoring

5.1 Background

During the Space Shuttle Program NEPA review and documentation process it was recognized that there would be environmental consequences and change associated with operations of the KSC physical plant that are beyond those related directly to launch effects and processing activities (NASA, 1972, 1978, 1979; AIBS 1982). This realization and the NASA commitment to regulatory compliance and stewardship led to development of the KSC Ecological Program (NASA 1983, Hall et al., 1992). This pro-active holistic program included three basic areas of activity:

- Construction and operations monitoring to assess the day to day activities related to all aspects of facilities operation, maintenance and new construction including launch, roads and grounds, facilities and land management actions.
- Long-term baseline monitoring of air quality, rainfall, water quality, vegetation communities and select wildlife populations to assess and quantify natural variability and trends.
- Ecological studies to develop data, information, and knowledge needed to make informed decisions regarding environmental stewardship issues, and management information needs.

In spring of 1984, KSC management hosted the USFWS Western Energy and Land Use Team to conduct an Adaptive Ecosystem Modeling workshop to identify monitoring and research needs to guide activities of the Ecological Program (Hamilton et al., 1985). Three major areas were identified that included;

- Man made contributions through land management, construction, operations, and launch,
- Fire ecology and the need for prescribed burns to reduce wildfire risk and improve habitat quality,
- Hydrology as it relates to vegetation community distributions, habitat quality, wildlife occupancy, and transport and fate of chemicals.

The focus of this section is documentation of ecological trends, changes, and impacts associated with operations and management of the KSC facility and MINWR and CNSS for the last 30 years in direct support of the Space Shuttle Program and other NASA actions. Table 12 lists the major areas of concern identified during the Adaptive Ecosystem Modeling workshop.

5.2 Construction and Operations

Identified areas of ecological concern include construction and facilities management, solid and liquid waste management, stormwater management, mitigation and restoration, prescribed fire, exotic and invasive species, and citrus management. These activities are subject through time to the changing regulatory compliance environment. The KSC ERD (NASA, 2010) provides detailed discussions of regulatory requirements for Center operations. At KSC, facilities are found primarily in two distinct areas of the Center, the Launch Complex 39 Area (LC39) and the KSC Industrial Area.

Table 12. Summary of major areas of environmental systems and management activities identified during model development at the USFWS Western Energy Land Use Team lead Adaptive Ecosystem Modeling workshop at KSC in 1984.

Ecosystem	Area of Concern
Uplands	Shuttle launch
	Construction of facilities
	Solid/liquid waste management
	Prescribed burning
	Storm water management
	Control of exotic and invasive plants
	Restoration
	Citrus management
	Facility maintenance
Impoundments/wetlands	Water level manipulation/mosquito control
	Opening/building dikes
	Prescribed burning
	Dike maintenance
	Shuttle launch
	Wastewater treatment
	Control of exotic invasive plants
Estuary	Water and sediment quality
	Dredging and dredge disposal
	Primary production/Submerged Aquatic Vegetation
	Control of boat traffic
Wildlife and Fisheries	Management for protected species
	Sport and commercial fishing
	Exotic invasive species control

The majority of new construction occurs in or near these regions due to proximity of infrastructure such as roads, water, sewer, electrical, and natural gas. Major facilities in each area include:

- **Launch Complex 39 Facilities**

- Shuttle Landing Facility (SLF)
- Orbiter Processing Facility (OPF)
- Vehicle Assembly Building (VAB)
- Launch Control Center (LCC)
- Transporter / Crawler
- Transporter Crawlerway
- Mobile Launch Platform (MLP)
- Operations Support Building (OSB)
- Processing Control Center (PCC) Building
- Logistics Facility
- Launch Pad 39-A
- Launch Pad 39-B
- Press Site

- **Industrial Area Facilities**

- Headquarters Building (HQ)
- Operations and Checkout Building (O&C)
- Central Instrumentation Facility (CIF)
- Vertical Processing Facility (VPF)
- Space Station Processing Facility (SSPF)
- Hypergol Maintenance Facility (HMF)
- Spacecraft Assembly & Encapsulation Facility 2 (SAEF-2)
- Payload Hazardous Servicing Facility (PHSF)
- Launch Equipment Test Facility (LETF)
- Parachute Refurbishment Facility (PRF)

Most construction and facilities modification projects occur in areas previously developed as part of the Apollo Program. New construction during the Space Shuttle Program was assessed by the KSC NEPA process and efforts to minimize and mitigate negative impacts were followed. Operations monitoring and regulatory drivers have led to development of several KSC management plans including;

- Osprey management plan
- Least tern management plan

- Gopher tortoise management plan
- KSC Sustainability Plan

Ongoing activities designed to improve KSC ecosystem management and sustainability include development of a light management plan to reduce impacts on nesting and hatchling sea turtles, development of a wetlands management approach for future construction and commercial occupants, development of a Scrub-jay habitat plan, creation of a Fire Action Team to assist with interagency coordination and issues associated with operations and the USFWS prescription burn program, and involvement with the NASA Agency Climate Adaptation Science Investigators program to assess issues associated with future climate change risks and vulnerabilities.

5.2.1 Shuttle Landing Facility (SLF)

The SLF currently occupies about 1,350 acres including the mid-field park site, the tow-way to the VAB, and the hangar facility. The paved runway is 15,000 feet (4,572 m) long, with a 1,000-foot (304.8 m) overrun on each end. The width is about the length of a football field, 300 feet (91.4 m), with 50-foot (15.2 m) asphalt shoulders on each side. The concrete runway is 16 inches (40.6 cm) thick in center, and 15 inches (38.1 cm) thick on the sides. The landing strip is not perfectly flat; it has a slope of 24 inches (61cm) from the center line to the edge to facilitate drainage. Figure 71 is an aerial view of the SLF looking north. During the Space Shuttle Program the facility supported activities including:

- Shuttle landings and roll-over to the orbiter processing facilities,
- Shuttle pilot training with the shuttle training aircraft,
- Crew arrivals and departures to and from Houston, Texas,
- Payload and cargo deliveries and return,
- Shuttle transportation with the mate and de-mate device, and
- Other NASA aircraft operations



Figure 71. Aerial view of the SLF and associated support structures. Construction has altered 1,350 acres of flatwoods, palm-oak-wax myrtle, palm savanna, and hammocks. An additional 173 acres of fresh to brackish open water habitat was created.

An Environmental Assessment for the SLF was developed by J.E. Greiner Company, Inc. in 1973 (NASA, 1973). Their findings indicated construction would remove 708 acres of biotic communities from the MINWR and excavation would create 173 acres of impounded waters that would serve as a storm water and chemical spill management system. Impacted communities included 377 acres of flatwoods, nine acres of hammocks, 252 acres of palm-oak-wax myrtle, 11 acres palm savanna, 22 acres *Spartina* marsh, 14 acres ruderal, and 23 acres of open water. Construction created 339 acres of ruderal managed grass habitat. Projections in the EA indicated the impounded water would support a healthy aquatic community. The ditches are connected to Banana Creek by a short canal and weir, allowing recruitment of estuarine species. These ditches sustain high densities of turtles, alligators, and many sport fish including red drum, seatrout, snook, largemouth bass and sunfish. It is also one of the most important tarpon habitats on KSC. The U.S. Department of Agriculture Wildlife Service is supporting updates to the wildlife management plan at the SLF to reduce risks of wildlife interactions including bird strikes. The single largest ecological effect of the SLF is its contribution to landscape fragmentation and influence on fire management planning and the spread of fire across the landscape. The SLF occupies approximately 1% of the 140,000 acre KSC property and represents roughly 22 % of the area used for KSC operations.

5.2.2 Space Station Processing Facility (SSPF)

After construction of the SLF in the early 1970's the next large construction project outside the LC39 and KSC Industrial Areas was the SSPF (Figure 72).



Figure 72. Aerial view of the SSPF built to support testing and verification and integration of Space Station hardware and modules. Construction of this facility initiated programs to restore and create habitat for the federal protected Florida Scrub-jay.

The SSPF is utilized to test and prepare space station modules and components to ensure success prior to launch. This project occurred after the Florida Scrub-jay was listed as Threatened by the U.S. Fish and Wildlife Service Endangered Species Office in 1987. The SSPF was located just east of the KSC Industrial Area in what was identified as Scrub-jay habitat. Construction of the SSPF removed 28 ac (11.3 ha). Under the Biological Opinion issued by the Endangered Species Office of the USFWS, NASA was required to purchase 56 ac (22.7 ha) off site, or restore or create 84 ac (34 ha) of Scrub-jay habitat as compensation for that loss (Wesley, 1991a).

The SSPF construction project was important in that it led to creation of a scrub habitat compensation program at KSC. Federal agencies may enter into an early consultation process (50 CFR 402.11) in which a preliminary biological opinion may be issued to the agency by the Endangered Species Office as a guide related to projects expected to impact a threatened or endangered species. NASA (1992) chose to enter such a consultation process with the USFWS (Wesley, 1991b) regarding scrub impacts of current and future construction and chose to perform compensation that would benefit the Florida Scrub-jay population on its property. This required a plan that included scrub restoration and creation on KSC. The KSC Habitat Compensation Plan (NASA, 1992) proposed a phased approach to compensation for future projects that would restore and create up to 300 ac (121.5 ha) of

scrub habitat at several areas on KSC. As used here, restoration is the mechanical treatment and prescribed burning of existing scrub of marginal or declining habitat value for Florida Scrub-jays and creation is reestablishment of scrub vegetation on abandoned, well drained agricultural sites.

The first year NASA would restore 74 ac (30 ha) of existing habitat and create 10 ac (4 ha) for a total of 84 ac (34 ha) of compensation. In each succeeding year, as new projects are approved and designed, their impacts to scrub habitat will be determined by a project-specific Biological Assessment. Actual impacts may be greater or less than those originally estimated. Some projects planned may not be built at all. Each Biological Assessment will be submitted to the USFWS under the Section 7 consultation process. Depending on the total area impacted in a given year, compensation sites will be selected so that an appropriate amount of scrub habitat will be restored or created. The final ratio of compensation will be 2:1. Ratios are higher in the initial year of the program and decline toward the end. Not all of the potential 193 ac (78.1 ha) of impact are covered in the present plan. NASA will be required to identify additional compensation acreage when 150 ac (60.7 ha) of impacted habitat is reached. Phasing of compensation is required because: 1) the exact nature, extent, and timing of all future projects is not known now; and 2) monies are provided through the Construction of Facilities (Schmalzer, 1994).

5.2.3 Wastewater and Stormwater

KSC is continually upgrading and modifying the wastewater and stormwater management systems to meet evolving Federal and State regulatory requirements and to minimize impacts to the surrounding ecosystems. Prior to the Clean Water Act and amendments, domestic wastewater was discharged into Banana Creek near the VAB and Buck Creek south of the Industrial Area after secondary treatment. In 1985, KSC stopped domestic discharges to State waters and implemented two novel treatment approaches. At the VAB Area, waste water was discharged to a wetland treatment system located north of Banana Creek between State Route 3 and the railroad tracks. In the Industrial Area, domestic waste water was discharged to an upland pine flatwoods site south of the water treatment facility. During the Space Shuttle Program and the Joint Base Operations Contract between KSC and CCAFS a new advanced waste water treatment facility was constructed on CCAFS (Figure 73). Waste water from KSC was routed to this new facility for processing under FDEP permit requirements. This eliminated discharge to surface ecosystems.



Figure 73. CCAFS waste water treatment facility.

Stormwater was directed away from facilities through ditches, and pumps were used to control surficial aquifer levels near citrus groves. The regulatory and current status of domestic, industrial and stormwater permits and management systems are described in the KSC ERD (NASA, 2010). KSC currently maintains an operating permit for one facility treating Industrial Wastewater (IWW).

- Seawater Immersion Facility at Beach Corrosion Test Laboratory - The Beach Corrosion Test Laboratory is located near Complex 40 along the Atlantic Ocean. The facility is used for testing the resistance of materials and coatings to the natural elements. The IWW is generated when seawater is withdrawn from the ocean and passed over test materials before being discharged back to the ocean.

KSC has over one hundred surface water management systems to control stormwater runoff. The four largest stormwater systems are the Region I system that serves the Industrial Area (Figure 74). The western VAB area is served by the Sub-basin 11 system. The VAB South system that serves the south VAB area and the SLF system that serves the SLF (see Figure 71).

In addition to those stormwater management systems permitted by the SJRWMD, KSC manages an NPDES Stormwater permit for industrial activities. This permit covers six industrial operations at KSC, which include the Contractors Road Locomotive Yard, the SLF, the Ransom Road Reclamation Yard, the Transportation, Storage and Disposal Facility (TSDF), and the Fleet Maintenance Facility (NASA, 2010).

KSC does not meet the criteria established by FDEP that would categorize it as an urban area and is therefore not required to obtain a permit as a municipal separate storm sewer system (MS4) (NASA, 2010).

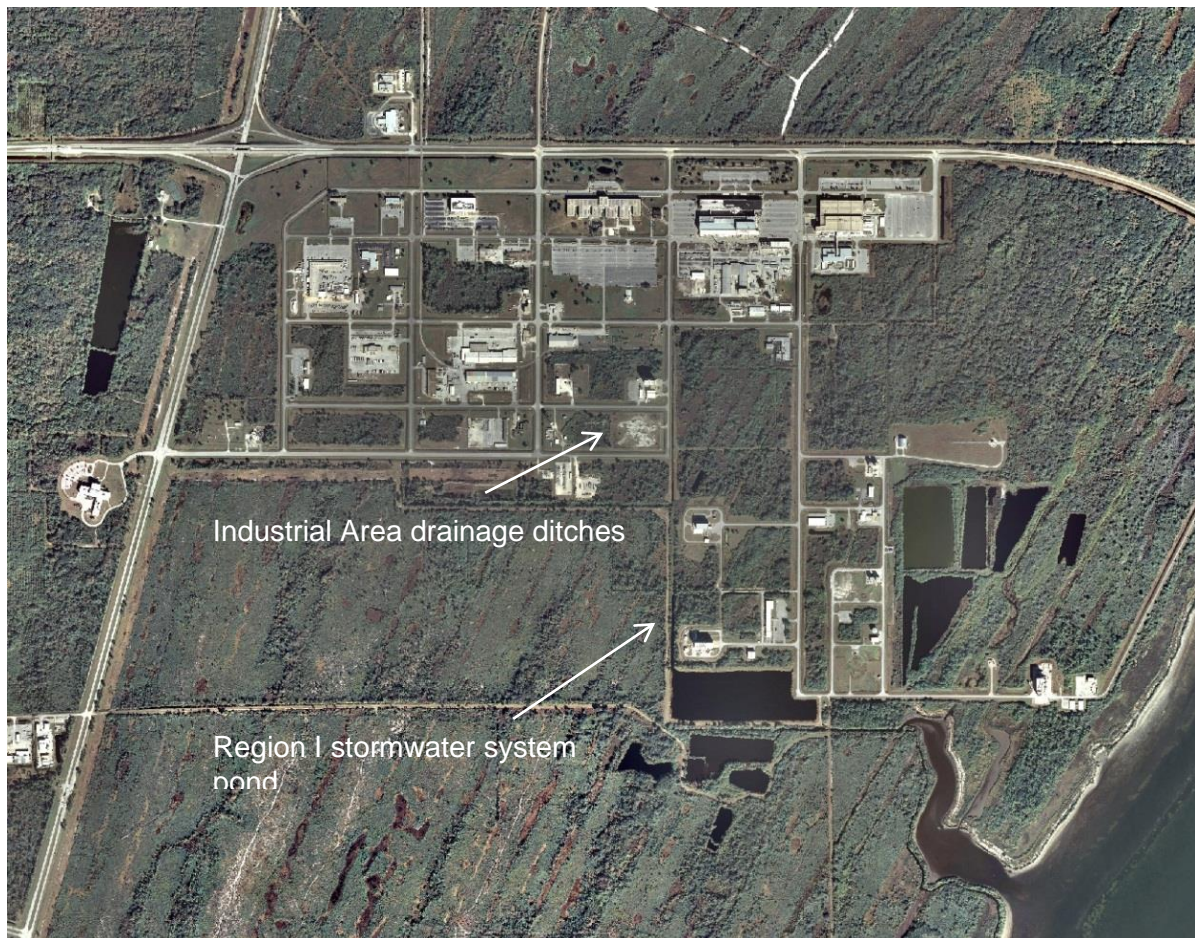


Figure 74. Aerial view of the Region I stormwater management system. This system in the southeast corner of the KSC Industrial Area receives runoff through a series of drainage ditches.

5.2.4 Remediation Program

At KSC and throughout the Cape Canaveral Barrier Island ecosystem a second potential source of chemical contamination is the surficial aquifer and soils. During the 40 year Space Shuttle Program, regulatory requirements were implemented to locate and investigate potential areas of soil and groundwater contamination for the purpose of developing impact

minimization and clean-up strategies. The KSC ERD (NASA, 2010) provides a summary of these regulatory requirements and a list of known and potential contamination release sites that were created during the Mercury, Gemini, Apollo, and the early Space Shuttle Program. One example is the Wilson Corners site (Figure 75). Wilson Corners was originally the location of a general store. As space-related activities developed in the area, the site was converted to a rocket engine components cleaning laboratory, which was operated by a private aerospace contractor. NASA acquired the site in 1963 and remodeled the facility into the offices and laboratory of the Propellant and Systems Components Laboratory (PSCL).



Figure 75. Location of the Wilson Corners soil and groundwater remediation site.

Ancillary structures were added to the site, including an open cleaning tower for the solvent cleaning of fuel lines and other large components. Both domestic and laboratory wastes discharged to on-site drain fields. The predominant solvent used at the facility until the early 1970's was trichloroethene (TCE). The PSCL operated from 1963 until 1974. NASA razed the buildings and ancillary structures, and the site was abandoned for two years. In 1976, the National Park Service (NPS) placed temporary prefabricated office buildings on the site which became the headquarters for the nearby Canaveral National Seashore. In November 1977, a routine analysis of a water sample from an on-site potable well revealed TCE in concentrations of several thousand micrograms per liter ($\mu\text{g/l}$) (NASA, 2001). A simulation of the contamination plume is shown in Figure 76 based on groundwater well data.

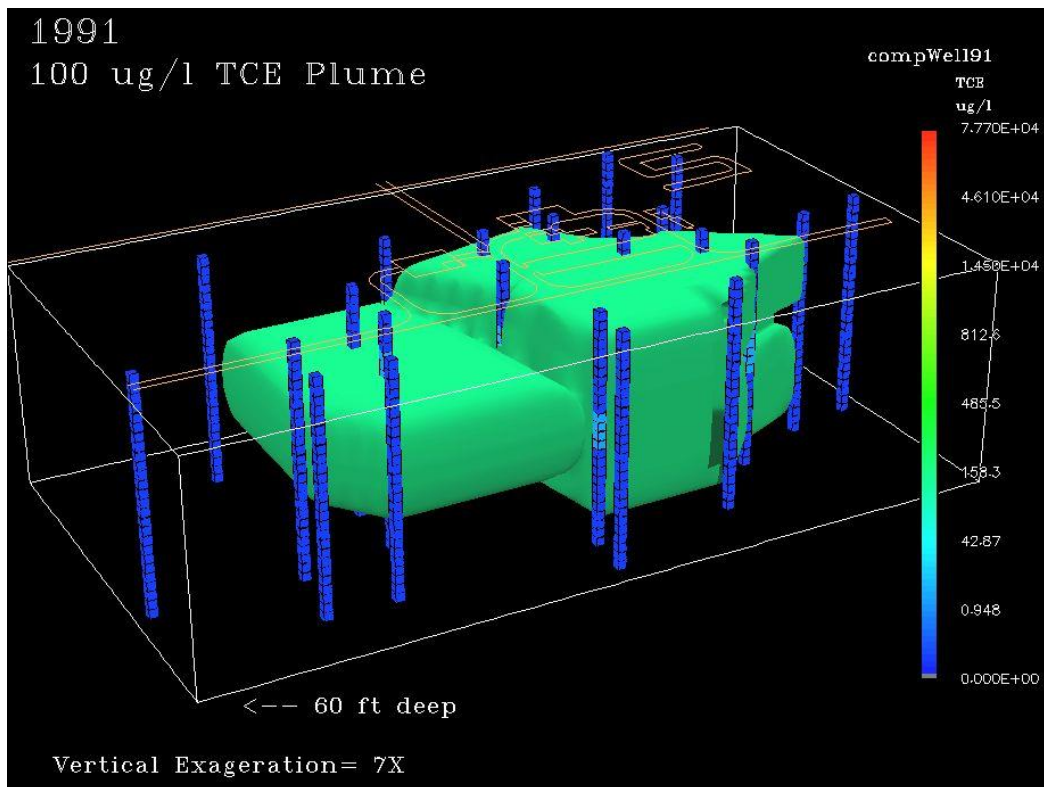


Figure 76. Three dimensional model of the TCE plume in the surficial aquifer at Wilson Corners based on groundwater well data.

5.2.3 Wildlife Interactions

Construction activities and physical plant operations encounter issues with the abundant and often protected wildlife on KSC and the MINWR. To address these events the KSC EPB

develops and maintains specific guidance documents for ensuring wildlife and human safety. Examples of these encounters include the need to move wildlife such as gopher tortoises from sites before mechanical modification. Gopher tortoises, a species protected by the State and proposed for listing under the Endangered Species Act, are attracted to elevated disturbed area such as camera pads, small levees, and foundations where burrowing is easy. Repair work or installation of new underground utilities along roadways frequently require tortoise surveys and relocations.

Ospreys (Figure 77) commonly nest on tree snags, telephone poles, weather towers, or other elevated structures such as launch pad service structures and lightning arrestors. These birds are State and federally protected and it is illegal to disturb their nests when eggs or chicks are present. Other taxa encountered include least terns on gravel roof tops, alligators near stormwater ponds and swales, wild pigs along roads and near parking lots, vultures and raccoons near dumpsters.



Figure 77. Adult osprey and fledglings on a nest at KSC. Nest sites can interfere with operations and maintenance activities requiring movement in the non-breeding season.

5.3 Long-term baseline monitoring

The Ecological Program's long-term baseline monitoring was designed to provide information on ambient air quality, rainfall, surface and ground water quality, sediments, soils, vegetation, and species of special concern for use in assessing natural and man-made alterations of KSC and the surrounding ecosystems with emphasis on the Space Shuttle Program. These data and information are available for use in environmental management applications (permit applications, environmental assessments (EA), or environmental impact statements (EIS)) and support updates of the KSC ERD.

5.3.1 Air Quality and Rainfall

Long-term monitoring of ambient air quality at KSC is conducted as part of the Ecological Program activities. Parameters evaluated include the EPA criteria pollutants, particulates, meteorological conditions, rainfall volume, and rain chemistry. Air quality instrumentation is operated according to standards and quality assurance guidelines defined by the EPA. The rainfall collection station is operated as part of the National Atmospheric Deposition Program (NADP). The location of the Permanent Air Monitoring Site (PAMS) and the NADP rain collector on KSC are shown in Figure 79. PAMS is located approximately 0.4 km (0.25 mi) southeast of the Environmental Health Facility site, and approximately 1.6 km (1.0 mi) north of the KSC Headquarters Building (Figure 78). PAMS includes continuous analyzers for monitoring sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), ozone (O₃), total inhalable (10-micron) particulates and a meteorological tower with instrumentation for wind speed, wind direction, high (30 m) temperature, and relative humidity.



Figure 78. Locations of the Permanent Air Monitoring Station (PAMS) and the National Atmospheric Deposition Station (FL99) north of the KSC Industrial Area.

The major objectives of the long-term ambient air monitoring program are as follows:

- The development of baseline data sets that can be used to qualify the range of natural variability at KSC.
- The recognition of significant trends in air quality that can impact facility development and permitting requirements.
- The development of supporting information for use in permit applications and the KSC ERD.

Ambient air quality at KSC is influenced by NASA operations, land management practices, vehicle traffic, and emission sources outside of KSC. Currently, daily air quality conditions are most influenced by vehicle traffic, standard refurbishment and maintenance operations, cruise ship activity at Port Canaveral, and wildfires and controlled burning operations. Prior to 2011, KSC air quality was also influenced by emissions from two regional power plants

located on the Indian River west of the Center. These units have been taken off-line. Space shuttle launches and vegetation fuel load reduction controlled burns influence air quality as episodic events. One of the most influential air quality fluctuations on a routine basis is created by the emissions from automobiles entering and departing KSC each day. Mobile sources and the control of the emissions are regulated under Title II of the Clean Air Act, but the regulations have no applicability to the environmental requirements of KSC. A summary of air source emissions from KSC is provided in the KSC ERD (NASA, 2010).

NEPA documents developed in support of the Space Shuttle Program identified the potential for HCl emission to impact weather and rainfall pH (NASA, 1972, 1978). The NADP rainfall monitoring program is a national effort to assess trends in rainfall chemistry including pH across the country. Results of 28 years of weekly monitoring are presented in Figure 79, Figure 80, and Figure 81 for precipitation, pH, and SO₄, respectively with a three year running trend line. Precipitation is highly variable with no obvious trend with a long term average around 130 cm per year. pH and SO₄ appear to be inversely related with pH trending upward the last decade and SO₄ trending downward.

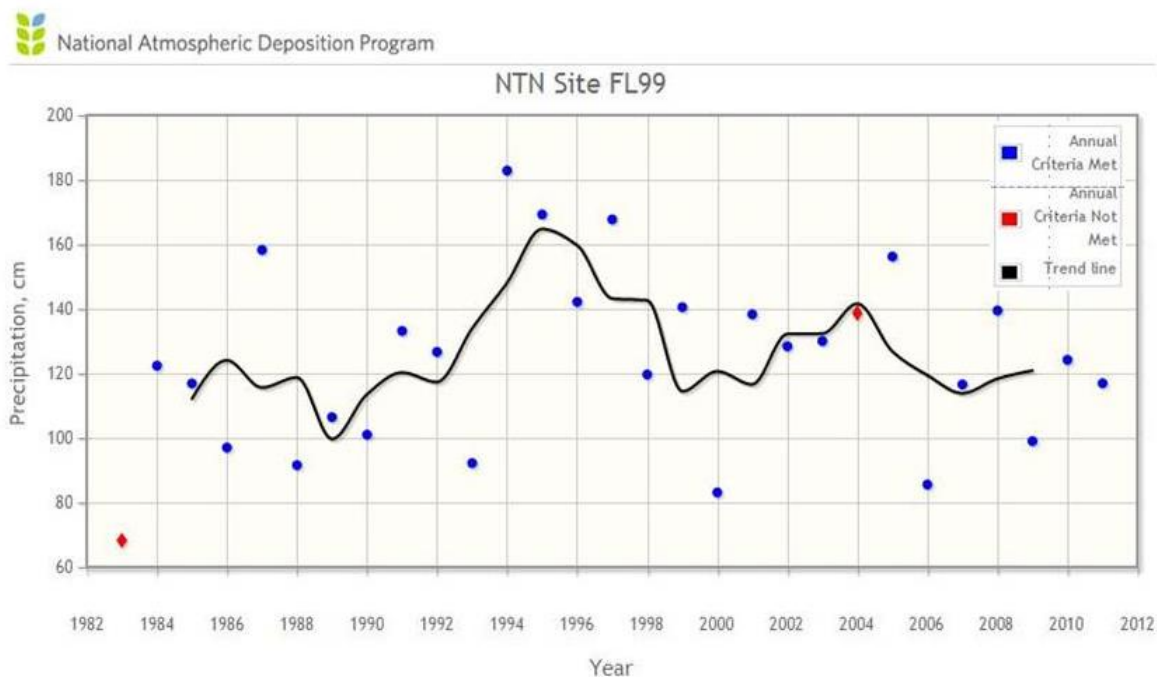


Figure 79. Annual precipitation calculated from weekly measurements at the National Atmospheric Deposition station on KSC between 1983 and 2011.

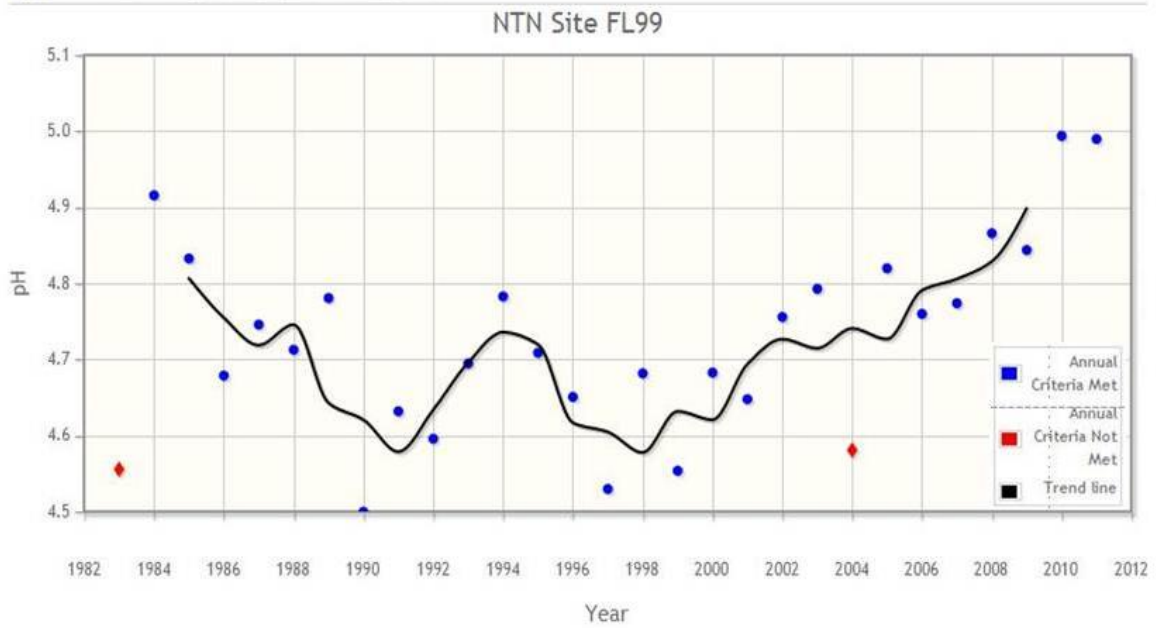


Figure 80. Annual pH calculated from weekly measurements at the National Atmospheric Deposition station on KSC between 1983 and 2011.

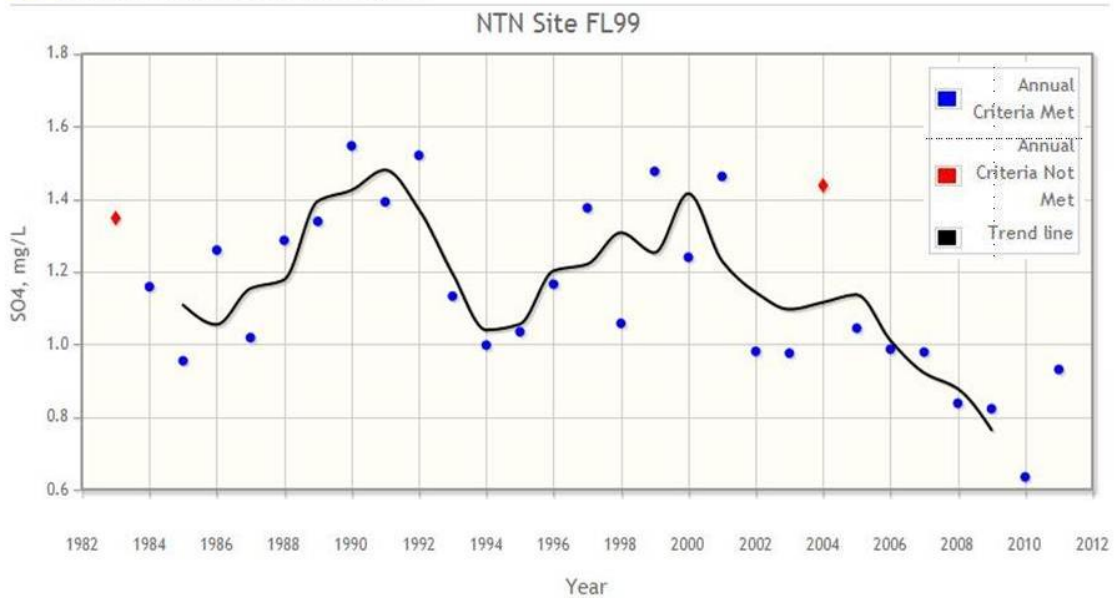


Figure 81. Annual SO₄ (mg/l) calculated from weekly measurements at the National Atmospheric Deposition station on KSC between 1983 and 2011.

5.3.2 Water Quality and Submerged Aquatic Vegetation

Kennedy Space Center and the associated Merritt Island National Wildlife Refuge no longer have industrial or domestic wastewater discharges to the surrounding lagoons, and all stormwater is managed through the National Pollutant Discharge Elimination System (NPDES) stormwater permit program. Non-point source discharges from the natural areas of KSC through overland flow, including extensive wetlands or groundwater seepage, are considered natural when calculating total maximum daily loads of nutrients to the lagoon.

Surface water quality at KSC is considered to be generally good; however, the long-term influences of the rapid cultural eutrophication in the watershed are not absent. The best regions are adjacent to undeveloped areas of the lagoon, such as the north Banana River, Mosquito Lagoon, and the northernmost portion of the Indian River. In order to document the surface water quality of waters surrounding KSC several different monitoring programs are used. NASA, SJRWMD and Brevard County maintain water quality monitoring stations around and within KSC boundaries. The SJRWMD lagoon wide network maintains two surface water quality monitoring stations within KSC. The surface water quality data from this program are used for long-term trend analysis and offers a supportive role in land use planning for the entire Indian River lagoon. Since 1984, eleven sites within the boundary of KSC were monitored quarterly until 2000 and biannually to present. Parameters collected include nutrients, phenols, grease and oil, color, total suspended solids, total dissolved solids, chlorophyll, turbidity and metals. Most of the basic surface water parameters such as salinity, dissolved oxygen (DO), pH, temperature and conductivity follow seasonal and diurnal patterns typical of the IRL and other estuarine systems.

The SJRWMD has identified submerged aquatic vegetation (SAV) distribution and as the best overall indicator of water quality in the lagoon. SAV health is dependent first and foremost on the quality of the underwater light field. Light penetration responds to turbidity caused by plankton blooms which respond to excessive nutrient loadings. Figure 82 shows a summary of the SAV long-term monitoring data based on annual measurements at 37 sites around KSC. Provanca and Scheidt (1999) described variation in species composition along these sites at KSC during the first 15 years of monitoring. Salinity and rainfall accounted for several observed trends through 1998. In general, SAV beds remained healthy in KSC waters across the 28 year period of sampling even though other areas of the lagoon lost SAV beds as a result of eutrophication. Figure 83 and Figure 84 show the distribution of SAV based on maps created using aerial photography from 1943 and 2009. In the KSC region SAV beds have a similar distribution but there is an increase in the algal component. This may be an artifact of the quality of the 1943 imagery, lack of groundtruthing, or the result of increased nutrient availability in the water column.

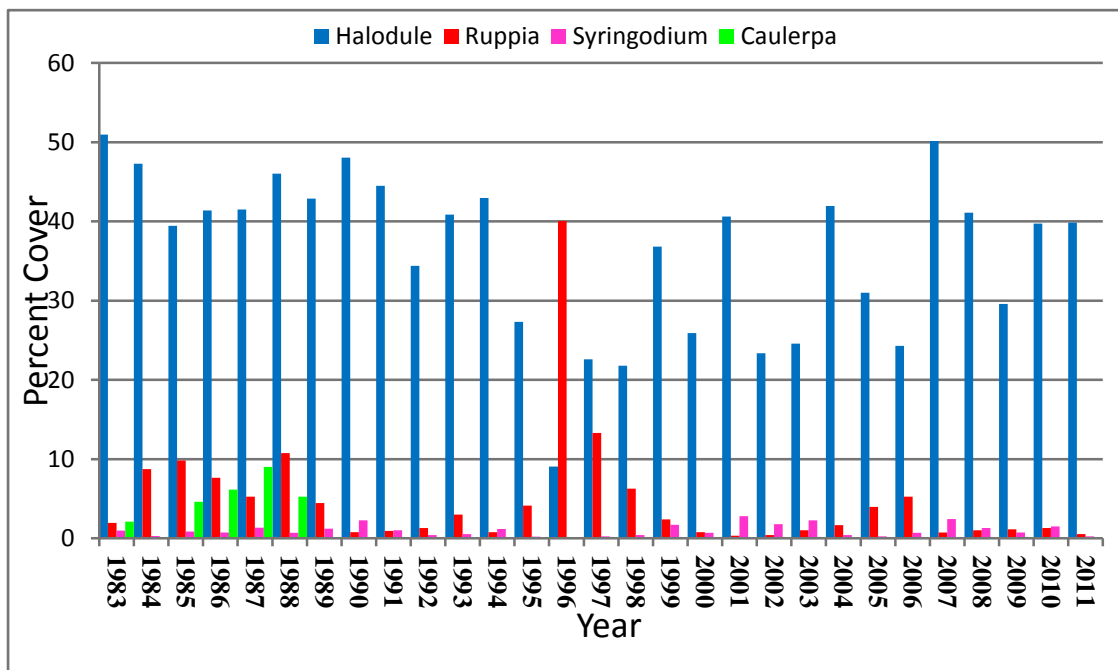


Figure 82. Results of SAV monitoring over a 28 year period at 36 locations around KSC. SAV beds remained healthy throughout the 40 year Space Shuttle Program.

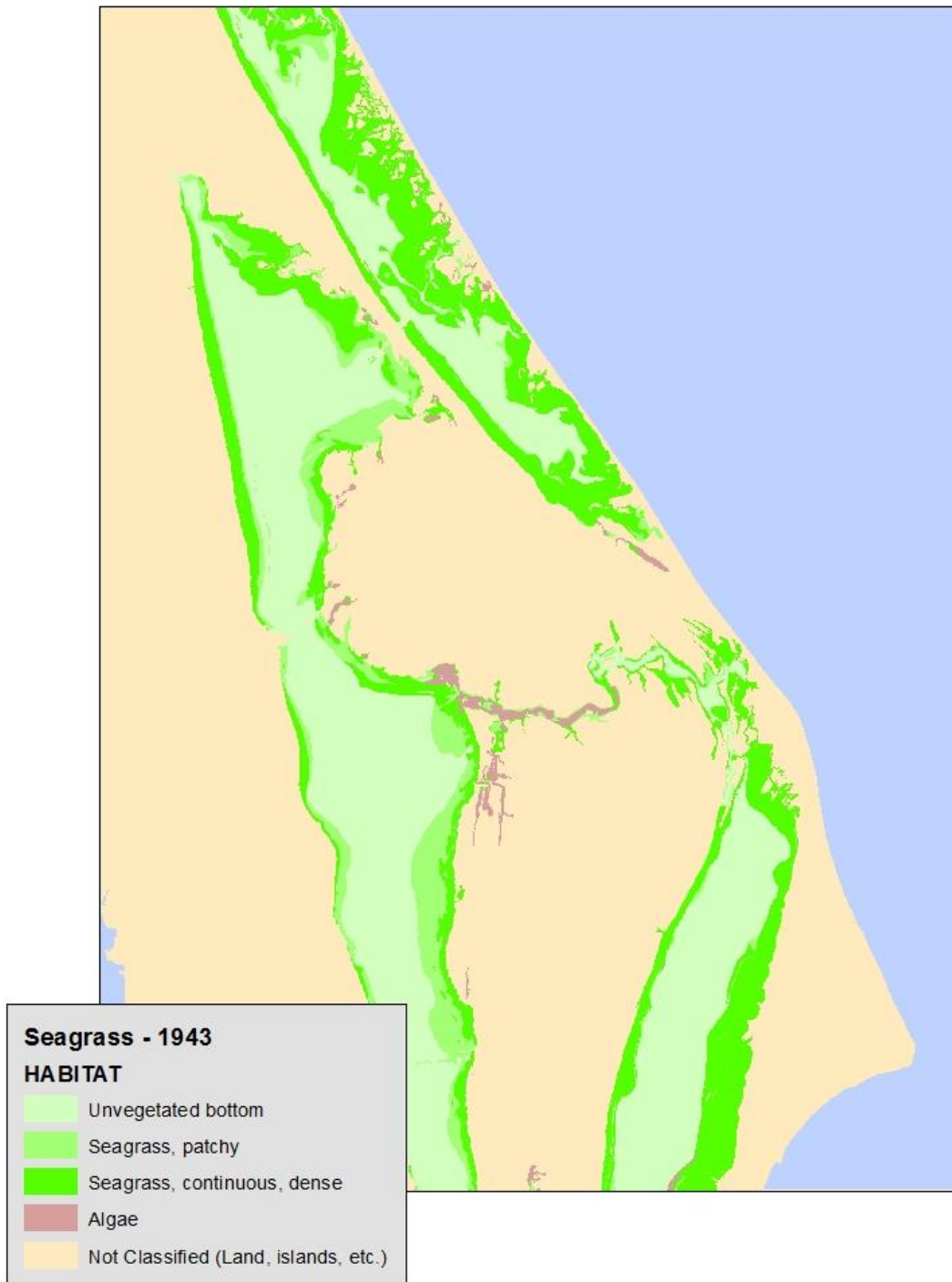


Figure 83. Spatial distribution of submerged aquatic vegetation based on analysis of 1943 aerial black and white photographs.

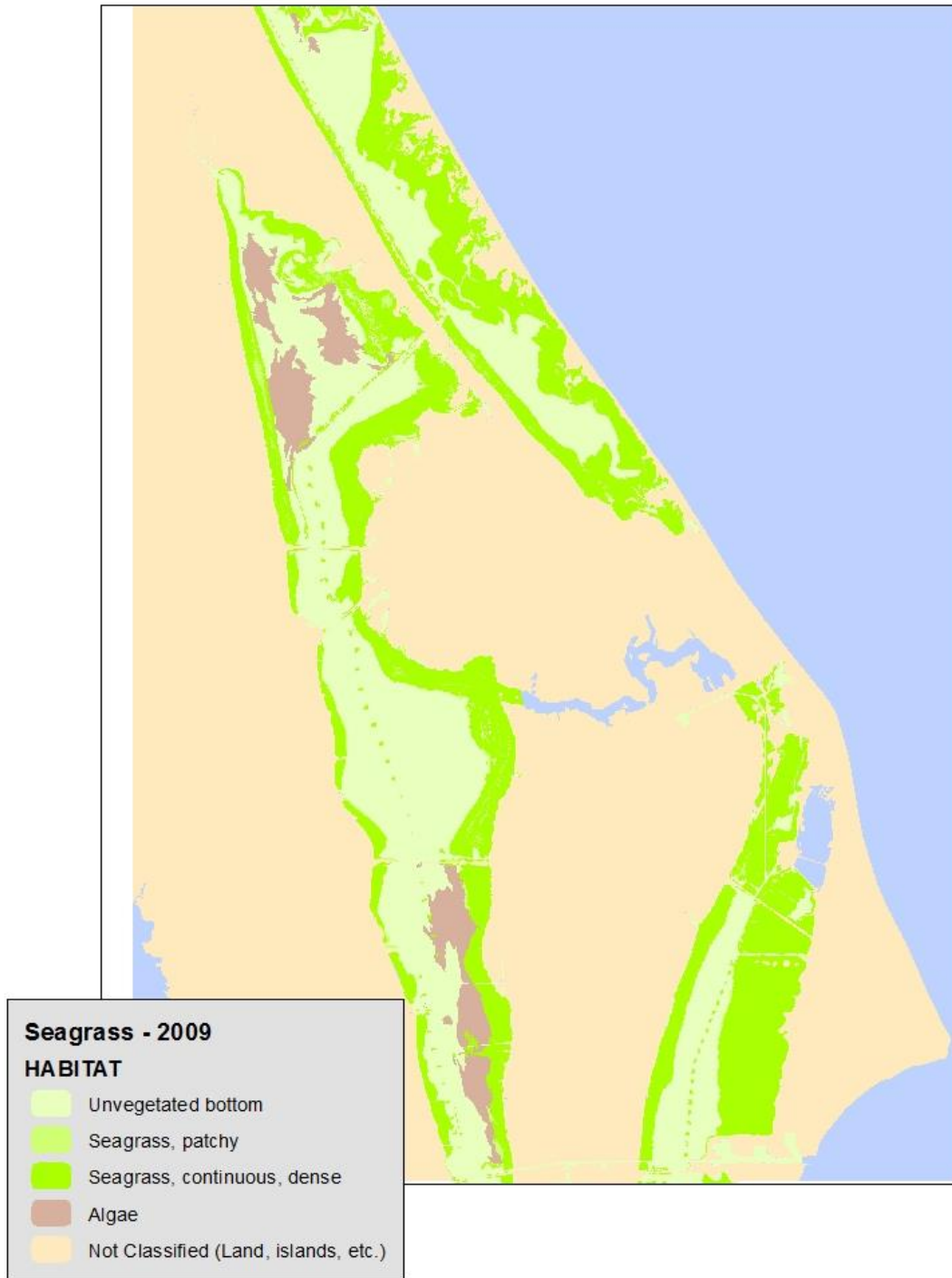


Figure 84. Spatial distribution of submerged aquatic vegetation based on analysis of 2009 aerial true color photographs.

5.3.3 Marine Turtles

The KSC beach is a ten kilometer (km) stretch of shoreline, closed to the public, situated between CCAFS to the south and CNS to the north (Figure 85). KSC provides nesting beach habitat for three species of marine turtles (Figure 86), loggerheads (*Caretta caretta*), green turtles (*Chelonia mydas*), and leatherbacks (*Dermochelys coriacea*). The juvenile and subadult life stages of green and loggerhead sea turtles also occur in the KSC waters of the IRL. The KSC beach is part of the state-wide collaborative Florida Index Nesting Beach Survey (INBS) program used to track sea turtle nesting from May 15th through August 31st each year. The USFWS Endangered Species office issued its latest interim Biological Opinion (BO) on May 13, 2009. The interim BO addresses light management policies and activities at KSC that impact sea turtle nesting and emerging hatchlings. Artificial lighting on marine turtle nesting beaches disrupts the ability of hatchlings to find the sea from their nest, an effect that is termed "hatchling disorientation". In some cases, adult sea turtle nesters can become disoriented causing them to unnecessarily wander landward, making them susceptible to dehydration, predation, and vehicle encounters.

The close proximity of LC39 processing and launch facilities to the KSC sea turtle nesting beach requires balancing the importance of safety and security for the KSC space mission while minimizing impacts on environmental resources. Light sources at nearby facilities are critical for the safety of workforce and operations; however, excessive and outdated lighting continues to be problematic for sea turtle nesting habitat on adjacent beaches. A steady increase in the number of disorientation events appear correlated with the natural beach profile that is shifting the presence of the primary dune and altering associated dune vegetation. Lights from nearby facilities, shielded in the past behind elevated primary dune profiles, are now exposed and illuminate the nesting beach. Even the dark areas of conservation-managed lands are subjected to industrial and urban sky glow. Figure 87 shows an example of lights on Pad 39B at midnight. Artificial lighting along the coastline of KSC continues to impact the behavior of both nesting and hatchling sea turtles. Efforts to (1) reduce light pollution through education, (2) conserve energy, (3) restore primary dune profiles and associated vegetation are being implemented for the multi-management tasks of wildlife conservation, protection of KSC infrastructure, and creation of a dark sky environment to keep the stars visible. Figure 88 shows the annual loggerhead nest counts for the period between 1983 and 2012. During this period there has been an average of 1,161 nests on KSC each year.

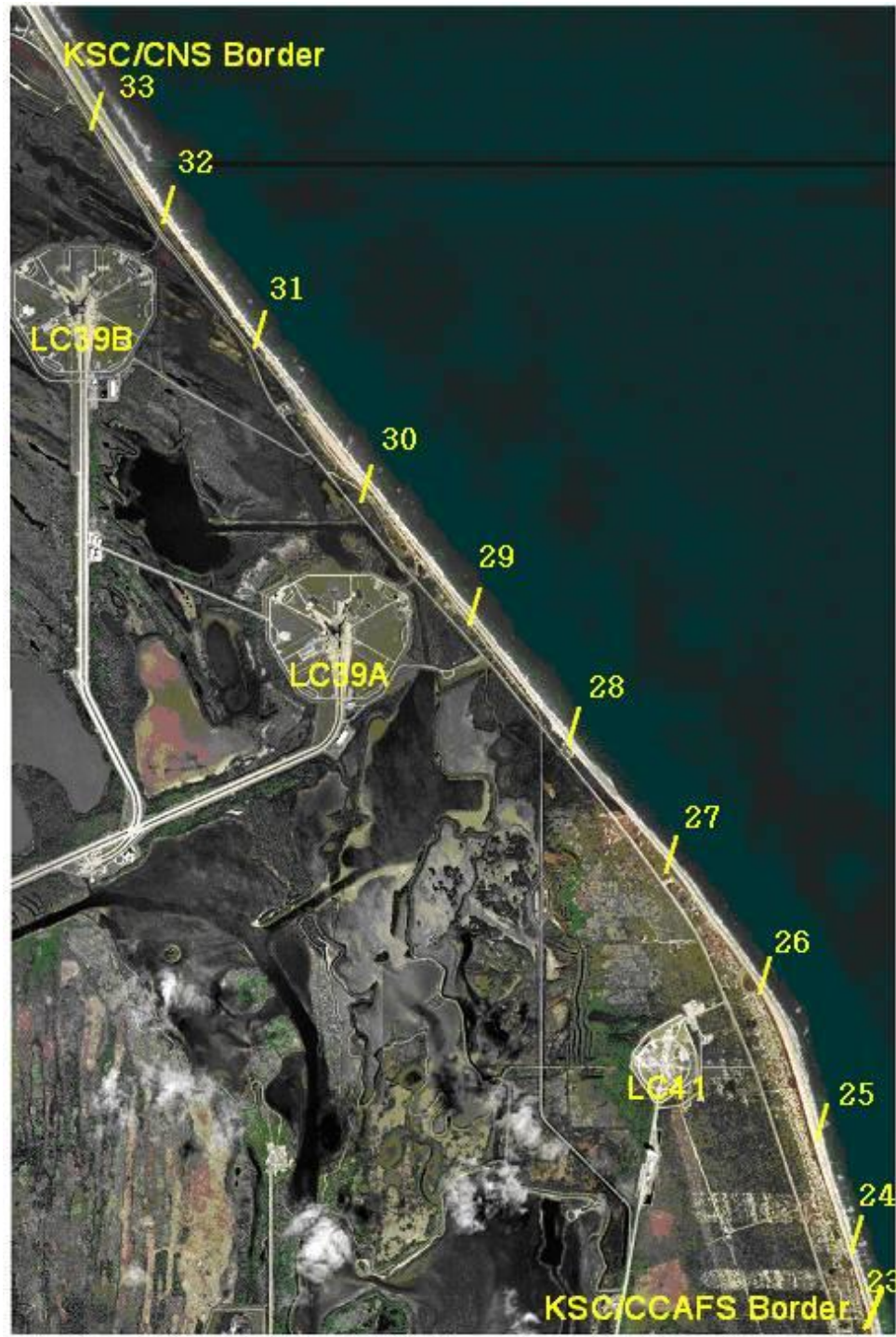


Figure 85. KSC sea turtle nesting beach. Yellow numbers indicate the general locations of kilometer markers used for recording sea turtle nesting data for the INBS program.



Figure 86. Marine turtles nesting at KSC (from left to right; loggerhead, green turtle, and leatherback turtle). Nesting season generally occurs between May and November.



Figure 87. Night image of Pad 39B showing the light pollution that can produce disorientation of sea

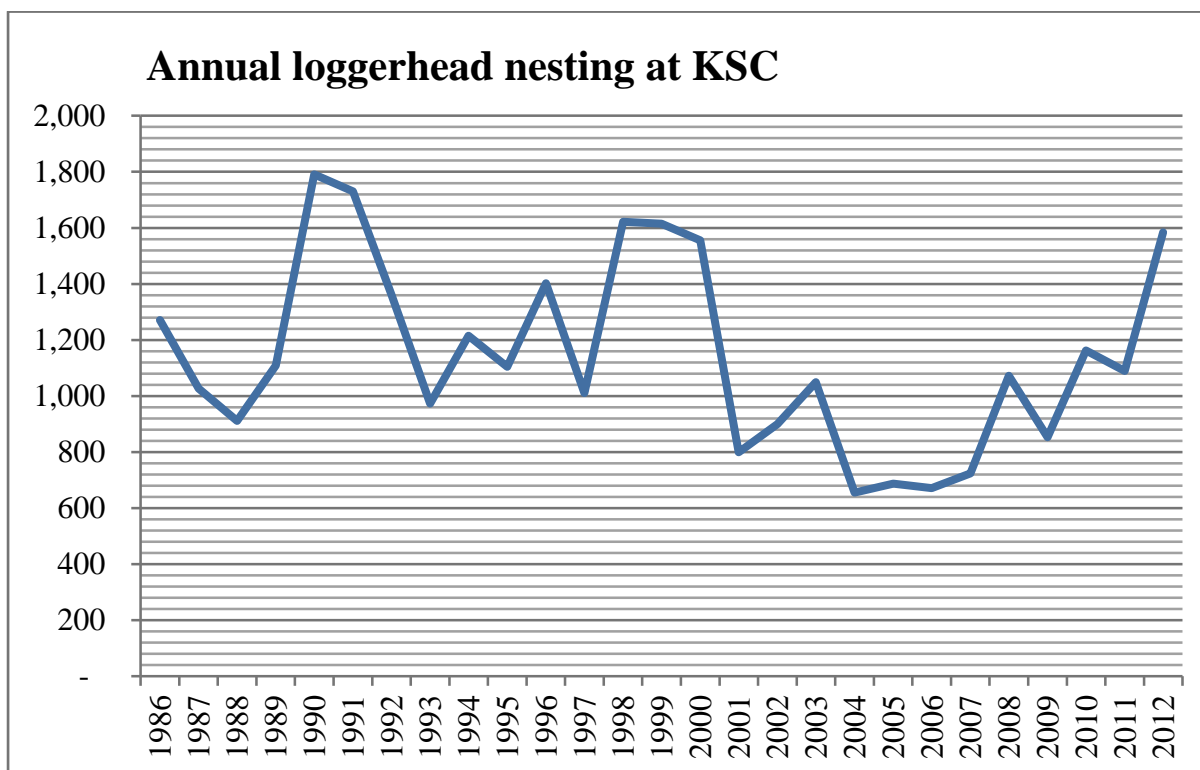


Figure 88. Annual loggerhead sea turtle nest counts at KSC between 1983 and 2012.

5.3.4 Manatee Use of KSC Lagoons

Monitoring the distribution and abundance of manatees at KSC through aerial surveys began in 1977 (NASA 1979, Provancha and Provancha 1989). The manatee (*Trichechus manatus*) is federally listed as endangered. A summary of the KSC aerial survey data is presented in Figure 89, where summer season counts (means) are displayed. Summer counts are considered the best to monitor trends in manatee use of the Banana River because the fall and spring periods have such high variability (Miller et al., 1998). It is speculated that this increase is in response to habitat degradation (water quality and SAV loss) in other areas of the lagoon as well as some recovery of region wide population numbers. Spring time visitation by manatees has long been the peak period for each year. These numbers increased to over 1,000 animals on KSC in spring of 2010, representing what is likely to be 20% of the statewide population.

Provancha and Hall (1991) performed an enclosure study related to manatee use of the SAV beds in the protected waters of KSC. Increasing numbers of manatees observed in grazing

herds here in the spring of each year lead to questions of impacts by these herbivores on the SAV system. At that time, the KSC SAV carrying capacity for manatee use was calculated and suggested to be far greater than observed use.

In 1990, to further protect this endangered species, the USFWS created a sanctuary for manatees covering the majority of the KSC section of the Banana River. The USFWS officially designated the following areas at KSC as Critical Habitat:

- the entire inland section of water known as the Indian River, from its northernmost point immediately south of the intersection of U.S. Highway 1 and Florida State Road 3,
- the entire inland section of water known as the Banana River, north of KARS park, and
- all waterways between the Indian and Banana Rivers (exclusive of those existing manmade structures or settlements which are not necessary to the normal needs of survival of the species).

To protect manatees in KSC waters and elsewhere, such as Port Canaveral and the Canaveral Locks, NASA installed jet drives on the SRB retrieval ships, Liberty Star and Freedom Star, eliminating the potential for impacts with the ships propellers. There were no incidences of manatee injury associated with these ships during the entire Space Shuttle Program.

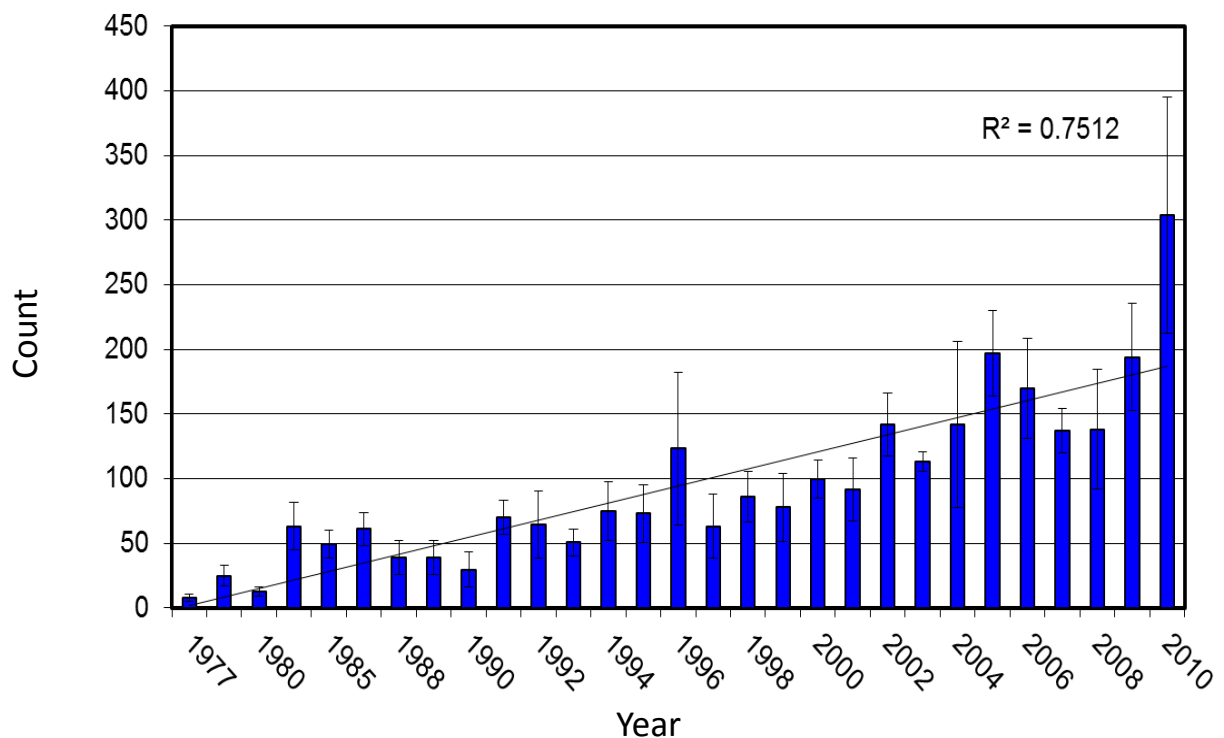


Figure 89. Results of 33 years of manatee monitoring in the waters of KSC. At the beginning of the active Space Shuttle Program manatee use of the area was very low. Numbers have increased throughout the program.

5.3.5 Impoundments

Beginning in the early 1980s and through the duration of the Space Shuttle Program, the SJRWMD, MINWR, and KSC refocused their efforts into restoring these impounded saltmarshes in an attempt to regain habitats for both fish and bird use. The impoundment method of mosquito control had been effective in reducing the mosquito populations but at the same time, radically altered the saltmarsh habitat. Hypersaline and hyposaline conditions eradicated saltmarsh vegetation and in places years of freshwater input through rainfall and runoff converted the saltmarsh habitat into freshwater marsh. Efforts to restore these marshes included installation of culverts and in some areas complete dike removal. An example of the restoration process success is shown in Figure 90, Figure 91, and Figure 92.



Figure 90. Impounded marsh (C21/36) that converted to freshwater and became a mono-specific cattail habitat with little value to wading birds or estuarine fish and invertebrates. Culverts were installed to reconnect the marsh to the lagoon.



Figure 91. Impounded marsh (C21/36) post re-connection to the estuary by a system of culverts. Freshwater cattail has been eliminated making room for natural saltmarsh vegetation and saltmarsh fauna.



Figure 92. Wading bird population aggregation foraging on small fish and invertebrates in saltmarsh habitat at KSC.

The initial restoration efforts focused on reconnecting impoundments using culverts placed in the dikes. This provided the flexibility to use the culverts to control water levels in the marshes if needed. The culverts had flap gates installed which allowed water to enter and exit the marsh, but could be closed if mosquito breeding increased. This method improved flushing of the marsh and allowed limited access for invertebrates and fish. It became evident that keeping these culverts open did not create the mosquito population that was expected. And it helped restore a more natural water quality condition in the marsh. However, this limited the fish and invertebrate access to the marsh to culvert locations only, still keeping access low.

Follow-on restoration efforts involved complete removal of the dikes that were constructed for mosquito control. This was accomplished by placing the fill material that had been dredged from the interior of the marsh, back into the perimeter ditch and leveling the dike areas down to existing marsh elevation. This allowed for natural inundation of the marsh improving natural recruitment of native saltmarsh vegetation, invertebrates, fish and wading bird populations.

5.3.6 Bald Eagles

Bald eagles (Figure 93) arrive each year on KSC in the fall, nest during the winter, and leave KSC in early spring after the young have fledged. Records of bald eagle nesting have been kept on KSC continuously since 1978 by MINWR and/or FFWCC. The numbers of nests have increased steadily over the years, in keeping with the general recovery of bald eagle populations in the U.S. since the banning of the pesticide DDT. In the KSC Institutional EIS of 1979 it was reported that there were 6 active nests (NASA, 1979). Between 1998 and 2009, the number of nests was 12, and the average number of known fledglings per year was 12. Eagle nest trees are protected from disturbance within zones of no activity or permitted-only activity. One nest located on KSC is very well known locally as it has been used almost continuously for at least 40 years. The nest measures 2.0 m (seven ft) in diameter and is three m (ten ft) deep. It is a regular stop for KSC tour buses, and has been equipped with video and still cameras during different time periods, providing an incredible up-close look at life in the nest (NASA, 2010).



Figure 93. Nesting bald eagle in a pine tree on KSC. The number of active nests has doubled since the KSC Institutional EIS was published in 1979.

5.4 Special Studies

Throughout the NEPA process, beginning with the first KSC Institutional EIS (NASA, 1991), and the Programmatic Space Shuttle EIS (NASA, 1972) it was apparent there was insufficient knowledge and information about the local environment to make sound and often complex judgments regarding shuttle effects. Through the mid-1970's, NASA initiated a series of studies to better define existing environmental conditions as well as the potential stressors that could be produced by the Space Shuttle Program with emphasis on the SRBs. The AIBS was contracted to review the quality and utility of this new knowledge, including observations of impacts from the first shuttle launches and to make recommendations about future KSC monitoring needs. AIBS identified the limited utility of these first studies that were primarily descriptive in nature and the need for KSC to have an institutional monitoring program that could continue to develop knowledge about processes in the local ecosystem so science based impact assessments could be carried out in the future (AIBS, 1982).

Results from monitoring the early shuttle launches (see [Section 4.0](#)) indicated that the areas with the greatest launch impacts were either not particularly important to listed species relative to other KSC lands or that the species using launch impact areas were present only during short periods and usually spent their time in the larger KSC landscape. Most species of regulatory concern were influenced more by KSC-wide land management activities, and especially fire.

5.4.1 Biodiversity and Protected Species

KSC hosts more federally endangered and threatened species than any other federal installation in the continental United States and provides core populations for many listed species because of its geographic context and variety of habitats (NASA, 2010). Regulatory lists of protected species are dynamic and species were being added to Endangered Species protection lists early in the Space Shuttle Program. Because of KSC's importance to global and regional wildlife biodiversity and the changing regulatory environment, a comprehensive review of all wildlife species was conducted to prioritize monitoring activities. Breininger et al. (1998) developed a ranking system for the importance of the federal lands to maintenance of species populations based on range, habitat, threat, and current population condition (Figure 94). In addition, many species not listed are still capable of being indicators of environmental quality because they are sensitive to change, or their habitat is rapidly declining. The Space Shuttle Program may have had both direct and indirect effects on some of these taxa in either a negative or positive fashion. The species below emphasize species, or guilds, of closely related species that had a high priority.

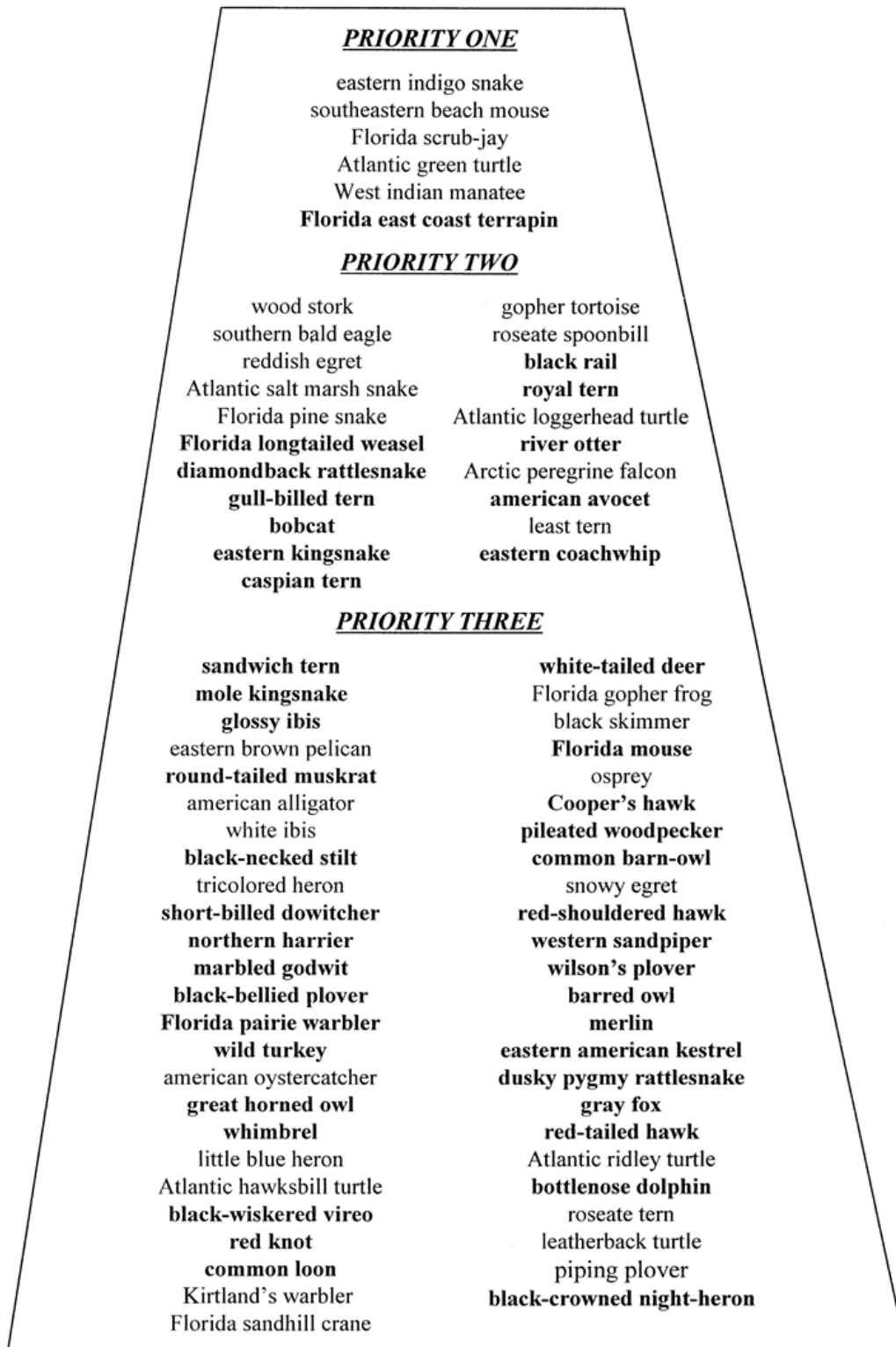


Figure 94. Ranking system for the importance of the KSC and surrounding federal lands to maintenance of species populations based on range, habitat, threat, and current population condition.

5.4.2 Vegetation and Land Management

As part of the Ecological Program, vegetation communities are monitored through both site specific study and remote sensing. Landcover maps are created periodically to identify community distributions and effects of construction and operations. Figure 95 is a KSC landcover map created from aerial photo interpretation and extensive groundtruthing. By updating these maps locations of community change and transitions can be identified. Table 13 summarizes the area of the different land cover classes in detail.

Table 13. Land cover types and areas at KSC.

Community	Land Cover Class	Hectares	Acres
upland	infrastructure - primary	564	1394
upland	infrastructure - secondary	255	630
	infrastructure	819	2024
upland	beach	122	301
	natural uplands devoid of vegetation	122	301
upland	ruderal - herbaceous	1498	3702
upland	citrus	748	1848
upland	ruderal - woody	598	1478
upland	Australian pine	45	111
	disturbed areas with exotic/invasive vegetation	2889	7139
upland	coastal strand	414	1023
upland	oak scrub	6105	15086
upland	palmetto scrub	1294	3198
upland	planted oak scrub	10	25
upland	pine flatwoods	1188	2936
	upland scrub and pine flatwoods	9011	22268
upland	upland coniferous forest	109	269
upland	upland coniferous / hardwood forest	848	2095
upland	upland hardwood forest	236	583
upland	cabbage palm	1093	2701
upland	hardwood hammock	3648	9014
upland	planted hardwoods	113	279
upland	planted pine	81	200
	upland forest	6128	15140
wetland	estuary	22399	55349
wetland	water - interior - salt	3103	7668
wetland	water - interior - fresh	381	941
wetland	barren land - may be inundated	103	255
wetland	ditch	151	373
wetland	marsh - saltwater	5260	12998
wetland	marsh - freshwater	2381	5884
wetland	mangrove	677	1673
wetland	wetland scrub-shrub - saltwater	735	1816
wetland	wetland scrub-shrub - freshwater	2158	5333
wetland	wetland coniferous / hardwood forest	632	1562
wetland	wetland hardwood forest	462	1142
	wetlands - estuary, marsh, shrub, forest	38442	94994
	TOTAL	57411	141866

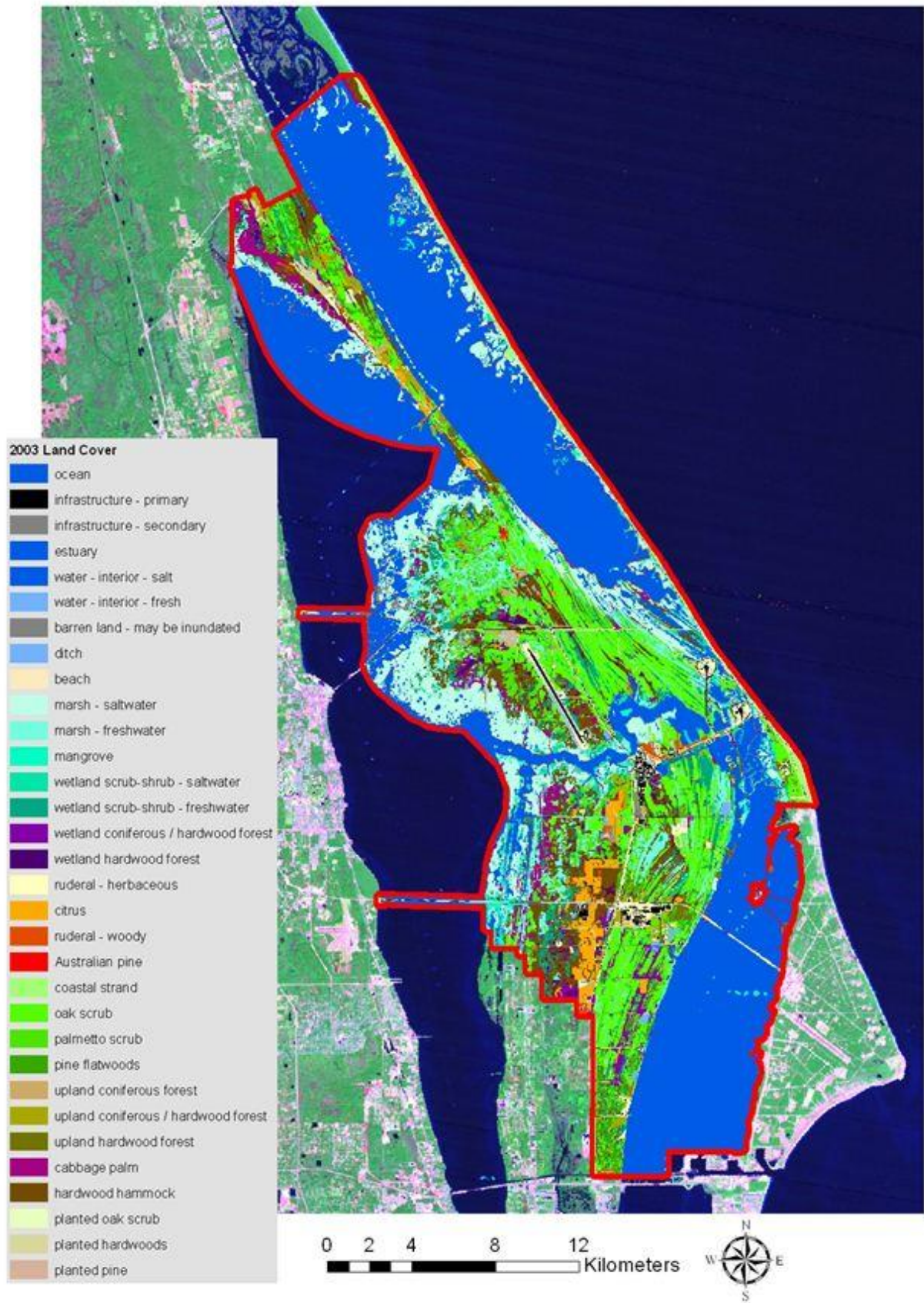


Figure 95. KSC landcover map showing the distribution of plant communities and facilities across the landscape.

A controlled burn program on KSC was initiated in the 1980s under an Interagency Agreement with MINWR. KSC was divided into fire management units allowing for safer and more controlled burns. The frequency and time since each unit was burned is shown in Figure 96 (Duncan et al., 2009). The history of fire management can be divided into three phases. The first phase lasted from 1963 to 1980 and was characterized by no comprehensive fire planning, very little prescribed fire, and very few wildfires. In 1981, the KSC/MINWR experienced a severe fire season. During this year, almost 17,000 acres (6880 ha) were burned in wildfires, and two refuge employees were killed. This started the next stage of fire management on the refuge that involved a concerted effort to upgrade the fire program. Extensive training of fire personnel was conducted, and new fire equipment was purchased. Prescribed burning objectives during this time were directed primarily towards the reduction of hazardous fuel loads. During the last phase, from the early 1990s to the present, efforts were made to change the emphasis of prescribed fire. Instead of a single objective, fuels management, using fire to modify and restore wildlife habitats became more important. This became especially important after the Florida Scrub-jay was listed by the USFWS Endangered Species Office as a Threatened species in 1985. Figure 95 summarizes the history of fire management on KSC.

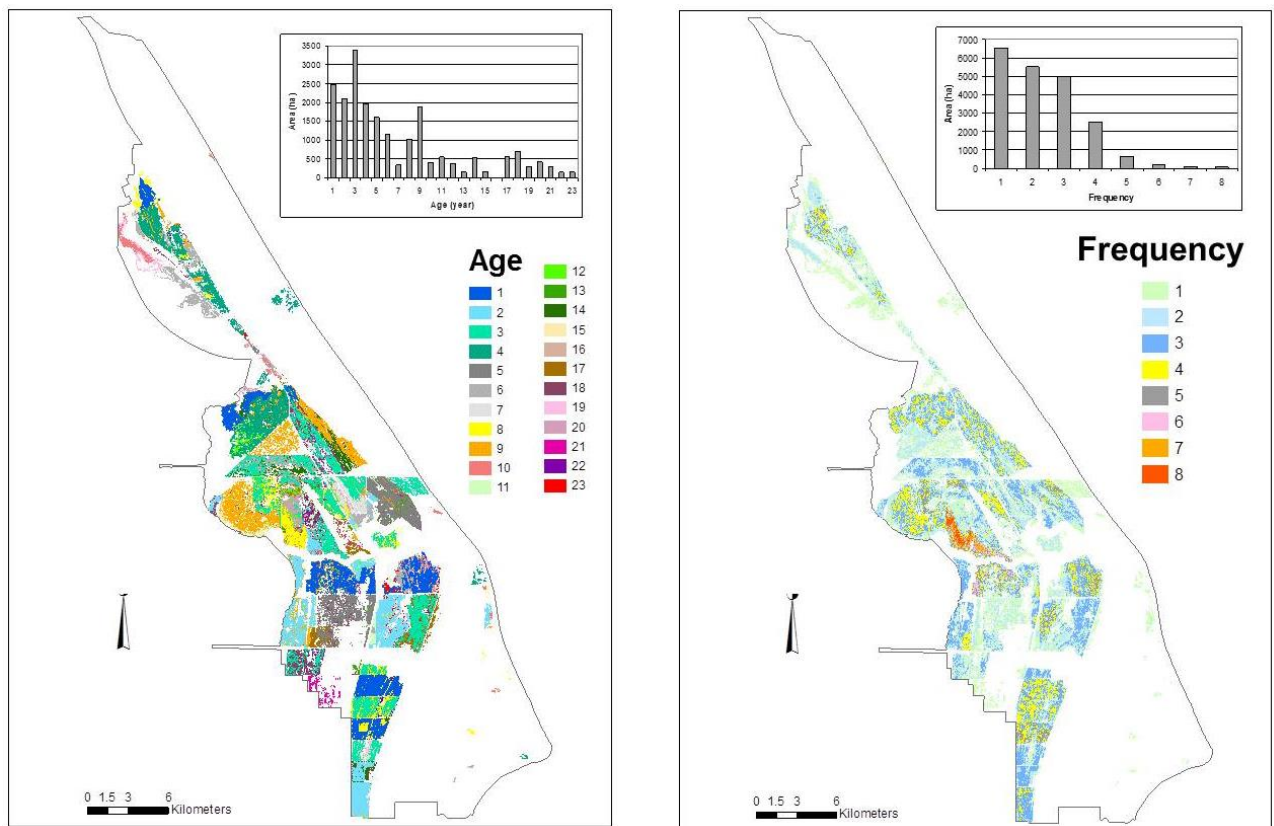


Figure 96. Fire history maps for fire management units on KSC.

Thirty-nine plant taxa occurring on KSC are listed as threatened, endangered, or of special concern on state lists (NASA, 2010). *Nemastylis floridana* and *Matelea gonocarpos* have been added due to recent work on Canaveral National Seashore. *Amyris balsamifera* has been deleted as it does not occur here. *Amyris elemifera* does occur but it is not a listed species. Taxa of special concern occur in all major habitats, but many are restricted to hammocks and hardwood swamps that constitute a minor proportion of the terrestrial vegetation. For some of these taxa (e.g., *Calamovilfa curtissii*), populations on KSC appear to be important for their regional and global survival. Spatial location data are available for some of these species; these are summarized in Figure 97.

Construction of the SSPF at KSC in 1991 resulted in the loss of 28 acres (11.3 ha) of Florida Scrub-jay habitat. Under the Biological Opinion issued by the Endangered Species Office of the USFWS, NASA was required to restore or create 56 acres (22.7 ha) of Scrub-jay habitat. Other proposed construction between 1992 and 1997 was expected to remove up to 137 (55.5 ha) additional acres of Scrub-jay habitat, which also required compensation. Expected impacts were incorporated into a Scrub-Jay Habitat Compensation Plan. The approach to compensation included a combination of restoration and creation techniques. Restoration involved mechanical cutting of scrub followed by prescribed burning. Creation involved planting of scrub species in abandoned citrus groves. Initially, scrub creation and restoration were performed at Happy Creek, Shiloh, Haulover Canal, and at areas adjacent to launch pads 39A and 39B.

5.4.3 Florida Scrub-Jay

The federal properties that include the KSC ecosystem provide for one of the three most important populations of the Florida Scrub-jay. The edge of the largest core KSC population occurs within two km of the LC-39 complex. This population declined substantially from degraded habitat quality caused by a reduced fire regime, which began in the 1950s (Duncan et al., 1999; Breininger and Carter, 2003; Breininger et al., 2002, 2009). Similar population declines are characteristic of statewide trends. However, the Happy Creek population appears to be stabilizing because of a collaborative effort in habitat restoration between MINWR and KSC (Figure 97). Generally, habitat quality across KSC is poor but improving though more extensive burning and mechanical cutting will be needed to meet recovery goals (Breininger et al., 2010).

Figure 98 shows an example of the KSC wide territory map of habitat quality and Figure 99 shows density data from the monitoring activities in Happy Creek. Monitoring studies of Florida Scrub-jay population responses to habitat quality and management at Happy Creek and throughout KSC (e.g., Breininger et al., 1995; Breininger and Oddy, 2004) have been used to develop statewide scrub management guidelines. These activities have also led to

Florida Scrub-jays serving as a national demonstration project for endangered species Adaptive Resource Management (Johnson et al., 2011). Funding by USFWS, FFWCC, and others was provided to monitor and recommend recovery actions for Florida Scrub-jays along the adjacent mainland. These studies contributed to a better understanding about how Florida Scrub-jays respond to a broader range of habitat quality and habitat management (Breininger et al., 2006). Implementation of recommended actions could lead to conservation of an east central Florida population additional to the one found on KSC.

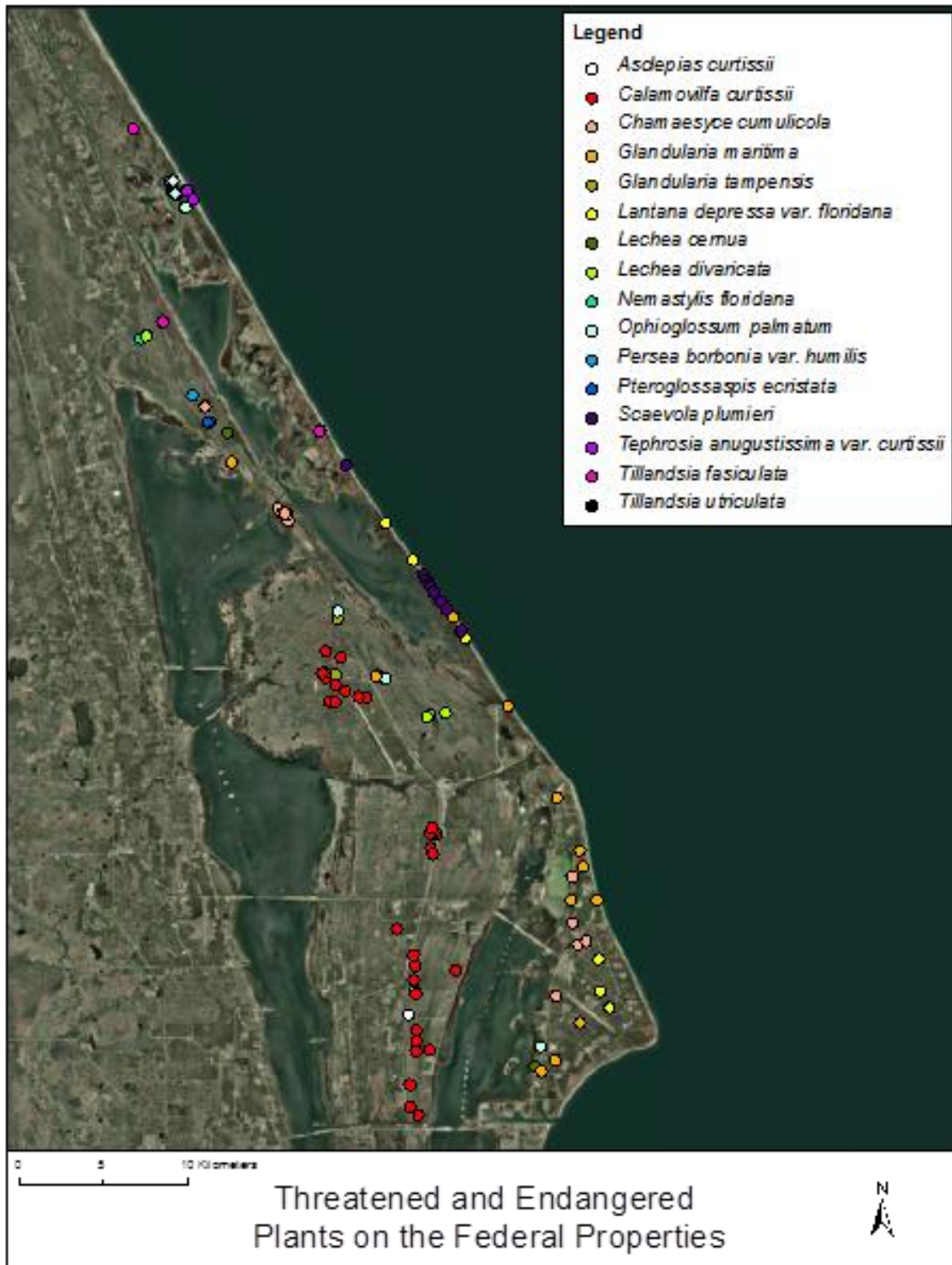


Figure 97. Known locations and list of threatened and endangered plants on the federal properties. Sixteen taxa are known to occur on KSC.

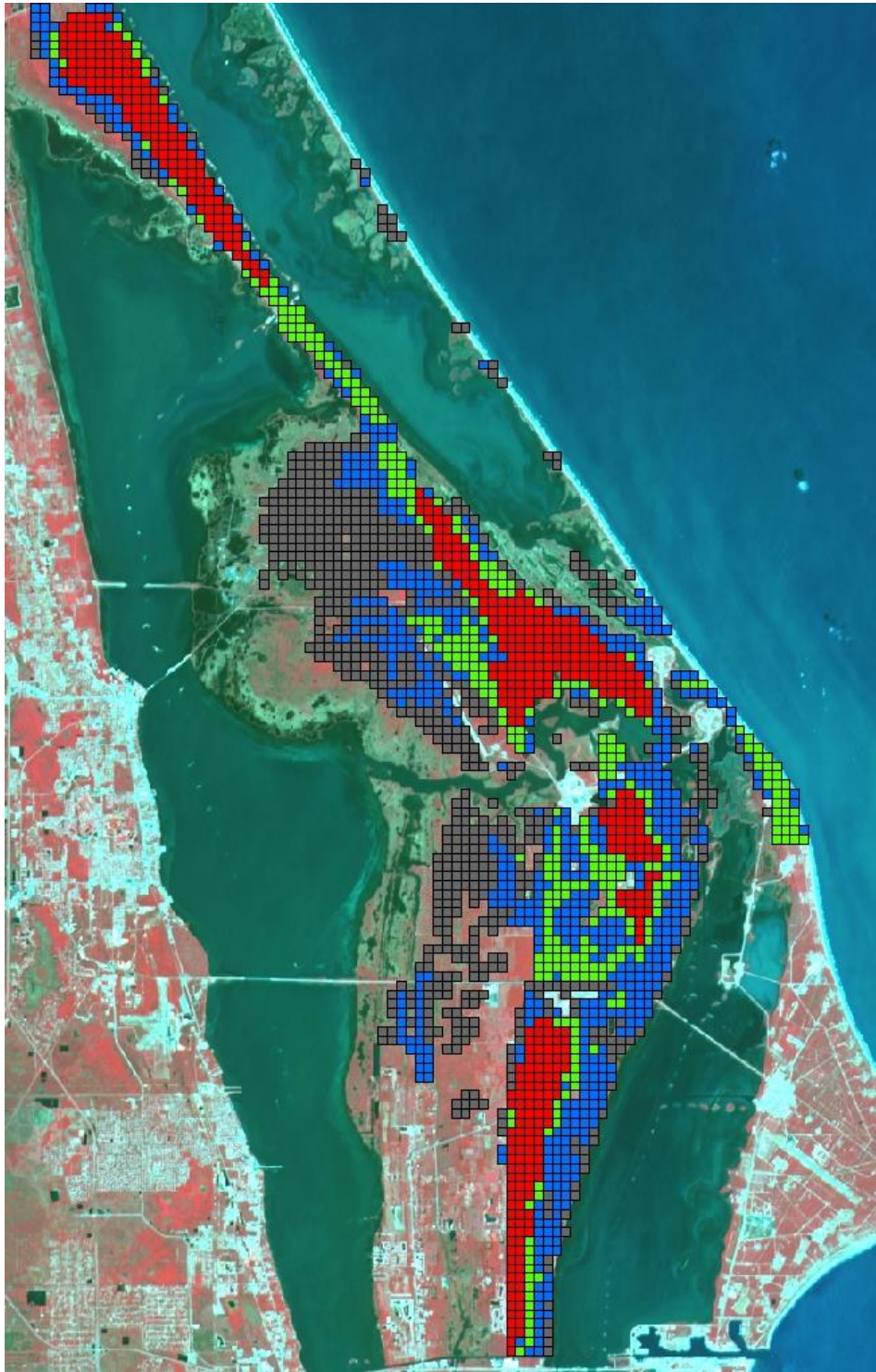


Figure 98. Distribution of potential Florida Scrub-jay territories across the KSC landscape.

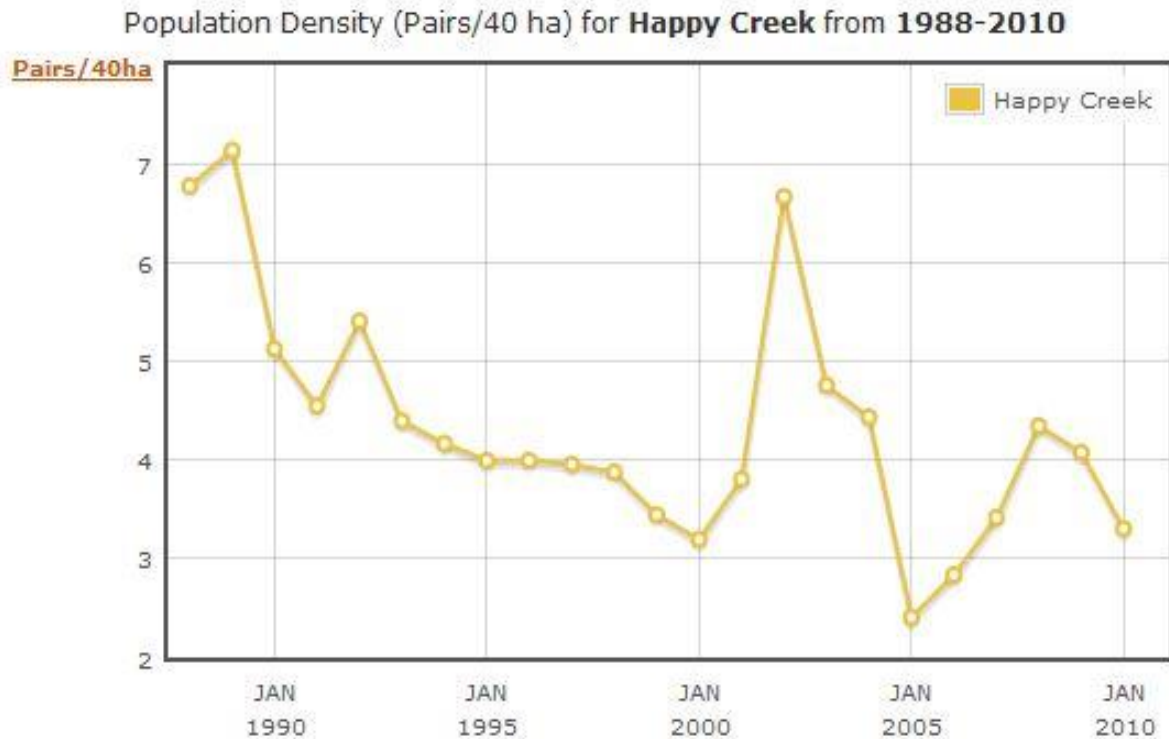


Figure 99. Florida Scrub-jay population density for the periods between 1988 and 2010 at Happy Creek on KSC.

5.4.4 Southeastern Beach Mouse

The federal properties that include KSC provide the only core population of the southeastern beach mouse (Figure 100), which has become extirpated in most areas of its historic range. Recent studies indicate that the species occurs along the entire coastline of the federal properties and scrub inland from the beach (Figure 101). The coastal dune habitat is narrowing adjacent to shuttle pads and there is little scrub. Studies there indicated spatial variation in their numbers without clear trends and that differences could not be attributed directly to launch deposition, nor habitat quality (Oddy et al., 2010). Better habitat in the vicinity of LC39 begins south of the shuttle pads and extends southward. Long-term studies of beach mice in these areas suggest that the population numbers fluctuate widely. Studies on CCAFS, which has more habitat than KSC, suggest that habitat management for Florida Scrub-jays benefits the southeastern beach mouse.



Figure 100. The southeastern beach mouse is listed as threatened by the USFWS. KSC and the associated federal properties provide habitat to the largest remaining population on the east coast.

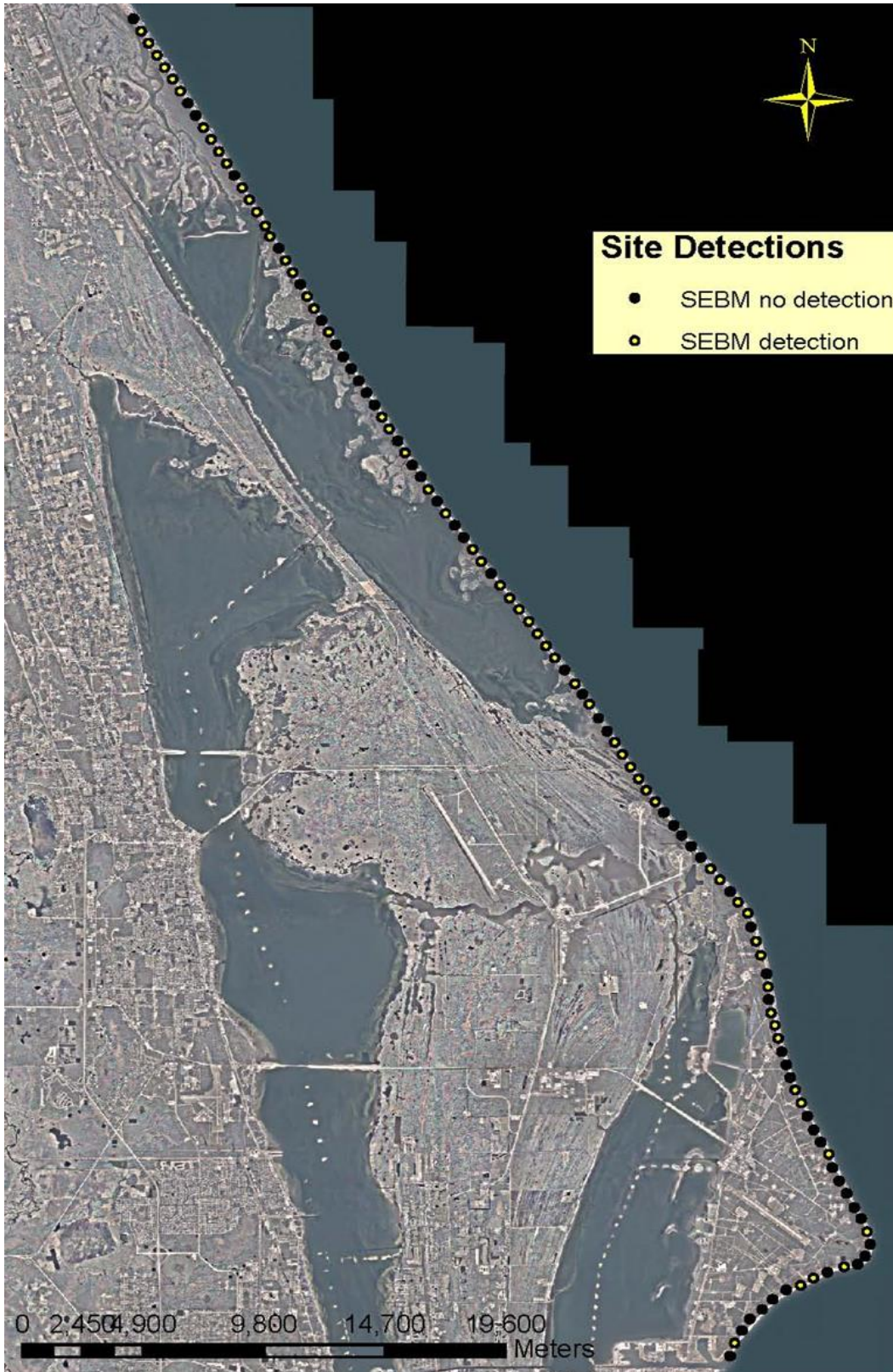


Figure 101. Results of southeastern beach mouse habitat occupancy sampling along the entire federal property. This work will be repeated annually to build knowledge on habitat association for development of land management practices.

5.5 Summary

From a holistic perspective, the Space Shuttle Program occurred during the period of global environmental awareness and stewardship. Implementation of the numerous state and federal environmental laws, regulations and executive orders that were promulgated between 1960 and the end of the Space Shuttle Program had significant positive effects on the KSC environment even though regional development and populations continued to grow at a rapid pace throughout the 40 year period outside the KSC boundary. In some cases regulatory implementation has proved highly successful while in other areas the regulations have had minimal influence to date. For example, regional populations of species protected by the Endangered Species Act at KSC such as alligators, manatees, bald eagles, and brown pelicans have expanded, while Florida Scrub-jay populations remain depressed below carrying capacity due to the complexity of their fire maintained habitat requirements, degrees of habitat fragmentation, and alterations, and difficulty in restoration using fire and other mechanical measures.

Regional air quality has improved as a result of stricter emission standards for automobiles and power plants but water quality degradation through eutrophication has continued to a point where in 2011 and 2012 algae blooms were so dense and long lived in the IRL that in some areas of KSC seagrass beds were completely eliminated due to the lack of light penetration and possibly grazing by the increasing seasonal manatee population. KSC has an active and successful Remediation Program that continues to clean soils and groundwater contamination created during the previous NASA programs and the early phase of the Shuttle Program. Initiation of a sustainability program during the Space Shuttle Program reduced the acquisition of energy inefficient and environmentally unfriendly products in favor of those that could be recycled or were made from recycled materials.

Continued development beyond the KSC boundary has placed increased importance on land management practices to sustain and improve habitat for protected species. Bald eagle nesting sites doubled between 1978 and 2011 as a result of the ban on DDT and the management activities of the MINWR. Manatees utilizing the lagoons around KSC went from counts of less than 50 in 1978 to more than 500 in 2011. In the early 1980s a prescribed fire program was initiated to reduce fuel loads to minimize wildfire potential. During the following decades the program transitioned to a habitat management focus with a goal of enhancing habitat quality for the Florida Scrub-jay and other associated species such as the southeastern beach mouse, indigo snake, and gopher tortoise.

In summary, the 30 year Space Shuttle Program at KSC has contributed directly and indirectly to both negative and positive ecological trends in the region through the long-term, stable expenditure of resources. These expenditures provided support to continued regional growth and development in conjunction with other sources that altered land use patterns,

eliminated and modified habitats, and contributed to cultural eutrophication in the IRL. At KSC the majority of shuttle related actions were conducted in previously developed facilities and industrial areas with the exception of the SLF and SSPF. Launch and operations impacts were minimal with local environments assimilating the acid deposition and no long-term acute impacts of metals were documented as a result of the low launch rate. Evaluations of possible sub-lethal concerns are ongoing.

Major positive Space Shuttle Program effects were derived from the adequate resources to implement the numerous environmental laws and regulations designed to enhance the quality of the environment and minimize impacts from human activities such as discharges of domestic and industrial wastewater, creation of stormwater management systems, remediation of past contamination sites, implementation of hazardous waste management systems, and creation of a culture of sustainability. Working with partners such as the USFWS and MINWR and the SJRWMD, wetlands and scrub restoration and management initiatives were implemented to enhance fish and wildlife populations at KSC.

KSC environmental managers recognized, through the early NEPA activities associated with shuttle and KSC EIS development, that science based ecological information was critical to the assessment of impacts and management of local natural resources. The simple lists of soil and water quality characteristics and species present on the landscape found in NEPA documents prepared in the 1970s were not adequate to address complex questions. In 1982, following the recommendations of AIBS and the USFWS, KSC established an in house capability for development of monitoring and management data and information. Since that time the KSC Ecological Program has strived to work with university, government and industry partners to develop cost effective scientific information related to ecosystem management questions for current and future issues facing KSC. [Appendix B](#) provides a list of scientific publications developed by the Ecological Program and [Appendix C](#) lists examples of research partners and significant ongoing and past program achievements.

Ongoing projects are “question driven”, being directed at development of information needs to address future KSC management requirements. This will include:

- the transition to a joint government and commercial launch facility,
- enhanced natural resource habitat management requirements for wetlands and scrub,
- assess potential impacts of emerging contaminants, and
- adaptation to climate change including sea level rise over the next 50-75 years.

Transition of KSC to a joint government and commercial site will require careful planning that utilizes the best available information to meet the multi-objective resource management needs supporting the coexistence of new launch and processing facilities with natural resources. New and improved habitat management approaches will be required to

accommodate the needs of the commercial space industry while ensuring the continued protection, preservation and enhancement of resources. Continued encroachment and new launch systems and fuels will require monitoring to ensure emerging contaminants are not impacting wildlife or human health. Information, knowledge and long range planning will be required to support climate change adaptation strategy development by KSC and potential customers.

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Appendix A: Space Shuttle Launch Information

List of Space Shuttle launch information including mission name, launch pad, date, and orbiter. Summary information is provided at the end of the table.

Launch	Name	Pad	Date	Orbiter
1	STS1	39A	4/12/81	Columbia
2	STS2	39A	11/12/81	Columbia
3	STS3	39A	3/22/82	Columbia
4	STS4	39A	6/27/82	Columbia
5	STS5	39A	11/11/82	Columbia
6	STS6	39A	4/4/83	Challenger
7	STS7	39A	6/18/83	Challenger
8	STS8	39A	8/30/83	Challenger
9	STS9	39A	11/28/83	Columbia
10	STS11	39A	2/3/84	Challenger
11	STS13	39A	4/6/84	Challenger
12	STS14	39A	8/30/84	Discovery
13	STS17	39A	10/5/84	Challenger
14	STS19	39A	11/8/84	Discovery
15	STS20	39A	1/24/85	Discovery
16	STS51d	39A	4/12/85	Discovery
17	STS51b	39A	4/29/85	Challenger
18	STS51g	39A	6/17/85	Discovery
19	STS51f	39A	7/29/85	Challenger
20	STS51i	39A	8/27/85	Discovery
21	STS51j	39A	10/3/85	Atlantis
22	STS61a	39A	10/30/85	Challenger
23	STS61b	39A	11/26/85	Atlantis
24	STS61c	39A	1/12/86	Columbia
25	STS51l	39B	1/28/86	Challenger
26	STS26	39B	9/29/88	Discovery
27	STS27	39B	12/2/88	Atlantis
28	STS29r	39B	3/13/89	Discovery
29	STS30r	39B	5/4/89	Atlantis
30	STS28	39B	8/8/89	Columbia
31	STS34	39B	10/18/89	Atlantis
32	STS33	39B	11/22/89	Discovery
33	STS32	39A	1/9/90	Columbia
34	STS36	39A	2/28/90	Atlantis
35	STS31	39B	4/24/90	Discovery
36	STS41	39B	10/6/90	Discovery
37	STS38	39A	11/15/90	Atlantis
38	STS35	39B	12/2/90	Columbia
39	STS37	39B	4/5/91	Atlantis
40	STS39	39A	4/28/91	Discovery
41	STS40	39B	6/5/91	Columbia
42	STS43	39A	8/2/91	Atlantis
43	STS48	39A	9/12/91	Discovery
44	STS44	39A	11/24/91	Atlantis
45	STS42	39A	1/22/92	Discovery
46	STS45	39A	3/24/92	Atlantis
47	STS49	39B	5/7/92	Endeavor
48	STS50	39A	6/25/92	Columbia
49	STS46	39B	7/31/92	Atlantis
50	STS47	39B	9/12/92	Endeavor
51	STS52	39B	10/22/92	Columbia
52	STS53	39A	12/2/92	Discovery
53	STS54	39B	1/13/93	Endeavor

Launch	Name	Pad	Date	Orbiter
54	STS56	39B	4/8/93	Discovery
55	STS55	39A	4/26/93	Columbia
56	STS57	39B	6/21/93	Endeavor
57	STS51	39B	9/12/93	Discovery
58	STS58	39B	10/18/93	Columbia
59	STS61	39B	12/2/93	Endeavor
60	STS60	39A	2/3/94	Discovery
61	STS62	39B	3/4/94	Columbia
62	STS59	39A	4/9/94	Endeavor
63	STS65	39A	7/8/94	Columbia
64	STS64	39B	9/9/94	Discovery
65	STS68	39A	9/30/94	Endeavor
66	STS66	39B	11/3/94	Atlantis
67	STS63	39B	2/3/95	Discovery
68	STS67	39A	3/2/95	Endeavor
69	STS71	39A	6/27/95	Atlantis
70	STS70	39B	7/13/95	Discovery
71	STS69	39A	9/7/95	Endeavor
72	STS73	39B	10/20/95	Columbia
73	STS74	39A	11/12/95	Atlantis
74	STS72	39B	1/11/96	Endeavor
75	STS75	39B	2/22/96	Columbia
76	STS76	39B	3/22/96	Atlantis
77	STS77	39B	5/19/96	Endeavor
78	STS78	39B	6/20/96	Columbia
79	STS79	39A	9/16/96	Atlantis
80	STS80	39B	11/19/96	Columbia
81	STS81	39B	1/12/97	Atlantis
82	STS82	39A	2/11/97	Discovery
83	STS83	39A	4/4/97	Columbia
84	STS84	39A	5/15/97	Atlantis
85	STS94	39A	7/1/97	Columbia
86	STS85	39A	8/7/97	Discovery
87	STS86	39A	9/25/97	Atlantis
88	STS87	39B	11/19/97	Columbia
89	STS89	39A	1/22/98	Endeavor
90	STS90	39B	4/17/98	Columbia
91	STS91	39A	6/2/98	Discovery
92	STS95	39B	10/29/98	Discovery
93	STS88	39A	12/4/98	Endeavor
94	STS96	39B	5/27/99	Discovery
95	STS93	39B	7/23/99	Columbia
96	STS103	39B	12/19/99	Discovery
97	STS99	39A	2/11/00	Endeavor
98	STS101	39A	5/19/00	Atlantis
99	STS106	39B	9/8/00	Atlantis
100	STS92	39A	10/11/00	Discovery
101	STS97	39B	11/30/00	Endeavor
102	STS98	39A	2/7/01	Atlantis
103	STS102	39B	3/8/01	Discovery
104	STS100	39A	4/19/01	Endeavor
105	STS104	39B	7/12/01	Atlantis
106	STS105	39A	8/10/01	Atlantis
107	STS108	39B	12/5/01	Endeavor
108	STS109	39A	3/1/02	Columbia
109	STS110	39B	4/8/02	Atlantis
110	STS111	39A	6/5/02	Endeavor

Launch	Name	Pad	Date	Orbiter
111	STS112	39B	10/7/02	Atlantis
112	STS113	39A	11/23/02	Endeavor
113	STS107	39A	1/16/03	Columbia
114	STS114	39B	7/26/05	Discovery
115	STS121	39B	7/4/06	Discovery
116	STS115	39B	9/9/06	Atlantis
117	STS116	39B	12/9/06	Discovery
118	STS117	39A	6/9/07	Atlantis
119	STS118	39A	8/8/07	Endeavor
120	STS120	39A	10/23/07	Discovery
121	STS122	39A	2/7/08	Atlantis
122	STS123	39A	3/11/08	Endeavour
123	STS124	39A	5/31/08	Discovery
124	STS126	39A	11/14/08	Endeavour
125	STS119	39A	3/15/09	Discovery
126	STS125	39A	5/11/09	Atlantis
127	STS127	39A	7/15/09	Endeavour
128	STS128	39A	8/28/09	Discovery
129	STS129	39A	9/16/09	Atlantis
130	STS130	39A	2/8/10	Endeavour
131	STS131	39A	4/5/10	Discovery
132	STS132	39A	5/14/10	Atlantis
133	STS133	39A	2/24/11	Discovery
134	STS134	39A	5/16/11	Endeavour
135	STS135	39A	7/8/11	Atlantis

Summary:

- **Launches from each pad**
 - 82 Launches from Pad 39A
 - 53 Launches from Pad 39B
- **Far-field deposition information**
 - **No deposition identified**
 - STS9 Pad 39A
 - STS51G Pad 39A
 - STS40 Pad 39B
 - **Cloud traveled out to sea**
 - Pad 39A-26 launches far-field out to sea (33%)
 - Pad 39B-14 launches far-field out to sea (27%)

Appendix B: List of Ecological Program Publications

List of publications developed by the KSC Environmental Management Branch Ecological Program and partners as part of direct Shuttle launch monitoring and long-term KSC wide monitoring activities.

- Boggs, A.S.P., R.H. Lowers, J.A. Cloy-McCoy, L.J. Guillette Jr. 2013. Organizational Changes to Thyroid Regulation in *Alligator mississippiensis*: Evidence for Predictive Adaptive Responses. Plos One 8, 1-9.
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- Boggs, A.S.P., H.J. Hamlin, R.H. Lowers, L.J. Guillette Jr. 2011. Seasonal variation in plasma thyroid hormone concentrations in coastal versus inland populations of juvenile American alligators (*Alligator mississippiensis*): Influence of plasma iodide concentrations. *General and Comparative Endocrinology* 174 362-369.
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**Appendix C: Examples of KSC Ecological Program Partnerships,
Areas of Activity, and Education Outreach Support**

Examples of research and natural resource management organizations having recent and ongoing interaction with the activities and staff of the KSC Ecological Program.

<i>Agency /Organization</i>	<i>Activity Area</i>
Stennis, Goddard, GISS, JPL, Langley	Remote Sensing, global change research, fire emissions, hyperspectral applications, sensor web
Environmental Protection Agency	Remediation, wetlands dynamics, water quality
U.S. Fish and Wildlife Service	Protected species, fire ecology, wetlands ecology
National Park Service	Water quality, wildlife biology, protected species,
U.S. Forest Service	Fire modeling, fuels characterization,
Los Alamos National Laboratory (DOE)	Fire modeling, catastrophic launch event modeling
NOAA/National Marine Fisheries Service	Protected species, acoustic monitoring, UAV technology
U.S. Geological Service	Marsh creation, hydrology, manatees, wading birds, scrub habitat management, Adaptive Resource Management, coastal dune vulnerability
Smithsonian Environmental Research Center	Global change, CO ₂ research in scrub, eddy flux network, food webs
U.S. Air Force (CCAFS, Avon Park, Vandenberg)	Protected species, launch effects, REEDM, habitat management, population monitoring
St. Johns and South Florida Water Management Districts	Seagrass monitoring, water quality, database design, GIS, remote sensing
Florida Department of Environmental Protection	Remediation projects, air permitting, protected species, water quality, TMDL
Brevard and Volusia Counties	Water quality, wildlife habitat and vegetation mapping, seagrass mapping
Hubbs Sea World	Marine mammals, sea turtles, and strandings
University of Puerto Rico	Remote sensing applications, coastal ecology, fisheries, education outreach
Universities of Florida and Central Florida	Wildlife biology, landscape mapping, remote sensing, GIS, NADP, eddy flux, sea level rise and surficial aquifer modeling.
Florida Institute of Technology	Remote sensing, geophysical modeling, fisheries science, vegetation ecology, wildlife biology, conservation genetics
Purdue University	GIS applications, spatial modeling, hydrology, REEDM and GIS applications
University of Texas	LIDAR analyses, GPS surveys, remote sensing

Agency /Organization	Activity Area
	data analyses
University of Virginia	Wetlands research, water quality, sediment chemistry, microbial community dynamics
Applied Biomathematics (SUNY)	Population viability models, risk models
University of California Santa Barbara, Point Reyes Bird Observatory	GIS and spatial modeling, protected species at Vandenberg
Texas A&M University	Manatee ecology, marine mammals
University of Tennessee	Ecology, microbial ecology
Archbold Biological Station	Scrub ecology, Scrub Jay biology, fire management
New Lisbon University Portugal	Oracle database tools, GIS, spatial models
Villanova University	Mangroves and climate change
Medical University of South Carolina	Alligators as a sentinel species, emerging contaminants, endocrine disruptors
University of Southern Maine	Metals in the environment, genotoxicity
University of Central Florida	Advanced circulation modeling, storm surge, sea level rise, surface water groundwater modeling

Examples of Significant Achievements

The following is a summary of some major projects and achievements conducted as part of the KSC Ecological Program over the last 30 years. Examples of the extensive education outreach activities of the program are shown in the number of M.S. and Ph.D. degrees that have been supported. Education outreach activities have included involvement with the Space Life Sciences Training Program, the Graduate Student Research Program, Summer High School Apprentice Research Program, Summer Industrial Fellowships for Teacher, and many others. In addition to these activities we have maintained numerous long-term monitoring projects associated with KSC ecosystems and protected species. All data are housed in our Oracle database. If you have access inside the KSC firewall you can visit our web page at <http://KLTEP.ksc.nasa.gov>

Ongoing projects

Fire Action Team – The Ecological program has initiated a Fire Action Team consisting of members from the USFWS, USAF, NPS, County, and State to address problems associated with controlled burning, fuels reduction and the severe need for improved habitat conditions associated with the multi-objective (wildlife, urbanization, launch, agriculture, recreation) management needs of regional ecosystems. Fire history data, lightning frequency data, and

simulation models indicate a need to consider changing the current practices of fuels management to more closely mimic natural fire regimes of the past. This could produce a mosaic of habitat conditions on the landscape while reducing the risk of large and extensive wildfires.

KSC Climate Change Adaptation Science Investigation - This project is being conducted in conjunction with the Goddard Institute for Space Studies and Columbia University with NASA Earth Sciences and NASA Office of Strategic Infrastructure funding. The objective is to examine the risks to KSC, and assured access to space, associated with downscaled estimates of sea level rise and changing climate projected by GISS for the next 80 years. Areas of assessment include facilities, infrastructure, roads, launch pads, workforce and natural resources with emphasis on endangered species habitats.

KSC and Merritt Island National Wildlife Refuge Scrub Jay Adaptive Resource Management (ARM) Demonstration - KSC was selected as one of three sites nationwide for a demonstration project emphasizing the USGS Adaptive Resource Management approach for land management. KSC was selected based on the rich 30 year history of data and research on the Florida scrub jay and its habitat requirements that are fire dependent. This is a joint project with the KSC Ecological Program, USFWS at Merritt Island and USGS from the University of Florida and the Patuxent Wildlife Research Center.

Regional Southeastern Beach Mouse Habitat Occupancy Investigation – The federally protected southeastern beach mouse has been identified as a top priority for management by the USFWS and KSC. This project is being conducted to develop quantitative information on the habitat requirements and management strategies needed to ensure population sustainability in light of projected land development and future sea level rise projections. This is a joint multi-year project with the KSC Ecological Program, USFWS, USAF at CCAFS, and the NPS at CNS.

Florida Atlantic Coast Telemetry Array – The Ecological Program, in conjunction with the State of Florida, regional universities and the Naval Undersea Warfare Center has established the Florida East Coast (FACT) array of VEMCO underwater telemetry stations for tracking the movement of tagged fish, sharks, and sea turtles. This multi-year project is operated as part of a larger US east coast network that extends from the Bahamas to New York. The array is providing never before known information on the multi-year movement patterns of species across the entire range of the network. The KSC secure area fisheries reserve has been shown to support spawning activities of redfish as far south as Sebastian Inlet. A Sturgeon tagged in New York has been observed adjacent to the KSC beach.

Ecotoxicology and Population Dynamics of the American Alligator – This project, being conducted with the Medical University of South Carolina, the Hollings Marine Laboratory and the National Institute of Basic Biology in Japan is investigating the effects of emerging contaminants such as BPA, pharmaceuticals, and other endocrine disruptors on the endocrine system and gene expression in the American Alligator and other crocodylians around the world. This international project is utilizing alligators as a sentinel for both ecological and human effects assessment of these modern contaminants at KSC and across Florida.

KSC Beach Erosion and Dune Vulnerability Assessment Team - The KSC Environmental Management Branch has created a Dune Vulnerability Team (DVT) consisting of members from the KSC Ecological Program, USFWS, USGS, and University of Florida, to address issues associated with beach and dune erosion in the vicinity of launch Pads 39A and 39B. Over the last thirty years extensive beach erosion has reduced the capacity of the existing dune system

to absorb storm surges from northeasters and tropical storms, greatly increasing risk to the NASA launch pads, roads, facilities and infrastructure in that area. Overwash of dunes is becoming common and damage to protected species habitat is expanding. The DVT is investigating the cause of the high erosion rate in the area by assessing the topography, bathymetry, sediment characteristics, and wave energy fields. Data and information developed by the program are being incorporated into beach nourishment permit applications, NEPA documentation, and engineering designs for potential future use.

Past Projects

Baseline Chemical Characterization of KSC - The KSC Remediation Program Office funded a study to develop background information on chemical concentrations of nutrients, metals, pesticides, herbicides, solvents, and other potential contaminants. These data are used in the assessment.

Elevated CO₂ effects on upland scrub communities - The Department of Energy funded a 10 year study through the Smithsonian Environmental Research Center to assess the effects of elevated atmospheric CO₂ on terrestrial plant communities at KSC. The project was supported by the Ecological Program and University researchers from the US, Australia and Europe.

Assessment of Impounded Wetlands Management Practices - This EPA funded multi-year project investigated the ecological effects of different wetland management strategies on biogeochemical cycles, fisheries, and water fowl productions. Partners included the USGS, USFWS, University of Virginia, and SJRWMD.

Long-term Land Use Changes in the Indian River Lagoon Watershed (1920-1990) - The Ecological Program staff developed a series of maps that depicted land use in the 1920s, 1940s, and 1990s for the purpose of assessing influences of storm water runoff on the Indian River Lagoon. Maps were based on soils and vegetations models, and interpretation of historic aerial imagery.

Environmental Effects of Rocket Launches - The Ecological Program is recognized worldwide as having expertise on the environmental impacts of rocket launch activities. Assessments have included the Space Shuttle, Titan, Atlas and Delta vehicles.

Baseline Characterization of Fisheries Resources in Port Canaveral - This USAF funded project was the first comprehensive fisheries resource survey of Port Canaveral, Florida. The manmade habitats support a diverse fish community that resembles an off shore reef.

Scrub Fire Ecology and Restoration - This activity's focus was on the effects of mechanical treatment and controlled burning on the ecology of scrub ecosystems in east central Florida. Emphasis was placed on vegetation responses to different management techniques and response to repeated fire through a 30 year period.

Scrub Jay Demography and Habitat Utilization - More than thirty years of information has been collected at KSC relevant to the demography and habitat use and suitability for the federally protected Florida Scrub-jay.

Education Outreach

List of graduate students, thesis, and dissertations supported by NEPA information collection activities and the Ecological Program at KSC during the 40 year Space Shuttle Program.

Year	Author(s)	Thesis Level	Topic	Title
<i>In Progress</i>	Foster, T.	Ph.D. Dissertation- University of South Florida, Tampa, FL	Plant Physiology	Not Available
	Holloway-Adkins, K.	Ph.D. Dissertation- Florida Atlantic University, Ft. Lauderdale, FL	Sea Turtles	The Impact Of Herbivorous Fishes And Juvenile Green Turtles (<i>Chelonia mydas</i>) On The Macroalgal Community*
	Kozusko, T	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Science Education	Not Available
	Nifong, J.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Alligator Food Habits	Not Available
2012	MacKenzie, R.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Beach Geomorphology	Shoreline Uncertainties on a Sandy Coast: Cape Canaveral, Florida
	Garreau, C.M.	M.S. Thesis - University of Florida, Gainesville, FL	Fisheries health	Development Of Methods For Non-Lethal Health Assessment Of The Red Drum (<i>Sciaenops ocellatus</i>) Inside NASA's Kennedy Space Center No-take Fisheries Reserve*

Year	Author(s)	Thesis Level	Topic	Title
	Munoz, A.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Snakes, predation	Behavioral analysis of yellow ratsnake (<i>Elaphe obsoleta quadrivittata</i>), a predator of the threatened Florida scrub-jay (<i>Aphelocoma coerulescens</i>) in the Kennedy Space Center's Merritt Island National Wildlife Refuge
	Weiler-Lazarz, A. M	M.S. Thesis - University of Central Florida, Orlando, FL	Scrub recovery in agriculture lands	Factors limiting native species establishment on former agricultural lands
2011	Boggs, A.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Alligator Thyroid Profiles	Influences Of Estuarine Environments And Endocrine Disrupting Chemicals On The Thyroid System Of The American Alligator (<i>Alligator mississippiensis</i>)*
	Schroeder, R.	Ph.D. Dissertation- Old Dominion University, Norfolk, VA	Roots; Elevated CO ₂	Effects of 11 years of CO ₂ enrichment on root biomass and spatial distribution in a Florida scrub-oak ecosystem
2010	Gianelli	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Snook	Life History And Ecology Of The Smallscale Fat Snook, <i>Centropomus parallelus</i> (<i>Centropomidae</i>) In East Central Florida, And Methodology To Identify The Regional Snook Species*
2009	Breiningger, D.	Ph.D. Dissertation- University of Central Florida, Orlando, FL	Scrub Jay	Landcover Change And Population Dynamaics Of Florida Scrub-Jays And Florida Grasshopper Sparrows*
-	Duncan, B.W.	Ph.D. Dissertation- University of Central Florida, Orlando, FL 171p	Fire Regime	Native Fire Regime As A Reference For Establishing Management Practices

Year	Author(s)	Thesis Level	Topic	Title
-	Mota, M.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Sea Turtles	Beach Restoration In Florida: Effects On Sea Turtle Nesting And Hatchling Physiology*
2008	Jones, L.	M.S. Thesis - University of Central Florida, Orlando, FL	Scrub CO ₂	Modeling Canopy Photosynthesis Of A Scrub-Oak Ecosystem Under Elevated CO ₂
2007	Barber, A.L.	M.S. Thesis - University of Central Florida, Orlando, FL	Oyster Reefs	Restoration Of Intertidal Oyster Reefs Affected By Intense Recreational Boating Activity In Mosquito Lagoon, Florida*
-	Crabill, T.	M.S. Thesis - Towson University, Towson, MD	Salamanders	Are Roadside Ditches Viable Wetland Habitats For Aquatic Salamanders?*
-	Hall, C.	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Radiative Transfer Modeling	Parameterization And Sensitivity Analyses Of A Radiative Transfer Model For Remote Sensing Plant Canopies
-	Hamlin, H.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Alligator Hormone Profiles	Nitrate As An Endocrine Disrupting Contaminant In Captive Siberian Sturgeon, <i>Acipenser baeri</i>
-	Krumins, J.A.	Ph.D. Dissertation- Rutgers, The State University Of New Jersey, New Brunswick, NJ	Soil Microbes Biodiversity	The Causes And Consequences Of Biodiversity In Multitrophic Communities*
-	Stover, D.	Ph.D. Dissertation- Old Dominion University, Norfolk, VA	Roots; Elevated CO ₂	Effects Of Elevated CO ₂ On Fine Root Dynamics In A Florida Scrub Oak Ecosystem*
2006	Page, A.	Ph.D. Dissertation- Old Dominion University, Norfolk, VA	Roots; Elevated CO ₂	Effects Of Elevated CO ₂ On Belowground Carbon Sequestration In A Florida Scrub Oak Ecosystem*

Year	Author(s)	Thesis Level	Topic	Title
-	Stiner, J.L.	M.S. Thesis - University of Central Florida, Orlando, FL	Oyster Reefs	Predation On The Easter Oyster <i>Crassostrea virginica</i> On Intertidal Reefs Affected By Recreational Boating*
-	Stolen, E.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Wading Birds	Habitat Selection And Foraging Success Of Wading Birds In Impounded Wetlands In Florida
2005	Barton, B.T.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Cascading Effects Of Predator Removal On The Ecology Of Sea Turtle Nesting Beaches*
-	Reyier, E.	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Fish Reserves	An Ichthyoplankton Survey Of The Northern Indian River Lagoon System, Florida, With Emphasis As To The Function Of An Estuarine No-Take Fisheries Reserve
2004	Pike, D.A.	M.S. Thesis - Towson University, Towson, MD	Gopher Tortoise	Patterns Of Survival And Movements Of Gopher Tortoises, <i>Gopherus polyphemus</i> , During The First Year Of Life*
2003	Herring, G.	M.S. Thesis - North Carolina State, Raleigh, NC	Scaup Nutrient Reserves	Assessing Nutrient Reserves And Local Population Dynamics Of Wintering Lesser Scaup In East-Central Florida*
2002	Abgrall, M.	M.S. Thesis - University of Central Florida, Orlando, FL	Bryozoan	Settlement Preferences, Recruitment, And Dispersal Potential Of The Bryozoan <i>Bugula neritina</i> On Drift Macroalgae In Mosquito Lagoon, Volusia County, Florida*
-	Ethlinger, G.	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Horseshoe Crab	Spawning Behavior And Larval Biology Of The American Horseshoe Crab, <i>Limulus polyphemus</i> , In A Microtidal Coastal Lagoon*
-	Foster, T.	M.S. Thesis - University of South Florida, Tampa, FL	Plant Physiology	Functional Groups Based On Leaf Physiology: Are They Spatially And Temporally Robust*

Year	Author(s)	Thesis Level	Topic	Title
-	Gimond, M.	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Remote Sensing	Development And Sensitivity Analysis Of A Hyperspectral Optical Monte Carlo Model For Coastal And Estuarine Water Quality Applications*
-	Herbert, T.	M.S. Thesis - Old Dominion University, Norfolk, VA	Roots; Elevated CO ₂	Fine Root Vitality And Its Application In A Minirhizotron Study Of CO ₂ Enrichment In A Florida Scrub Oak Ecosystem*
-	Love, M.S.	M.S. Thesis - University of Central Florida, Orlando, FL	Seagrass	Spatiotemporal Heterogeneity Of Seagrass Beds In The Indian River Lagoon*
-	Piercy, A.	M.S. Thesis - University of Central Florida, Orlando, FL	Stingrays	Seasonal Changes In The Preproductive System Of The Male Atlantic Stingray, <i>Dasyatis sabina</i> *
-	Stevens, P.W.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Fish	Test Of Salt Marsh As A Site Of Production And Export Of Fish Biomass With Implications For Impoundment Management And Restoration*
-	Weidlich, J.S.	M.S. Thesis - University of Central Florida, Orlando, FL	Mammals	A Survey of The Mammals Of The Archie Carr And Pelican Island National Wildlife Refuges*
2001	Aubrey, C.W.	M.S. Thesis - University of Central Florida, Orlando, FL	Sharks	Sharks Of The Inshore Coastal Atlantic Waters Of Brevard County, Florida, With Emphasis On The Spinner Shark, <i>Carcharhinus Brevipinna</i>
-	Demuth, J.P.	M.S. Thesis - Southeastern Louisiana University, Hammond, LA	Gopher Tortoise	The Effects Of Constant And Fluctuating Incubation Temperatures On Sex Determination, Growth, And Performance In The Tortoise <i>Gopherus polyphemus</i> *

Year	Author(s)	Thesis Level	Topic	Title
-	Hite, W.G.	M.S. Thesis - University of Central Florida, Orlando, FL	Small Mammals	The Distribution And Dynamics Of Small Mammals, Reptiles And Amphibians In A Mosquito Impounded Salt Marsh Landscape*
-	Holloway-Adkins, K.G.	M.S. Thesis - University of Central Florida, Orlando, FL	Green Turtle	A Comparative Study Of The Feeding Ecology Of <i>Chelonia mydas</i> (Green Turtle) And The Incidental Ingestion Of <i>Prorocentrum</i> Spp.*
-	Osegovic, K.M.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Hatching Success, Embryonic Mortality, And Infertility In Loggerhead (<i>Caretta caretta</i>) And Green (<i>Chelonia mydas</i>) Sea Turtles Nesting In Brevard County, Florida*
-	Rebman, J.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Backscatter Coefficients	Inclusion Of A Fluorescence Term In An Analytical Two-Flow Model To Simulate The Distribution Of Irradiance In Coastal Waters*
-	Roman, A.C.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Squirts	Spatial And Temporal Analysis Of The Growth Dynamics Of The <i>Ascidian perophora viridis</i> *
-	Shelly, D.R.	M.S. Thesis - University of Central Florida, Orlando, FL	Fish	An Investigation Of Fish Assemblages Inhabiting The Halifax And Lower Tomoka Rivers, Volusia County, Florida*
2000	Dilustro, J.	Ph.D. Dissertation- Old Dominion University, Norfolk, VA	Roots; Elevated CO ₂	Effects Of Elevated Atmospheric CO ₂ On Root Growth, Turnover, And Decomposition In A Scrub Oak Ecosystem*
-	Oddy, D.M.	M.S. Thesis - University of Central Florida, Orlando, FL 94p	Beach Mice	Population Estimate And Demography Of The Southeastern Beach Mouse (<i>Peromyscus polionotus niveiventris</i>) On Cape Canaveral Air Force Station, Florida*
-	Sastre, M.	M.S. Thesis - University of Puerto Rico	Remote Sensing	Avis Imagine Analysis for KSC Vegetation*

Year	Author(s)	Thesis Level	Topic	Title
1999	Dattilo, K.M.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	-	Effects Of Grazer Density On The Seagrass <i>Thalassia testudinum</i> From Indian River Lagoon, Florida*
-	Dunlevy, C.A.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL 173p	-	An Analysis Of Factors Contributing To Land Loss On Pelican Island National Wildlife Refuge, Florida*
-	Herren, R.M.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	The Effect Of Beach Nourishment On Loggerhead (<i>Caretta Caretta</i>) Nesting And Reproductive Success At Sebastian Inlet, Florida*
-	Morris, J.A.	M.S. Thesis - University of Central Florida, Orlando, FL	Stingrays	Aspects Of The Reproductive Biology Of The Bluntnose Stingray, <i>Dasyatis say</i> , In The Indian River Lagoon System, Florida*
-	Noke, W.D.	M.S. Thesis - University of Central Florida, Orlando, FL	Bottlenose Dolphin	Interactions Between The Indian River Lagoon Blue Crab Fishery And The Bottlenose Dolphin <i>Tursiops truncatus</i> *
-	Stevens, P.W.	M.S. Thesis - University of Florida, Gainesville, FL	Fish	The Vacillation Between Saltmarsh And Mangrove Communities At The Transition Between Temperate And Subtropical Climate In Florida*
-	Witchner, R.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Bottlenose Dolphin	Behaviors Of The Atlantic Bottlenose Dolphin (<i>Tursiops Truncatus</i>) In Non-Restricted And Restricted Boating Areas The Indian-Banana River Complex, Florida*
1998	Burcsu, T.	M.S. Thesis - University of North Carolina, Pembroke, NC	Remote Sensing Biomass	Above-Ground Biomass Estimation Using High Spatial Resolution Multispectral Remote Sensing In An Oak-Saw Palmetto Scrub Community*

Year	Author(s)	Thesis Level	Topic	Title
-	Earnest, L.M.	M.S. Thesis - University of South Florida, Tampa, FL 83p	Wetlands	Effects Of Hydrologic Re- Connection On Vegetation In Two Mosquito Control Impoundments On Kennedy Space Center, Merritt Island, Florida*
-	Spence, D.J.	M.S. Thesis - University of Central Florida, Orlando, FL	Maritime Hammock	Composition And Change Of Maritime Hammock Flora In East-Central Florida After 20 Years*
-	Stolen, M.K.	M.S. Thesis - University of Central Florida, Orlando, FL	Bottlenose Dolphin	Age, Growth, And Mortality Of Bottlenose Dolphins From The East Coast of Florida*
1997	Amesbury, E.	M.S. Thesis - University of Central Florida, Orlando, FL	Stingrays	Embryo Development And Nutrition In The Atlantic Stingray, <i>Dasyatis sabina</i> (<i>Elasmobranchii</i> , <i>Dasyatidae</i>)*
-	Mota, M.J.	M.S. Thesis - University of Central Florida, Orlando, FL	Manatee	Adrenal Gland Circulatory Anatomy In The Florida Manatee, <i>Trichechus</i> <i>manatus latirostris</i> *
-	Prusak, J.L.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Characterization Of A Marine Turtle Population Utilizing Neritic Reefs In Northern Indian River County, Florida*
-	Redfoot, W.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Population Structure And Feeding Ecology Of Green Turtles Utilizing The Trident Submarine Basin, Cape Canaveral, Florida As Developmental Habitat*
1996	Boyle, S.R.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL 134p	Erosion Rates	A Landscape Approach To Florida Scrub-Jay (<i>Aphelocoma</i> <i>coerulescens</i>) Habitat Use In Brevard County, Florida*
-	Dreschel, T.	Ph.D. Dissertation- Florida Institute of Technology, Melbourne, FL	Environmental Education	NASA Educator Workshops: Exploring Their Impact On Teacher Attitudes And Concerns*

Year	Author(s)	Thesis Level	Topic	Title
-	Gimond, M.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Remote Sensing	Methodology Evaluation For Estimating Specific Absorption Coefficients For Water Constituents For Remote Sensing Applications*
-	Legare, M.L.	M.S. Thesis - University of Rhode Island, Kingston, RI 59p	-	The Effectiveness Of Tape Playbacks In Estimating The Population Densities Of Breeding Black Rails (<i>Laterallus jamaicensis</i>) In Florida*
-	Poulakis, G.R.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Fish	Patterns Of Habitat Use By Fishes Within A Newly Reconnected Impounded Mangrove Marsh In East-Central Florida*
-	Stolen, E.D.	M.S. Thesis - University of Central Florida, Orlando, FL	Black Vulture	Roosting Behavior And Foraging Ecology Of Black Vultures In Central Florida
1995	Lamb, A.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Radiative Transfer Modeling	Sensitivity Analysis Of An Optical Remote Sensing Model*
-	Malhotra, R.	M.S. Thesis - University of Georgia, Athens, GA	Marsh Scrub Encroachment	A GIS Based Study Of Shrub Encroachment In Coastal Florida Marshlands Following Fire*
-	Rameneswamy, M.	Ph.D. Dissertation - University of Georgia, Athens, GA	Raccoon Predation	Raccoon Depredation Of Sea Turtle Nests At Canaveral National Seashore, Florida: Implications For Species Management And Conservation (<i>Caretta caretta</i> , <i>Procyon lotor</i> , <i>Chelonia mydas</i>)*
1994	Linderoth, Ondrea	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Seagrass	Seagrass Coverage And Diversity Changes Due To Mosquito Impoundment Influences In Selected Impoundments In The North Indian River Lagoon, Brevard County, Florida*

Year	Author(s)	Thesis Level	Topic	Title
1993	Kilburn, C.	M.S. Thesis - Purdue University, West Lafayette, IN	GIS	Toward An Inferential Approach To Predicting Space Shuttle Exhaust Cloud Deposition*
1992	Larson, V.L.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Scrub-Jay Habitat Use	A Method For Assessing The Conservation Value Of Natural Communities At A Local Scale*
1991	Garland, J.L.	Ph.D. Dissertation. University of Virginia, Charlottesville, VA	-	Carbon Flux Within Hydroponically-Based Plant Growth Systems: Analysis Of Microbial Community Structure And Function*
-	Hardesty, J.	M.S. Thesis - University of Florida, Gainesville, FL	Bald Eagle	Conservation Of Coastal Nesting Bald Eagles In Florida: History, Demography, and Habitat Use*
-	Karlen, D.J.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Water Quality/Benthic	A Comparison Of The Water Quality, Benthic Infauna And Macrofauna Between An Impounded And A Natural Tidal Creek*
1990	Cottrell, S.A.	M.S. Thesis - University of Central Florida, Orlando, FL	Spotted Seatrout	Age And Growth Of Spotted Seatrout In The Indian River Lagoon, Florida*
-	Kehl, M.J.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Seagrass	Comparison In Habitat Use By Macrofauna In <i>Halodule wrightii</i> And <i>Caluerna prolifera</i> In The Banana River*
-	Kinlaw, A.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Spotted Skunk	Estimation Of A Population Of Spotted Skunks At Canaveral National Seashore, Florida With The Jolly-Seber Model And An Examination Of Assumption Violations Of The Model*
-	Logiudice, F.T.	M.S. Thesis - University of Central Florida, Orlando, FL	Stingrays	The Morphology And Density Distribution Of The Cone Photoreceptor In The Retina Of The Atlantic Stingray, <i>Dasyatis sabina</i> *

Year	Author(s)	Thesis Level	Topic	Title
-	Snodgrass, J.W.	M.S. Thesis - University of Central Florida, Orlando, FL	Fish	Comparison Of Fishes Occurring In Monospecific Stands of Algae And Seagrass*
1989	Bennett, D.B.	M.S. Thesis - University of Florida, Gainesville, FL 154p	Stormwater Runoff	Water Resources Analysis Of A Multiobjective Drainage Network In The Indian River Lagoon Basin*
1988	Giovanetto, L.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Gopher Tortoise	Habitat Use By The Gopher Tortoise (<i>Gopherus polyphemus daudin</i>) In Scrub And Slash Pine Flatwoods On John F. Kennedy Space Center*
-	Rydne, D.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Metals in Fish	Concentrations Of AL, CD, PB, V, And ZN In Fishes Inhabiting Ponds Exposed To Space Shuttle Launch Exhaust*
-	Schmid, T.H.	M.S. Thesis - University of Central Florida, Orlando, FL	Stingrays	Age, Growth, And Movement Patterns Of <i>Dasyatis sabina</i> , In A Florida Coastal Lagoon System*
-	Smith, R.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Sailfin Molly	Variation In Female Somatic Condition And Its Relationship To Reproduction In The Sailfin Molly, <i>Poecilia latipinna</i> (<i>Pices: Poeciliidae</i>)*
-	Wibbels, T.	Ph.D. Dissertation-Texas A&M University, College Station, TX	Sea Turtles	Gonadal Steroid Endocrinology Of Sea Turtle Reproduction*
1987	Gipe, T.G.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Scrub Jays	Effects Of Prescribed Burning On The Suitability Of Habitat For The Florida Scrub Jay <i>Aphelocoma coerulescens</i> (<i>BOSC</i>)*

Year	Author(s)	Thesis Level	Topic	Title
-	Rydene, D.A.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Fish	Concentrations Of Al, Cd, Pb, V, And Zn In Fishes Inhabiting Ponds Exposed To Space Shuttle Launch Exhaust*
1986	Jones, K.L.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Stormwater Runoff	Quantitative Assessments Of Stormwater Runoff From The Vehicle Assembly Building Area Of The John F. Kennedy Space Center, Florida*
-	McMurtray, J.D.	M.S. Thesis - University of Georgia, Athens, GA	Racoon Predation	Reduction Of Racoon Predation On Sea Turtle Nests At Canaveral National Seashore, Florida*
-	Mion, L.P.	M.S. Thesis - University of Florida, Gainesville, FL	Wetlands	Low-Energy Wastewater Recycling Through An Oligohaline Coastal Marsh Ecosystem*
-	Smith, R.B.	M.S. Thesis - University of Central Florida, Orlando, FL 38p	Sailfin Molly	The Effect Of Food On Reproduction In The Sailfin Molly, <i>Poecilia latipinna</i> (<i>Poeciliidae</i>)*
-	Witherington, B.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Human And Natural Causes Of Marine Turtle Clutch And Hatchling Mortality And Their Relationship To Hatchling Production On An Important Florida Nesting Beach*
1985	Large, H.L.	M.S. Thesis - University of Central Florida, Orlando, FL	Sailfin Molly	Life History Tactics Of The Sailfin Molly (<i>Poecilia latipinna</i>) In Contrasting Environments*
1984	Issifou, K.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Metals	A Comparative Study Of Trace Metals In Coastal Lagoons Of The Ivory Coast And Florida*
-	Pogban, T.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Hydrocarbons	A Comparative Study Of Polycyclic Aromatic Hydrocarbons In Coastal Lagoons Of Florida And The Ivory Coast*

Year	Author(s)	Thesis Level	Topic	Title
-	Raymond, P.W.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	The Effects Of Beach Restoration On Marine Turtles Nesting In South Brevard County, Florida*
1982	Wetherington, J.D.	M.S. Thesis - University of Central Florida, Orlando, FL	Sailfin Molly	The Influence Of Somatic Investment On The Pattern Of Reproduction In <i>Poecilia latipinna</i> (Pisces: Poeciliidae)*
1981	Breining, D.R.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Scrub-Jay Habitat Use	Habitat Preferences Of The Florida Scrub-Jay (<i>Aphelocoma coerulescens</i>) On Merritt Island National Wildlife Refuge, Florida*
-	Demmer, R.J.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	The Hatchlings And Emergence Of Loggerhead Turtle (<i>Caretta caretta</i>) Hatchlings
-	Grizzle, R.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Benthos	Opportunistic Species Of Macro-benthos In A Sewage-Polluted Lagoon, And An Analysis Of The Indicator Concept*
-	Mendonca, M.T.	M.S. Thesis - University of Central Florida, Orlando, FL	Green Turtle	Movements And Reeding Ecology Of Immature Green Turtles (<i>Chelonia mydas</i>) In Mosquito Lagoon, Florida*
-	Mulligan, T.	M.S. Thesis - University of Central Florida, Orlando, FL	Fish	Summer-Season Populations Of Epibenthic Marine Fishes In The Indian River Lagoon System, Florida*
1980	Clark, S.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Wood Storks	Attentiveness And Time Budget Of A Pair Of Nesting Wood Storks*
-	Goldberg, J.A.	M.S. Thesis - University of Central Florida, Orlando, FL	Small Mammals	Population Dynamics Of Small Mammals In Two Plant Communities Of The Merritt Island National Wildlife Refuge*

Year	Author(s)	Thesis Level	Topic	Title
-	Schooley, J.K.	Ph.D. Dissertation- University of Florida, Gainesville, FL	Fish	The Structure And Function Of Warm Temperate Estuarine Fish Communities*
-	Strand, D.K.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Feral Hog	Reproductive Ecology And Behavior Of The Florida Hog (<i>Sus scrofa</i>)*
1979	Antonelli, D.S.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Feral Hog	Population Structure And Habitat Use Of The Feral Hog (<i>Sus scrofa</i>) On Merritt Island National Wildlife Refuge, Florida*
-	Keim, M.H.	M.S. Thesis - University of Central Florida, Orlando, FL	Small Mammals	Small Mammal Population Dynamics And Community Structure In Three East Central Florida Communities*
-	McGehee, A.M.	M.S. Thesis - University of Central Florida, Orlando, FL	Sea Turtles	Factors Affecting The Hatching Success Of Loggerhead Sea Turtle Eggs: (<i>Caretta caretta caretta</i>)*
-	Poffenberger, D.L.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Feral Hog	An Investigation Of The Movements Of Feral Swine (<i>Sus scrofa</i>) In East-Central Florida*
-	Siegal, R.	M.S. Thesis - University of Central Florida, Orlando, FL	Diamondback Terrapin	The Reproductive Biology Of The Diamondback Terrapin, <i>Malaclemys terrapin tequesta</i> *
1978	Caldwell, R.D.	M.S. Thesis - University of Central Florida, Orlando, FL	Arthropods	Arthropod Community Dynamics In Three Ruderal Old Fields With Possible Effects Of Solid Rocket Fuel Exhaust*
-	Peck, D.V.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Feral Hog	The Role Of Nutrients And Energy In Diet Selection Of Feral Swine (<i>Sus scrofa domesticus</i>) In East-Central Florida*
1977	Baber, D.W.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Feral Hog	Social Organization And Behavior In The Feral Hog, <i>Sus scrofa</i> , Linnaeus*

Year	Author(s)	Thesis Level	Topic	Title
-	Kochman, I.H.	M.S. Thesis - University of Florida, Gainesville, FL	Snakes	Differentiation and Hybridization In The Natrix Fasciata Complex (Reptilia: Serpentes): A Non-Morphological Approach*
1976	De Guehery, L.E.	M.S. Thesis - University of Central Florida, Orlando, FL	Solid Rocket Motor Fuels	Some Effects Of Solid Rocket Motor Fuel Exhausts On Avian Embryos
1975	Tower, D.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Soils and Sediments	Heavy Metal Distribution In The Sediment Of Waters Near Kennedy Space Center*
1974	Harrison, M.H.	M.S. Thesis - University of Central Florida, Orlando, FL	Rice Rat	Nest-Building Behavior And Food Habits Of The Rice Rat, From Merritt Island, Brevard County, Florida*
1973	Daggett, J.M.	M.S. Thesis - Florida Institute of Technology, Melbourne, FL	Soils and Sediments	The Sediments Of The Indian River And Impounded Waters Near The Kennedy Space Center*