Houston-Galveston Area Council
The Effect of Disaster Debris on Landfills
Analysis and Recommendations Report

October 2019

Houston-Galveston Area Council

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EXECUTIVE SUMMARY

The purpose of this report is to analyze the effect disasters and the resulting quantities of debris can have on the lifespan of landfills. A disaster such as a hurricane can generate a tremendous amount of debris. How that debris is managed and whether any measures are taken to reduce or divert the debris can have a significant impact on the lifespan of landfills serving the local communities. Hurricane Ike, which struck the upper Texas coast in 2008, generated more than 20 million cubic yards (CYs) of debris in the Houston-Galveston Region. Hurricane Harvey, which made landfall in 2017 in the coastal bend of Texas before moving northward, generated more than 13 million CYs of debris. Debris of those quantities, if not properly managed, could severely shorten the lifespan of the landfills serving those communities.

This report examines the cities of Dickinson, Friendswood, and League City in Galveston County. Team members from Tetra Tech, Inc., the firm contracted by H-GAC to produce the report, examined past debris-generating incidents that occurred in the region and analyzed the experience of each of the cities in managing debris associated with Hurricanes Ike and Harvey. In particular, the report examines the amount and type of debris collected from each of the cities, the number of load tickets used to document each truckload of debris, methods used to reduce debris, and the landfills and other facilities used by the cities to dispose of disaster debris.

The report explores the capacities of the area landfills served by the cities and how they were affected by Hurricanes Ike and Harvey. The report examines the wider impacts of a Category 5 hurricane, the potential for debris generation, possible impacts to landfills, and how effective debris management strategies can be used to minimize those impacts to the lifespan of local landfills. The report identifies best practices and provides recommendations to jurisdictions facing a debris-generating incident.

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1. BACKGROUND

The mission of the Houston-Galveston Area Council (H-GAC) is to serve as the instrument of local government cooperation. H-GAC authorized the development of this report to analyze the effect disasters and the resulting quantities of debris can have on the lifespan of area landfills.

Tetra Tech examined the experiences of the cities of Dickinson, Friendswood, and League City in managing and disposing of debris generated by Hurricane Ike in 2008 and Hurricane Harvey in 2017. The use of a Debris Management Site (DMS) in staging and reducing debris from a disaster was explored.

These three cities were chosen as they are representative of midsized communities in the region, each are vulnerable to the same hazards, and each suffered severe impacts from Hurricanes Ike and Harvey. A brief synopsis for each of the cities is provided on the following pages.

Figure 1: Map Showing the Cities of Dickinson, Friendswood, and League City

CITY OF DICKINSON

Dickinson, Texas, is in Galveston County. According to U.S. Census data, the estimated population in July 2018 was 20,881. The median household income in Dickinson as of 2017 was $68,750. The city occupies a total area of 10.3 square miles, of which 9.9 squares miles are land and 0.42 square miles are water. The population density for the city is approximately 1,890 persons per square mile.

Figure 2: Map Showing the City of Dickinson

The city is along I-45 South (Gulf Freeway), approximately 26 miles south of Houston and approximately 18 miles north of Galveston Island. The city is bordered by League City to the north and west and Texas City to the south and east. There is a uniform pattern of open space and trees throughout the city. The city lies within the Dickinson Bayou Watershed. The watershed encompasses an area from Alvin, Friendswood, League City, Santa Fe, Texas City, Dickinson, and Algoa. In Dickinson, water feeds into Dickinson Bayou running east to west through the city, into the Dickinson Bay, and ultimately to Galveston Bay. The city's location within the Dickinson Bayou Watershed and its proximity to Galveston Bay and the Gulf of Mexico make it susceptible to the strong winds, storm surge, and flooding rains that can accompany tropical storms and hurricanes.

CITY OF FRIENDSWOOD

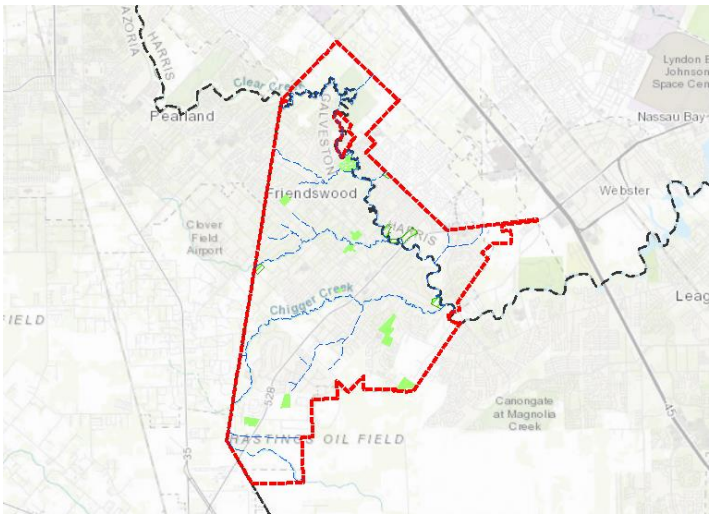

Figure 3: Map Showing City of Friendswood

Friendswood lies in both Galveston and Harris counties. According to U.S. Census data, the estimated population in July 2018 was 40,181. The median household income in Friendswood as of 2017 was $98,609. The city occupies a total area of 20.9 square miles, of which 20.7 square miles are land and 0.2 square miles are water. The population density for the city is approximately 1,725 persons per square mile.

The city is bordered by League City to the south and east, Pearland to the west, and Houston to the north and east. There is a uniform pattern of open space and trees throughout most of the city with a few areas of heavy tree cover. Clear Creek functions as the boundary in the city between Harris and Galveston counties. The larger portion of the city, south of Clear Creek, is in Galveston County. The smaller portion of the city, north of Clear Creek, lies in Harris County. Clear Creek flows west to east through the city and ultimately feeds into Clear Lake, which flows into Galveston Bay. Clear Creek is subject to both riverine and coastal tidal flooding. The southern portion of the city drains into the Dickinson Bayou Watershed. The city's proximity to Galveston Bay and the Gulf of Mexico make it susceptible to the strong winds, storm surge, and flooding rains that can accompany tropical storms and hurricanes.

CITY OF LEAGUE CITY

League City is in both Galveston and Harris counties. According to U.S. Census estimates, the population of League City was 106,244 in July 2018. The median income in the city as of 2017 was $100,996. The city occupies 53 square miles, of which 51.3 square miles are land and 1.7 square miles are water. The population density for the city is approximately 1,630 persons per square mile.

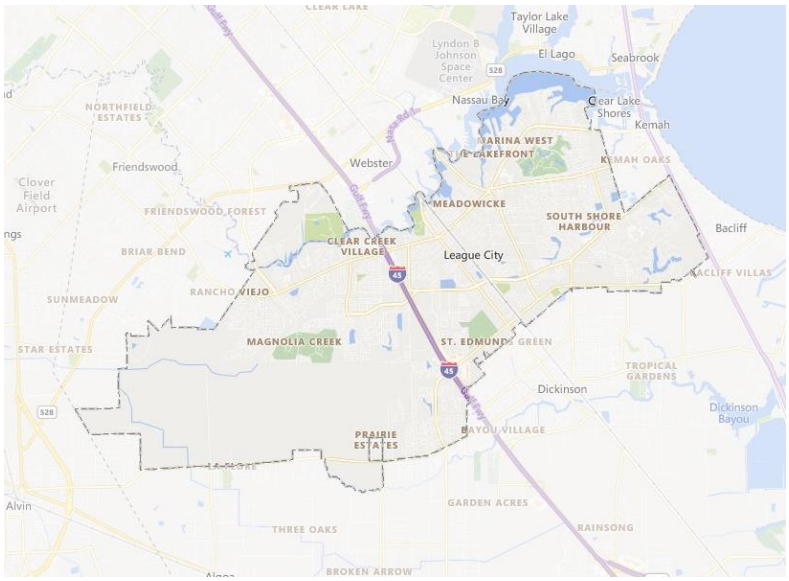

Figure 4: Map Showing the City of League City

League City is bordered by Friendswood and Webster to the north, Kemah and the unincorporated area of Bacliff to the east, and Dickinson and an unincorporated area of Galveston County to the south. There is a uniform pattern of open space and trees throughout most of the city, with a few areas of light tree cover in new developments. Most of the city lies in Galveston County, with only a small portion of the city north of Clear Creek in Harris County. Clear Creek flows west to east through the city west of I-45 and along the northern border of the city east of I-45. Clear Creek feeds into Clear Lake, which flows into Galveston Bay. As a result, Clear Creek is vulnerable to both riverine and coastal tidal flooding. Parts of the city drain into the Dickinson Bayou Watershed. The city's proximity to Galveston Bay and the Gulf of Mexico make it susceptible to the strong winds, storm surge, and flooding rains that can accompany tropical storms and hurricanes.

PAST DISASTERS

All these cities are at risk from multiple hazards, including tropical storms/hurricanes, floods, tornadoes, severe storms, and hazardous materials incidents. To determine the hazard or hazards most likely to generate the most debris, the project team examined past incidents resulting in $1 million or more in damages. Table 1 on the next page shows the different types of disasters affecting these cities over the past 20 years and the property damage estimates from Galveston County jurisdictions affected by those disasters.

Table 1: Past Disasters Affecting Dickinson, Friendswood, and League City

DATE	INCIDENT	ESTIMATED PROPERTY DAMAGE
May 2, 2000	Thunderstorm	$1 Million
June 5, 2001	Tropical Storm Allison	$31.74 Million
July 4, 2003	Hurricane Claudette	$8.3 Million
September 23, 2005	Hurricane Rita	$15 Million
September 12, 2007	Hurricane Humberto	$2.5 Million
September 12, 2008	Hurricane Ike	$1.0 Billion
April 18, 2009	Flash Flood	$4.0 Million
April 2, 2013	Hail	$1.1 Million
October 31, 2015	EF 2 Tornado (League City)	$1.0 Million
October26, 2017	Hurricane Harvey	$10 Billion

Estimates reveal in the past 20 years hurricanes have resulted in the greatest amount of damage and debris. The two incidents resulting in the most damage in Galveston County were Hurricane Ike in 2008 and Hurricane Harvey in 2017.

2. HURRICANE IKE

SUMMARY OF EVENTS

Hurricane Ike made landfall on Saturday, September 13, 2008, at the north end of Galveston Island with 110 mph winds. Storm surge from the hurricane was between 15 and 20 feet in the area between Galveston Bay and just northeast of High Island. The Bolivar Peninsula was immersed under 4 to 10 feet of water. Hurricane Ike was a large storm with the diameter of tropical-force winds covering an area of 425 miles. The hurricane's center moved up through Galveston Bay, just east of Houston, and then moved northward across eastern Texas.

Because of the strong winds associated with Hurricane Ike, there were many downed trees across the region resulting in large amounts of vegetative debris. In addition, many structures were damaged from the high winds, storm surge, and flooding resulting in a large amount of construction and demolition (C&D) debris. C&D debris consists of damaged components of buildings and structures, such as lumber and treated wood, gypsum wallboard, glass, metal, roofing material, tile, carpeting and floor coverings, window coverings, pipe, concrete, fully cured asphalt, equipment, furnishings, and fixtures. White goods consisting of refrigerators, freezers, washing machines, clothes dryers, water heater, air conditioners, ovens, and ranges were also collected.

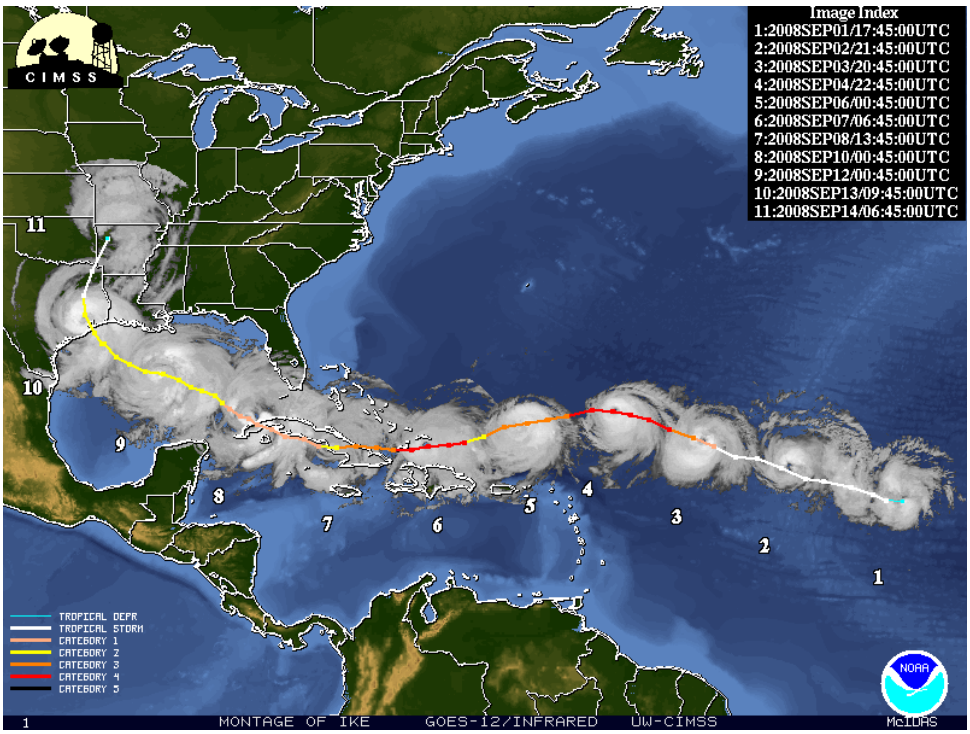

Figure 3: Hurricane Ike Track - National Weather Service

CITY OF DICKINSON – HURRICANE IKE

Hurricane Ike caused a considerable amount of debris in Dickinson. A total of 217,052 CYs of debris was collected in the city as a result of Hurricane Ike. The greatest portion of this debris, approximately 80 percent, consisted of vegetative debris. In addition, 223 white goods were collected. Ninety-nine percent of the vegetative debris was taken to Novus, a facility that processes mulch to sell. The Novus facility served as a final disposal site for most of the vegetative debris and some C&D debris from Dickinson. Most of the C&D materials, mixed loads (loads mixed with C&D and vegetative debris), and the remainder of the vegetative debris was taken to the North County Landfill, operated by Republic Waste, in League City.

Table 2: City of Dickinson Debris Collection Amounts from Hurricane Ike

FACILITY AND DEBRIS TYPE	LOAD TICKETS	TOTAL CY
NOVUS DICKINSON	**4,807**	**173,111**
Construction & Demolition	9	352
Mixed	6	150
Vegetative/Woody	4,792	172,609
REPUBLIC WASTE	**1,017**	**43,941**
Construction & Demolition	469	17,445
Mixed	523	25,569
Vegetative/Woody	25	927
GRAND TOTAL	**5,824**	**217,052**

Figure 4 shows the location of the landfill and Novus Dickinson sites.

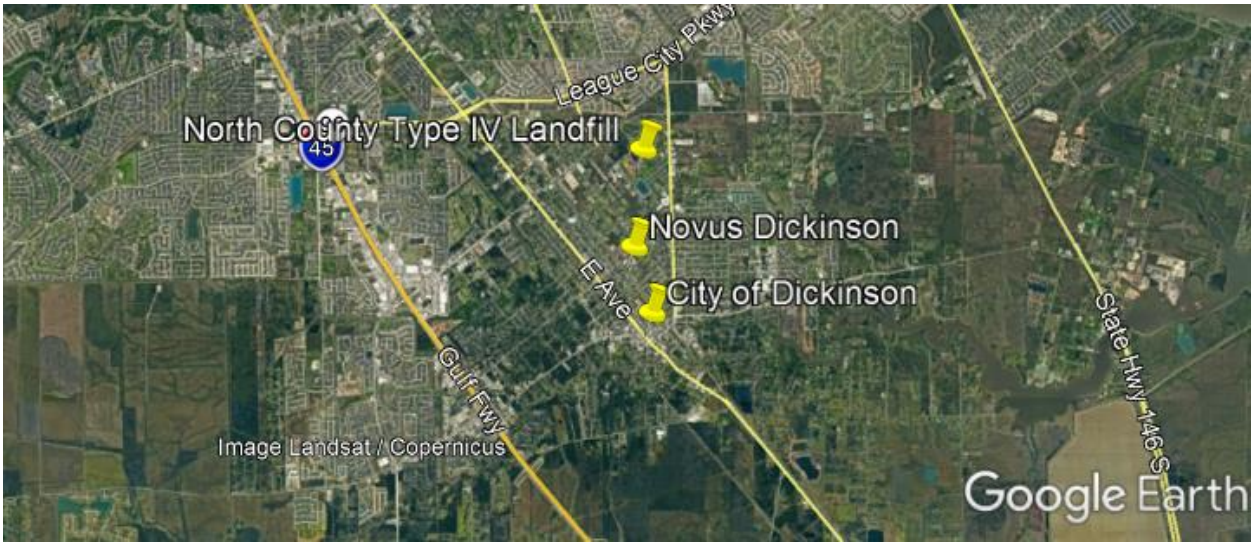

Figure 4: City of Dickinson Hurricane Ike Disposal and DMS Locations

CITY OF FRIENDSWOOD – HURRICANE IKE

Friendswood was severely impacted by Hurricane Ike. Approximately 488,214 CYs of debris was removed from the city and the Galveston County Consolidated Drainage District. Eighty-nine percent, or 435,431 CYs, was vegetative debris. The remaining 52,783 CYs consisted of C&D debris. A DMS was established on land at the Dixie Farm Road Landfill in Pearland to reduce the vegetative debris before disposal in the landfill portion of the facility. All C&D debris was direct-hauled from collection at the right-of-way to the Dixie Farm Road Landfill.

Table 3: City of Friendswood Debris Collection from Hurricane Ike

DIXIE FARM ROAD LANDFILL	LOAD TICKETS	TOTAL CY
Construction & Demolition	715	32,837
Mixed	446	20,248
Vegetative/Woody	9,390	435,129
GRAND TOTAL	**10,551**	**488,214**

Figure 5 shows the location of the landfill in relation to Friendswood.

Figure 5: City of Friendswood Disposal and DMS Locations

CITY OF LEAGUE CITY – HURRICANE IKE

League City was severely impacted by Hurricane Ike. 261,351 CYs of debris was collected from the city. Approximately 88 percent of the total collected, or 229,989 CYs, was vegetative debris and was taken to the city DMS for reduction. Twelve percent, or 31,362 CYs, consisted of C&D debris. In addition, 221 units of white goods were collected, and 39 hazardous trees were removed. A DMS was established at a city park, where vegetative debris was reduced through grinding. Following reduction, the resulting mulch was hauled to Novus mulch facilities in Dickinson and Pasadena. Mulch from the DMS was also taken to the Bolivar Peninsula. The mulch transported to Bolivar was used as a pad for the trucks operating at the DMS on the Bolivar Peninsula. C&D debris was hauled directly to the North County Landfill in Dickinson.

Table 4: City of League City Debris Collection from Hurricane Ike

FACILITY AND DEBRIS TYPE		TOTAL CY
DMS VEGETATIVE REDUCTION	**4,112**	**229,989**
League City DMS with haul-out to: • Novus Dickinson • Novus Pasadena • Bolivar Peninsula • North County Landfill		
NORTH COUNTY LANDFILL	**1,195**	**58,745**
Construction & Demolition	814	39,648
Mixed	363	18,344
Vegetative/Woody (direct haul to landfill)	18	836
GRAND TOTAL	**5,307**	**261,351**

Figure 6 shows the location of the landfill and Novus facilities in relation to League City.

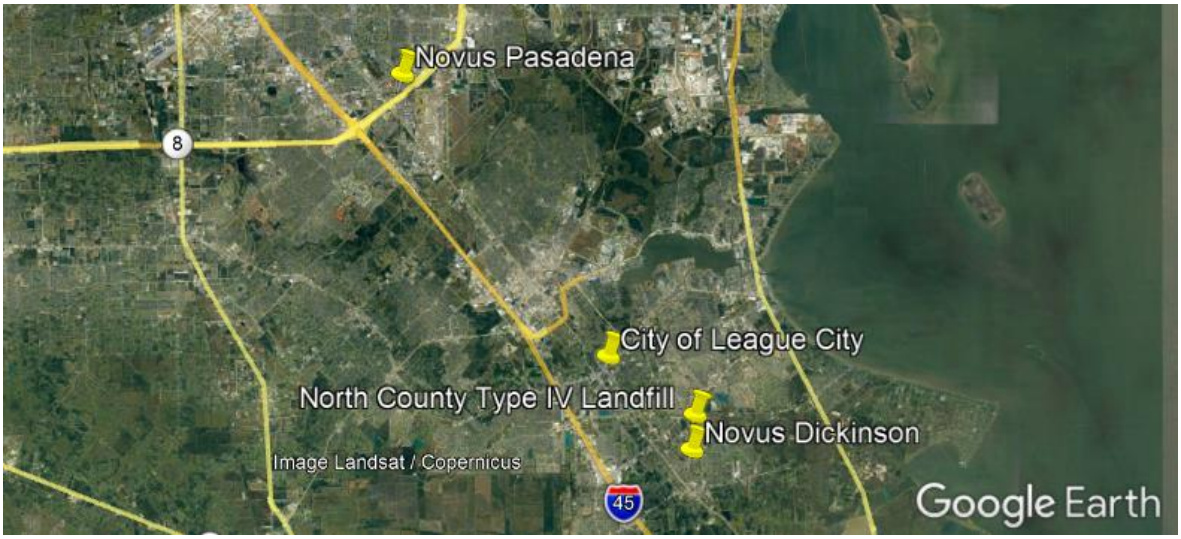

Figure 6: City of League City Disposal and DMS Locations

3. HURRICANE HARVEY

SUMMARY OF EVENTS

Hurricane Harvey made landfall near Port Aransas, Texas, at approximately 10 p.m. August 25, 2017, as a Category 4 hurricane with 132 mph sustained winds. The hurricane caused catastrophic damage in Rockport, Texas, and surrounding areas. Hurricane Harvey moved northwest and weakened to a tropical storm. From August 26 to 27, Harvey made a slow loop, then began to track eastward and back into the Gulf of Mexico. Harvey moved northward along the coast, then stalled for four days with its center near southeast Texas.

Figure 7: Hurricane Harvey History, The State and Federal Response, USEPA

Rainfall in Dickinson totaled 43.92 inches; rainfall in Friendswood totaled 56.00 inches; and rainfall in League City totaled 52.87 inches. As a result of the rainfall, catastrophic flooding was reported across the Houston-Galveston region, including Dickinson, Friendswood, and League City. Primary and secondary roads in the area were inundated with floodwater. At least 160,000 structures were flooded in Harris and Galveston counties.[1]

Debris management operations in Dickinson, Friendswood, and League City were markedly different from debris collections in response to Hurricane Ike. Because the cities did not experience the winds with Hurricane Harvey as with Hurricane Ike, there were not as many downed trees to remove. Instead, the mass flooding that occurred with Hurricane Harvey flooded thousands of homes and businesses, resulting in large quantities of C&D, white goods, vehicles, and electronics to be collected. The sections on the following pages highlight the debris quantities and types experienced by Dickinson, Friendswood, and League City following Hurricane Harvey.

[1] National Hurricane Center, Tropical Cyclone Report, Hurricane Harvey, May 9, 2018, Casualty and Damage Statistics

CITY OF DICKINSON – HURRICANE HARVEY

In Dickinson, torrential downpours of rain from Hurricane Harvey resulted in more than 80 percent of all households, or about 6,625 homes, sustaining damage.[2] Most of the debris, or 182,355 CYs, consisted of C&D materials. In addition, 7,684 units of electronics, 5,178 units of white goods, and 182,460 pounds of household hazardous waste were collected. There was no vegetative debris. Residents began dropping off debris at the parking lot of a closed furniture store. The city organized the illegal dump site into a functional residential drop-off site. Areas of the parking lot were designated for specific types of debris (such as C&D, white goods, household hazardous waste, and electronics) so the debris could be properly sorted for ease of collection and disposal by contractors. Compaction was conducted at the DMS, resulting in about a one-third compaction rate. Residents could drop off debris in the properly sorted areas. Debris from the DMS was hauled to the North County Landfill. C&D debris was hauled to the Galveston County Landfill and the North County Landfill. White goods and electronic waste were taken to Commercial Metals Company (CMC) in Galveston for recycling. Household Hazardous Waste (HHW) was taken to Clean Harbors in Deer Park. A total of 117,655 CYs of debris ended up in landfills. Table 5 summarizes the deposition of the Harvey debris.

Table 5: City of Dickinson Debris Collection from Hurricane Harvey

FACILITIES FOR C&D DEBRIS	LOAD TICKETS	TOTAL CY
GALVESTON COUNTY LANDFILL	238	6,301
CMC RECYCLING	14	353
HUGHES ROAD DMS/NORTH COUNTY L	3,638	167,088
NORTH COUNTY LANDFILL	229	8,613
GRAND TOTAL	4,119	182,355

Figure 8 shows the location of Dickinson in relation to the disposal facilities.

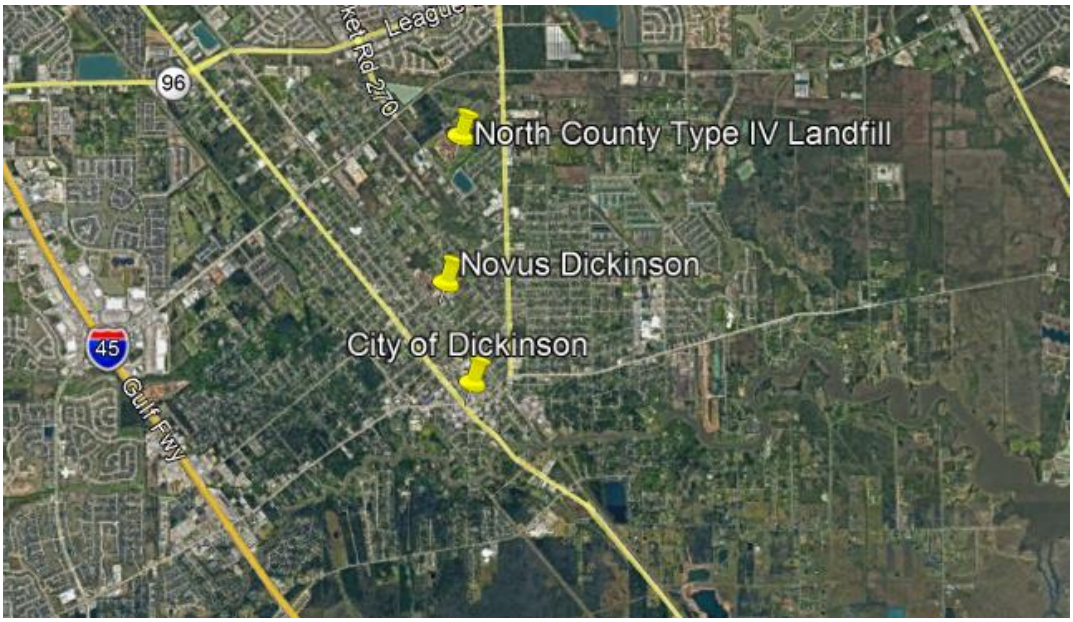

Figure 8: City of Dickinson Hurricane Harvey Disposal and DMS Locations

[2] "About 19,000 Houses, Structures Damaged by Harvey," The Galveston County Daily News, September 4, 2017

CITY OF FRIENDSWOOD – HURRICANE HARVEY

City of Friendswood officials estimated that Hurricane Harvey damaged approximately 3,000 homes.[3] Most of the debris, or 134,766 CYs, consisted of C&D materials. Another 1,191 CYs was vegetative debris. In addition, 2,545 units of electronics, 4,110 units of white goods, and 235,920 pounds of household hazardous waste were collected. White goods and electronic waste were taken to Commercial Metals Company (CMC) in Galveston for recycling. HHW was taken to Clean Harbors in Deer Park. A total of 135,957 CYs of debris ended up in landfills. All the C&D and vegetative debris was disposed of at the Dixie Farm Road Landfill as indicated in Table 6.

Table 6: City of Friendswood Debris Collection from Hurricane Harvey

DIXIE FARM ROAD LANDFILL	LOAD TICKETS	TOTAL CY
C&D	4,439	134,766
VEGETATIVE/WOODY	49	1,191
GRAND TOTAL	4,488	135,957

Figure 9 shows the location of the Friendswood in relation to the disposal facility.

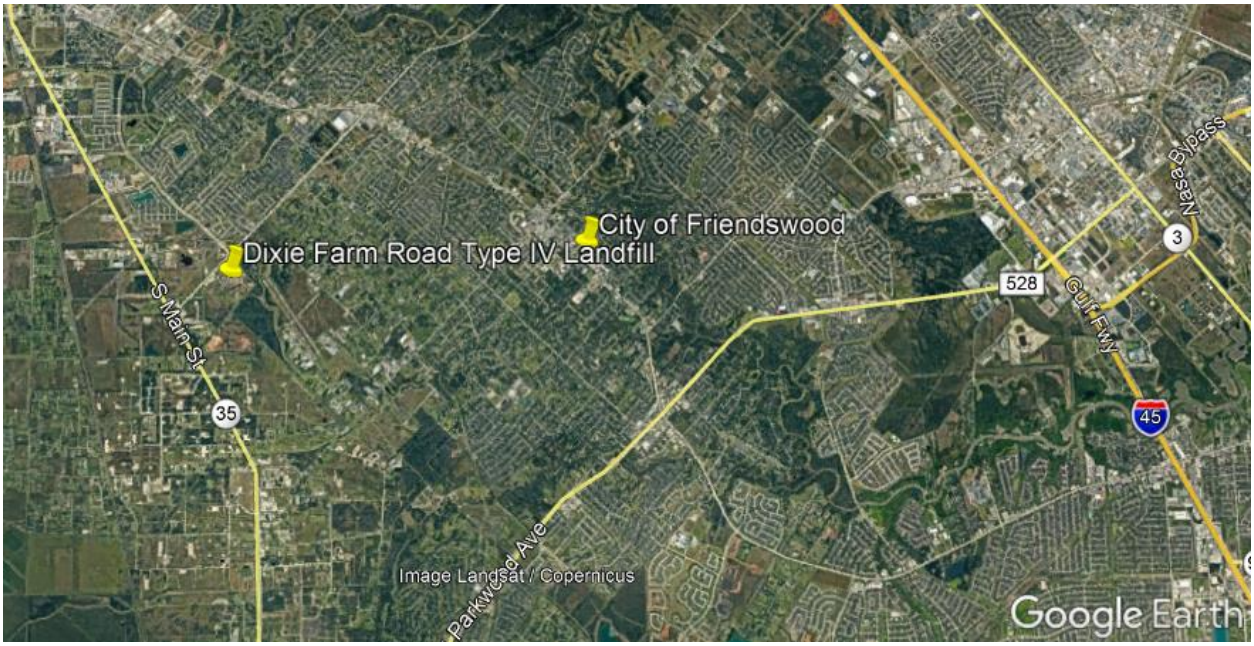

Figure 9: City of Friendswood Hurricane Harvey Disposal and DMS Locations

[3] "About 19,000 Houses, Structures Damaged by Harvey," The Galveston County Daily News, September 4, 2017

CITY OF LEAGUE CITY – HURRICANE HARVEY

In League City, approximately 6,000 homes were damaged by the heavy rains that accompanied Hurricane Harvey.[4] Most of the debris consisted of C&D debris. In addition, 3,491 units of electronics, 2,606 units of white goods, and 106,820 pounds of household hazardous waste were collected. There was no vegetative debris. White goods and electronic waste were taken to Commercial Metals Company (CMC) in Galveston for recycling. HHW was taken to Clean Harbors in Deer Park. The C&D debris was disposed of in several landfills in the area as listed in Table 7.

Table 7: City of League City Debris Collection from Hurricane Harvey

FACILITIES FOR C&D DEBRIS	LOAD TICKETS	TOTAL CY
COASTAL PLAINS LANDFILL	3	98
DIXIE FARM ROAD LANDFILL	17	617
GALVESTON COUNTY LANDFILL	24	1,001
NORTH COUNTY LANDFILL	2,513	114,746
GRAND TOTAL	2,557	116,462

Figure 10 shows the location of League City in relation to the disposal facilities.

Figure 10: City of League City Hurricane Harvey Landfill Locations

[4] "About 19,000 Houses, Structures Damaged by Harvey," The Galveston County Daily News, September 4, 2017

4. DEBRIS REDUCTION ACTIVITIES

HURRICANE IKE

Hurricane Ike generated a large amount of vegetative debris. During debris operations for Hurricane Ike, the cities of Dickinson, Friendswood, and League City each took a different yet effective approach to reducing the volume of vegetative debris.

In Dickinson, vegetative debris was picked up from the right-of-way and directly hauled to the Novus Dickinson facility. The Novus facility was paid to accept the materials. The materials were ground into mulch and added to the stock that Novus sells as a regular part of their business. This partnership between the City of Dickinson and Novus provided an efficient means to rid the community of the vegetative debris, provided a benefit to a local business, and helped divert the vegetative debris from local landfills.

In Friendswood, reducing vegetative debris was achieved through a DMS located on the premises of the Dixie Farm Road Landfill. The reduced vegetative debris was then taken from the DMS location directly to the landfill. Coordinating with a local landfill to use their land as a DMS offers three benefits: (1) it is much easier to get a landfill permitted as a DMS, as opposed to a park or other facility, because it is already approved for waste operations; (2) the city can avoid the use of city-owned land as a DMS; and (3) having the DMS at the landfill provides the opportunity to reduce the debris before it is transported the short distance into the landfill.

In League City, a DMS was established at a city park. After the vegetative debris was ground, the mulch was taken to three different locations: Novus Dickinson, Novus Pasadena, and the Bolivar Peninsula. League City paid a fee to Novus for the acceptance of the mulch at their facilities.

In each of the cities, C&D was not compacted until it was dropped at the landfill. All C&D was picked up on the side of the road and hauled directly to a landfill.

HURRICANE HARVEY

Because there was not the large quantity of vegetative debris in Dickinson, Friendswood, and League City following Hurricane Harvey as there was following Hurricane Ike, debris reduction activities in the cities were not as extensive. The cities of Friendswood and League City hauled debris directly from the right-of-way to area landfills. The City of Dickinson maintained the residential drop-off site/DMS, providing residents the opportunity to move the debris off their property instead of waiting for the right-of-way collection operations to arrive at their street. C&D was compacted on-site before it was transported to local landfills.

5. AREA LANDFILL CAPACITY

While there were several outlets for the debris for the cities of Dickinson, Friendswood, and League City following Hurricanes Ike and Harvey, there were only four primary landfills used for the final disposal of debris, as listed in Table 8.

Table 8: Primary Landfills Used by the cities of Dickinson, Friendswood, and League City During Ike and Harvey

LANDFILL NAME	TYPE	OPERATED BY	ADDRESS
Coastal Plains Landfill	I	Waste Management	21000 E Hwy 6 Alvin, TX 77511
Dixie Farm Road Landfill	IV	Hill Sand Company, Inc.	4649 Dixie Farm Rd. Pearland, TX 77581
Galveston County Landfill	I	Republic Services	3935 Avenue A Alta Loma, TX 77510
North County Landfill	IV	Republic Services	2015 N Wyoming Ave. Dickinson, TX 77539

The Coastal Plains and Galveston County landfills are Type I landfills; the Dixie Farm Road and North County landfills are Type IV landfills. Type I landfills are the standard landfills for municipal solid waste. Type IV landfills accept only brush, C&D, and similar non-putrescible waste. Figure 11 shows the locations of the four landfills.

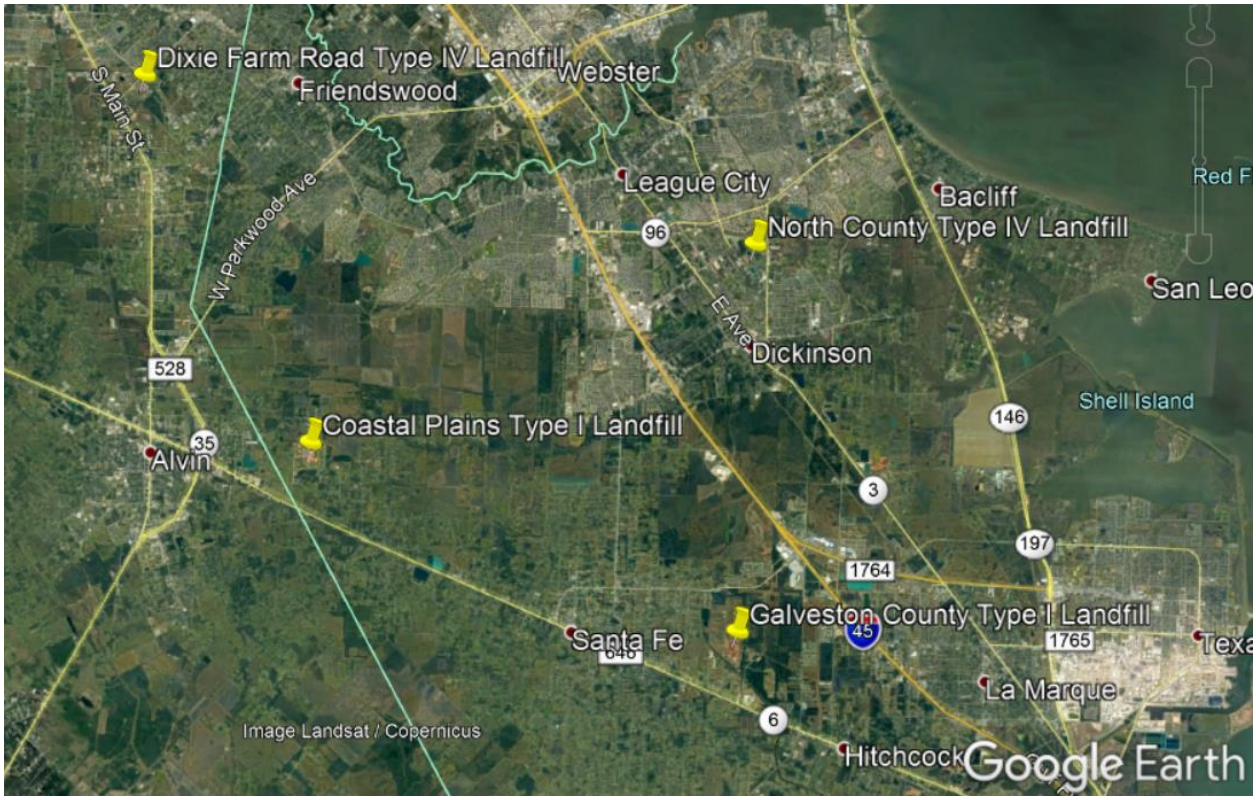

Figure 11: Location of Primary Landfills

The total amount of debris collected from Hurricane Ike for the three cities was 966,617 CYs. Due to debris reduction efforts employed to reduce vegetative debris, of the 966,617 CYs collected, approximately 811,991 CYs went to landfills.[5] Using the formula provided by the United States Army Corps of Engineers (USACE) where 4 CYs of mixed debris (both C&D and vegetative debris) equals 1 ton of debris, 811,991 CYs of debris will equate to 202,997 tons of debris.[6] Converting the CYs of debris into tonnage is needed because the amount of waste going into landfills is typically documented and reported in tons. This allows accurate comparison of the amount of disaster debris taken to landfills versus the amount of debris received at landfills annually.

Figure 12: House in Seabrook, Texas After Hurricane Ike Photo Credit: Brian Rutherford

Figure 13: Flood Debris Along a League City Street Following Hurricane Harvey Photo Credit: Brian Rutherford

By the time Hurricane Harvey reached the upper Texas coast, it was downgraded to a tropical storm and did not pack the hurricane-force winds that Hurricane Ike had upon landfall. Downed trees and roofing damage in the cities of Dickinson, Friendswood, and League City were not as severe with Hurricane Harvey as with Hurricane Ike. Therefore, the total amount of debris was significantly less at 370,074 CYs. Because the debris from Harvey was mostly C&D, a different formula was used to convert the amounts from CYs to tons. According to USACE, for C&D only, 2 CYs of C&D equals 1 ton. Applying that formula, the 370,074 CYs equates to 185,037 tons.

Using data from the Texas Commission on Environmental Quality (TCEQ), information was collected on the total amounts of material each of the four primary landfills collected from 2007 to 2018.[7] Reports from landfill facilities are based on a fiscal year, which runs from September 1 through August 31. An increase in landfill intake is noted in solid waste and debris collection data for fiscal year 2009 (September 1, 2008 to August 31, 2009) when Hurricane Ike debris operations took place. A spike in solid waste and debris collections is also noted for fiscal year 2018 (September 1, 2017 to August 31, 2018) when the debris operations for Hurricane Harvey would have taken place. The results are listed in Table 9. The remaining capacity of the landfills is listed in Table 10.

[5] Debris Monitoring Disposal Records

[6] Debris Estimating Field Guide, FEMA 329, September 2010

[7] Municipal Solid Waste in Texas: A Year in Review, TCEQ, Years 2007 to 2018

Table 9: Total Amount of Municipal Solid Waste and Debris Collected at the Primary Landfills in Tons From 2007–2018

LANDFILL	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
GALVESTON COUNTY LANDFILL	340,007	344,554	444,880	258,026	295,373	345,194	357,141	402,381	403,514	357,493	393,882	448,851
COASTAL PLAINS LANDFILL	536,710	627,403	646,665	523,005	550,406	418,640	437,147	488,307	495,363	531,755	521,025	455,410
NORTH COUNTY LANDFILL	63,521	66,798	334,131	12,305	392	39	40	18	30	24	20	51,442
DIXIE FARM ROAD LANDFILL	None	63,363	108,589	34,574	34,170	36,794	39,456	38,598	42,092	48,961	48,519	123,599
TOTAL	940,238	1,102,118	1,534,265	827,910	880,341	800,667	833,784	929,304	940,999	938,233	963,446	1,079,302

Table 10: Estimated Remaining Years of the Primary Landfills As of 2017

LANDFILL	Remaining Yards	Remaining Tons	Remaining Years
GALVESTON COUNTY LANDFILL	37,084,042	27,813,032	53
COASTAL PLAINS LANDFILL	12,062,148	11,459,041	22
NORTH COUNTY LANDFILL	3,689,381	2,423,923	50
DIXIE FARM ROAD LANDFILL	1,858,100	817,564	17

In charting the data, as pictured in Figure 14, a spike in waste intake at all four landfills can be seen in the latter part of 2008, after Hurricane Ike made landfall, through 2009, when debris collection efforts were occurring. The highest increase is seen in the Level IV landfills. The Dixie Farm Road Landfill took in three times as much waste in 2009 as it does in a typical year. The North County Landfill took in 334,131 tons in 2009 compared to approximately 65,000 tons per year the two years prior, which was five times its typical intake of waste.

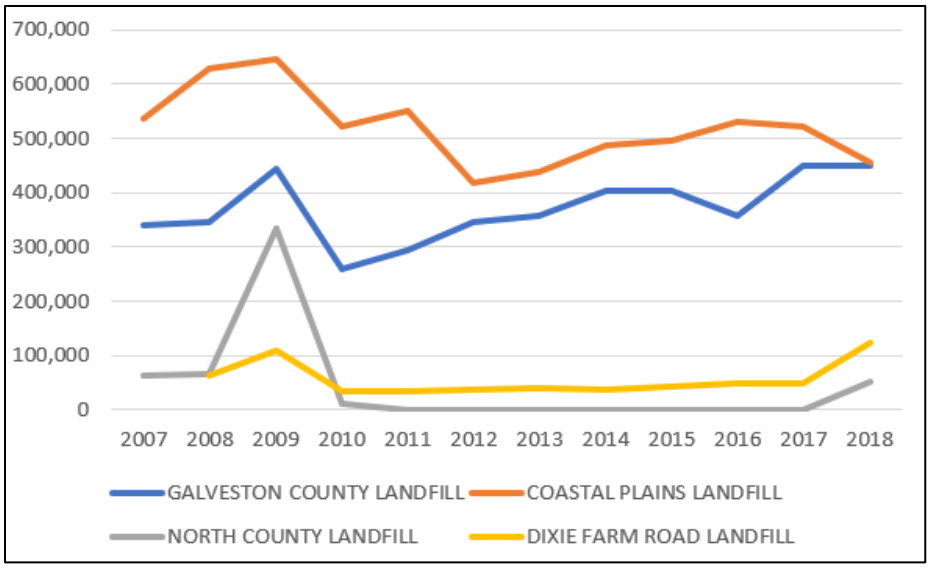

Figure 14: Tons of Waste Received into the Four Primary Landfills From 2007 to 2018

Waste intake from 2011 to 2016 at the Level IV Dixie Farm Road and North County landfills show level intake quantities. At the Galveston County Landfill, the intake quantities show a gradual increase until 2016, when there was a slight decrease. At the Coastal Plains Landfill, there was a steady increase year to year during the 2011 to 2016 time period.

For the year 2017, it is important to note that the reporting period for the *2017 Municipal Solid Waste in Texas: A Year in Review*, the report from which the data is taken, runs from September 1, 2016 to August 31, 2017. Debris activities for Hurricane Harvey did not begin in the Houston-Galveston region until the rains ended, flooding subsided, and roads were cleared of debris. Therefore, debris operations for Hurricane Harvey are not represented until the 2018 reporting period.

In 2018, the Dixie Farm Road and North County landfills experienced significant increases coinciding with debris operations for Hurricane Harvey. The most dramatic change in waste intake is the North County Landfill, which took in only 24 and 20 tons the prior two years but took in 51,442 tons in 2018. The Coastal Plains Landfill numbers start decreasing in 2016, but of the three cities, only League City used the Coastal Plains Landfill and only for three loads during Hurricane Harvey debris operations.

HURRICANE MODELING AND LANDFILL CAPACITY

While Hurricanes Ike and Harvey were both disasters that resulted in extensive damage and large quantities of debris, the worst threat to the region, according to the *Galveston County Multi-Jurisdictional Hazard*

Mitigation Plan and the *City of Dickinson Mitigation Plan*, is a Category 5 hurricane.[8] A Category 5 hurricane has the potential to generate substantial quantities of debris. According to the National Weather Service's Saffir-Simpson Hurricane Wind Scale, in a Category 5 hurricane a high percentage of framed homes will be destroyed with total roof failure and wall collapse. In addition, downed trees and power poles will isolate residential areas, adding to the complexity of response and debris operations.[9]

In the cities of Dickinson, Friendswood, and League City, a Category 5 hurricane has the potential to generate approximately 8,890,000 CY of debris. This figure was derived using the USACE debris estimating model. The USACE model takes into consideration the number of households in the community, the category of hurricane, the amount of vegetation and the concentration of businesses in the impacted areas, as well as whether precipitation associated with the storm can be categorized as light or heavy. The USACE model for estimating the debris quantities is described below:

$$Q=H(C)(V)(B)(S)$$

Where:

Q = CYs (CY) of debris

H = Number of households in the community

C = Storm category factor

V = Vegetative characteristic multiplier

B = Commercial multiplier

S = Precipitation characteristic multiplier

Storm Category

C is the storm category factor as shown below. It expresses debris quantity in CY per household by hurricane category and includes the house, its contents, and land foliage. A Category 5 hurricane category was used in estimating debris quantities.

Table 11: Storm Category Factor

Hurricane Category	Value of "C" Factor
1	2
2	8
3	26
4	50
✓5	80

Vegetative Cover

V is the vegetation multiplier as shown below. It acts to increase the quantity of debris by adding vegetation, including shrubbery and trees, on public rights-of-way.

[8] Galveston County Multi-Jurisdictional Hazard Mitigation Plan, 2016 (Both Friendswood and League City are part of the Galveston County Plan)
City of Dickinson Mitigation Plan, 2017 (The City of Dickinson Mitigation Plan is separate from the Galveston County Multi-Jurisdictional Hazard Mitigation Plan)

[9] National Hurricane Center and Central Pacific Hurricane Center, https://www.nhc.noaa.gov/aboutsshws.php

Light (1.1 multiplier) includes new home developments where more ground is visible than trees. These areas will have sparse canopy cover.

Medium (1.3 multiplier) generally has a uniform pattern of open space and tree canopy cover. This is the most common description for vegetative cover.

Heavy (1.5 multiplier) is found in mature neighborhoods and woodlots where the ground or houses cannot be seen due to the tree canopy cover.

A medium vegetative factor was used for debris estimation purposes.

Table 12: Vegetation Cover Multiplier

Vegetation Cover	Value of "V" Factor
Light	1.1
✓Medium	1.3
Heavy	1.5

Commercial Multiplier

B is the multiplier that considers areas that are not solely single-family residential but includes small retail stores, schools, apartments, shopping centers, and light industrial-manufacturing facilities. Built into this multiplier is the offsetting commercial insurance requirement for owner/operator salvage operations. For debris estimation purposes, a medium commercial multiplier factor was used.

Table 13: Commercial Multiplier Factor

Commercial Density	Value of "B" Factor
Light	1
✓Medium	1.2
Heavy	1.3

Precipitation Multiplier

S is the precipitation multiplier that considers either a "wet" or "dry" storm incident. For debris estimation purposes, a wet storm (medium to heavy) was used.

Table 14: Precipitation Multiplier

Precipitation Characteristic	Value of "S" Factor
None to Light	1
✓Medium to Heavy	1.2

After inputting the values into the equation, the following debris estimates for a Category 5 hurricane affecting Dickinson, Friendswood, and League City were derived. A value for Galveston County was also estimated because it is likely that every jurisdiction will require the services of the landfills located in and near the county. In addition, an average of the annual intake of waste for the primary landfills for years 2010 to 2016 was determined. The years 2010 to 2016 were chosen to determine the average, as those were years unaffected by hurricane debris collection activities. The average tonnage was then converted to cubic yards to provide a comparison to the cubic yardage in hurricane debris. It is important to note that the hurricane model was developed to provide a +/- 30 percent estimate of possible debris. In testing the model

against the Hurricane Ike debris actuals for Galveston County, a 5,256,576 CY estimate was given versus the actual debris quantity collected of 4,690,463, reflecting a 12 percent difference.

Table 15: Category 5 Hurricane Estimates and Annual Waste Intake of Primary Landfills

Category 5 Hurricane Debris Estimates	Estimate in CY
Dickinson	1,120,000
Friendswood	2,170,000
League City	5,600,000
Galveston County (The entire county including Dickinson, Friendswood, and League City)	19,060,000
Average Annual Waste Intake of the 4 Primary Landfills	3,514,992

According to the USACE model, a Category 5 hurricane striking Galveston County may generate approximately 19,060,000 CY of debris, which is roughly 5.4 times the annual intake of waste in the four primary landfills. However, as noted in the experience with Hurricane Ike, approximately 80 percent of the debris, or 15,248,000 CY, is likely to be vegetative debris that can be reduced through either air curtain incineration or grinding. Burning of vegetative debris typically results in a 95 percent reduction rate, which could reduce the vegetative debris to 762,400 CY. Chipping and grinding typically results in a 75 percent reduction rate, which could reduce the vegetative debris to 3,812,000 CY. In addition, compacting C&D debris, either in a DMS or at the landfill, can achieve a 50 percent reduction rate. Therefore, the 19,060,000 CY of debris generated from a Category 5 hurricane can be reduced to either 5,688,000 CY or 2,668,400 CY depending on whether air curtain incineration or grinding is used to reduce the vegetative debris. Additional reductions can be achieved by finding potential markets for mulch, recycling metals, concrete, and other materials.

6. RECOMMENDATIONS

A Category 5 hurricane could shorten the lifespan of area landfills by 5 years. However, by using debris reduction methods and partnering with local stakeholders and contractors with a potential role and resources in debris management, the impact of a disaster on the lifespan of local landfills can be minimized.

The cities of Dickinson and League City were able to develop such a partnership with a local mulch supplier to take and reuse much of the vegetative debris and divert it from local landfills. The City of Friendswood was able to coordinate with a local landfill to establish a DMS on its site to reduce vegetative debris before it was disposed of in the landfill. A vendor was used by all three of the cities to recycle white goods. The City of Dickinson set up a residential drop-off site to enable city residents to deliver and segregate their debris to expedite debris collection efforts. In addition to these activities, the Environmental Protection Agency (EPA) in their guidance document titled *Planning for Natural Disaster Debris* provides other tips for reusing and recycling debris such as shingles, concrete, metals, tires, and other debris that might result from a debris-generating incident.

To capitalize on opportunities to reduce, recycle, and reuse debris generated from a disaster, it is important for jurisdictions to pre-plan and identify those resources in their communities that might play a role and include them in local debris management plans. To follow are recommendations jurisdictions can implement to be better prepared to manage disaster debris and preserve the lifespan of the landfills that serve their communities.

Examine Hazards, Debris Types, and Amounts

Typically, jurisdictions will examine the hazards for which the jurisdiction has vulnerability as part of hazard mitigation or comprehensive emergency plan development. However, taking it a step further to estimate the types and amounts of debris that might be generated in a disaster can give the jurisdiction an idea of the scope of debris operations and the resources that might be needed to respond. In addition to the USACE hurricane debris model included in this report, a risk assessment tool from the Federal Emergency Management Agency (FEMA) called HAZUS can estimate losses and provide debris quantity estimates for hurricanes, earthquakes, floods, and tsunamis. In addition, the experience from past incidents can be used as a reference in planning for future incidents.

Develop a Resource List to Aid in Disaster Debris Management

After determining the types and amounts of debris that could be generated, jurisdictions should develop a list of resources that might be used to help manage disaster debris. Identifying resources in the jurisdiction or region that can aid in processing, reducing, and recycling disaster debris can aid in reducing the effect of disaster debris on the lifespan of local landfills. Potential resources might include metal recyclers, markets for chipped/ground vegetation for mulch or fuel, composting facilities, electronics processing facilities, and potential markets/uses for ash.

Involve Landfill Operators in Disaster Debris Management Planning

Jurisdictions should coordinate with area landfills, examine their availability to accept debris, and consider the potential need to long-haul debris out of the immediate area as necessary if local landfills do not have the capacity or ability to accept debris.

Involve Recycling Companies in Disaster Debris Management Planning

Include recycling, mulching, and other potential companies that might play a role in diverting debris from landfills in planning activities. Determine what processing capabilities they may have and the types of material they can accept as well as arrangements for transportation of the debris to their facility. The U.S.

EPA provides additional suggestions on potential partners in their guidance titled *Planning for Natural Disaster Debris*.[10]

Include Solid Waste Hauler in Disaster Debris Management Planning

The debris hauler will not pick up trash or bagged debris. Therefore, while disaster debris collections are being conducted, trash collection must also continue. Coordinate with the solid waste hauler so there is a clear understanding regarding collection protocols and routes while disaster debris collection is taking place.

Develop and Maintain Disaster Debris Management Plans

Having a Disaster Debris Management Plan (DDMP) can aid a jurisdiction by providing the organizational structure, guidance, and standardized procedures for the clearance, removal, and disposal of debris caused by a major debris-generating incident. In addition, the DDMP can spell out the roles and responsibilities of jurisdiction departments, outside agencies, and contractors that might be called on to assist in response to and recovery from a disaster. The *FEMA Debris Management Plan Review Job Aid* provides additional information on the elements to include in a DDMP.[11]

Develop a Public Information Plan

Following a debris-generating incident, information will need to be communicated to the public quickly regarding proper segregation of debris in the right-of-way and other instructions to expedite debris collections. Having a template prepared in advance will assist the jurisdiction in quickly disseminating the message to residents before they begin bringing debris to the right-of-way. In addition, coordinating the public information messages with neighboring jurisdictions helps to ensure a consistent message is shared, particularly in those areas that share the same news media outlets.

Identify Debris Management Sites in the Jurisdiction

The purpose of a DMS is to provide a location in the community to temporarily store, process, and reduce debris before it is transported to a final disposal facility. Operating a DMS can greatly reduce the quantities of debris going to local landfills. In addition, having the sites determined in advance will also provide the jurisdiction time to establish agreements as needed and determine where the reduced debris will be transported for final disposal or recycling.

Identify and Implement Mitigation Actions to Reduce Debris from Disasters

As a broader measure, jurisdictions can seek mitigation funding and opportunities to identify and implement mitigation actions to reduce debris from disasters. In short, this involves raising or removing structures from floodprone areas; retrofitting structures so they are better able to withstand natural hazards such as high winds, rain, and hail; and adhering to building codes and plans to ensure homes and other structures are not built in hazard areas like flood zones. The FEMA document titled *Mitigation Ideas, A Resource for Reducing Risk to Natural Hazards* provides suggestions for mitigation actions that can help reduce risk from natural hazards and disasters.[12] In addition, the FEMA document titled *Selecting Appropriate Mitigation Measures for Floodprone Structures* provides guidance to State and local officials working with community officials and property owners to implement projects that reduce or eliminate risks from flooding.[13]

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[10] Planning for Natural Disaster Debris, EPA, April 2019

[11] Public Assistance Alternative Procedures Pilot Program – Debris Removal, Debris Management Plan Review Job Aid, FEMA, June 2015

[12] Mitigation Ideas, A Resource for Reducing Risk to Natural Hazards, FEMA, January 2013

[13] Selecting Appropriate Mitigation Measures for Floodprone Structures, FEMA 551, March 2007