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Updated General Aviation Non-Airport Crash Density Values Using Data Obtained from the U.S. National Transportation Safety Board for 2000 through 2019

William C. Walker

March 2026

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Nuclear Facility Safety Division

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ACRONYMS AND ABBREVIATIONS

ACRAM	Aircraft Crash Risk Analysis Methodology
ANS	American Nuclear Society
APR	approach
CONUS	Contiguous United States
DOE	Department of Energy
EMG	emergency descent
ENR	en-route
FAF	final approach fix
FW	fixed wing
GA	general aviation
IAF	initial approach fix
ICAO	International Civil Aviation Organization
ICL	initial climb
IFR	Instrument Flight Rules
LDG	landing
LLNL	Lawrence Livermore National Laboratory
MNV	maneuvering
NRC	Nuclear Regulatory Commission
NTRL	National Technical Reports Library
NTSB	National Transportation Safety Board
ORNL	Oak Ridge National Laboratory
PBT	pushback/towing
PIM	post-impact
PoF	phase of flight
RW	rotary wing
STD	standing
TOF	takeoff
TXI	taxi
UND	uncontrolled descent
UNK	unknown
VFR	Visual Flight Rules

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ABSTRACT

This report updates non-airport general aviation (GA) crash density values for major US Department of Energy (DOE) sites and US Nuclear Regulatory Commission (NRC)–licensed power stations within the contiguous United States using National Transportation Safety Board (NTSB) data from 2000–2019. Following DOE-STD-3014-2006 and the Aircraft Crash Risk Analysis Methodology (ACRAM) standard, site-specific crash density is computed as $N \times P \times f(x,y)$, where $f(x,y)$ is a symmetric bivariate Gaussian kernel density statistical model. The NTSB dataset was cleaned to remove incidents, duplicate records, events with no or minor damage, non- Contiguous United States (CONUS) locations, and entries without geolocation; aircraft type (fixed-wing versus rotary-wing) and the International Civil Aviation Organization (ICAO) phase of flight were identified, with non-airport phases defined as en route, maneuvering, emergency descent, and uncontrolled descent. Consolidated crash databases were developed for 2000–2019 and 2010–2019 and analyzed for all GA (fixed-wing + rotary-wing), fixed-wing only, and rotary-wing only.

For 2000–2019, 7,639 non-airport GA accidents were identified (annualized 1.0E-04 crashes/yr/mi^2) yet provides sufficient data for robust estimation; results are reported to one significant digit consistent with DOE-STD-3014. Site-specific densities and sensitivity analyses on kernel bandwidth are provided for DOE and NRC sites, with tabulated contributions from the nearest accidents. The observed rotary-wing contribution indicates that nonlocal helicopter overflights are not negligible and should be included in crash frequency assessments. These updated estimates are intended to support development of ANS-2.36, Accident Analysis for Aircraft Crash into Reactor and Nonreactor Nuclear Facilities.

1. DATA COLLECTION AND HANDLING

1.1 REQUEST AND RECEIPT OF GA ACCIDENT / INCIDENT DATA

In January 2022 a data request was sent to the National Transportation Safety Board (NTSB) requesting the following General Aviation Accident/Incident Data (Federal Aviation Regulations Part 91) for calendar years 2000 through 2019:

- NTSB Accident Number
- Accident date
- Accident location (city, state, if available)
- Latitude
- Longitude
- Injury severity (e.g., non-fatal, fatal(1), fatal(2), etc.)
- Aircraft damage (e.g., minor, substantial, destroyed, etc.)
- Aircraft make (e.g., Beech, Cessna, Piper, etc.)
- Aircraft model (e.g., 172, PA32RT, FALCON 50, etc.)
- Number of engines (e.g., 1, 2, 3, 4, etc.)
- Engine type (e.g., reciprocating, turbo prop, turbo fan, turbo jet, electric, etc.)
- Broad phase of flight (e.g., landing, takeoff, climb, approach, cruise, maneuvering, go-around, etc.)
- Event type (Accident, Incident, etc.)

In February 2022, the NTSB provided an excel file with the requested data set. The GA Accident / Incident Data was reported on two spreadsheets within the Excel file:

- 2000-2007 GA Accidents / Incidents
- 2008-2019 GA Accidents / Incidents

1.2 FILTERING OUT EVENTS CLASSIFIED AS INCIDENTS

The NTSB data set included events listed as either accidents or as incidents. Per the NTSB, these are defined as follows:

> **Aircraft Accident** means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. For purposes of this part, the definition of "aircraft accident" includes "unmanned aircraft accident," as defined herein.
>
> **Incident** means an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.

Based on the above definition, events that were classified as Incidents were filtered out from further consideration. As noted in Table 1, accidents comprise 98.8% of all events in the data set and incidents comprise 1.2% of all events in the data set.

Table 1. Summary of GA accidents / incidents in NTSB data set [2000-2019]

Data Set	Accident Entries	Incident Entries	TOTAL
2000-2007	12,429	126	12,555
2008-2019	15,664	226	15,890
TOTAL	**28,093**	**352**	**28,445**
Distribution (%)	**98.8%**	**1.2%**	**100%**

1.3 IDENTIFYING AND FILTERING OUT DUPLICATE AIRCRAFT ACCIDENT EVENTS

A review of the NTSB data set noted multiple events entries associated with the same aircraft/accident. A column was added to the NTSB Data set to annotate duplicate events. Figure 1 illustrates an example where a single aircraft accident was listed multiple times in the NTSB data file associated with 2008-2019. A total of 1,159 duplicate accident events were annotated in and filtered out of the 2008-2019 data set. No duplicate accident events were found in the 2000-2007 NTSB data set.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Mkey	NTSBNumber	EventDa	EventYe	EventTy	City	StateOr	Latitude	Longitu	Highest	Aircraft	Aircraft	DamageLeve	EngineN	EngineT	PhaseN	Phase_	Other	Duplica	Rotary ng
15096	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	2	ELEC	Uncontroll	UND	Powered		
15097	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	9	ELEC	Uncontroll	UND	Powered	X	
15098	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	8	ELEC	Uncontroll	UND	Powered	X	
15099	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	7	ELEC	Uncontroll	UND	Powered	X	
15100	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	6	ELEC	Uncontroll	UND	Powered	X	
15101	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	5	ELEC	Uncontroll	UND	Powered	X	
15102	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	3	ELEC	Uncontroll	UND	Powered	X	
15103	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	1	ELEC	Uncontroll	UND	Powered	X	
15104	99537	DCA19LA154	4-Jun-19	2019	ACC	Manassas	VA	38.72194	-77.5178	NONE	AURORA	PAV	Substantial	4	ELEC	Uncontroll	UND	Powered	X	

Figure 1. Example of duplicate accident event entries in the 2008-2019 NTSB data set

1.4 FILTERING OUT ACCIDENTS WITH AIRCRAFT DAMAGE LISTED AS "NONE" OR "MINOR"

One of the fields provided in the NTSB data was a designation of the aircraft damage associated with the accident. The damage is listed as one of the four: (1) None, (2) Minor, (3) Substantial, and (4) Destroyed. As discussed in the Lawrence Livermore National Laboratory (LLNL) 1996 Report, Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard (i.e., ACRAM Report) [(1)]:

> *…different definitions of aircraft accidents and aircraft crashes were not necessary since virtually all general aviation accidents resulted in destruction of substantial damage to the aircraft. Therefore, for general aviation only, the terms aircraft accidents and aircraft crashes are used synonymously.*

Consistent with the ACRAM analysis, events that only result in minor aircraft damage or no aircraft damage were filtered out from further consideration. A total of 304 accidents removed from further consideration due to being designated as no damage, minor damage, or not assigned a damage category (See Table 3).

1.5 IDENTIFYING GA ACCIDENT DATA BY PHASE OF FLIGHT

The treatment of the Phase of Flight listed for each GA Accident event was dispositioned in a manner consistent with the analytical methodology employed by the ACRAM report and Table B-14 of DOE-STD-3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*. [(2)] As noted in Chapter 3 the ACRAM report:

> *Because of the number of phases of operation used by the NTSB in their general aviation accident summary document, and because the ACRAM standard only defined three flight phase for its frequency analysis, it was judged necessary to combine the phases of operation in a smaller set of flight phases that could be more easily matched with the ACRAM flight phases.*

Table 2 summarizes the Phase of Flight (PoF) categories as specified by the International Civil Aviation Organization (ICAO) [(3)] and as employed by the NTSB in the aviation accident database for General Aviation aircraft. As noted in Table 2, the following PoFs are considered to be associated with Non-Airport operations: (1) En-Route (ENR), (2) Maneuvering (MNV), (3) Emergency Descent (EMG), and (4) Uncontrolled Descent (UND).

Table 2. Broad Phases of Flight

NTSB Phase of Flight	Abbrev.	Description	Airport Operation / Non-Airport Operation
STANDING	STD	Prior to pushback or taxi, or after arrival, at the gate, ramp, or parking area, while the aircraft is stationary.	N/A
PUSHBACK / TOWING	PBT	Aircraft is moving in the gate, ramp, or parking area, assisted by a tow vehicle (tug).	N/A
TAXI	TXI	The aircraft is moving on the aerodrome surface under its own power prior to takeoff or after landing.	N/A
TAKEOFF	TOF	From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation.	Airport Operation
INITIAL CLIMB	ICL	From the end of the Takeoff subphase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation or the VFR pattern, whichever comes first.	Airport Operation

Table 2. Broad Phases of Flight (continued)

NTSB Phase of Flight	Abbrev.	Description	Airport Operation / Non-Airport Operation
EN ROUTE	ENR	Instrument Flight Rules (IFR): From completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF). Visual Flight Rules (VFR): From completion of Initial Climb through cruise and controlled descent to the VFR pattern altitude or 1,000 feet above runway elevation, whichever comes first.	**Non-Airport Operation**
MANEUVERING	MNV	Low altitude/aerobatic flight operations.	**Non-Airport Operation**
APPROACH	APR	Instrument Flight Rules (IFR): From the Initial Approach Fix (IAF) to the beginning of the landing flare. Visual Flight Rules (VFR): From the point of VFR pattern entry, or 1,000 feet above the runway elevation, to the beginning of the landing flare.	Airport Operation
LANDING	LDG	From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing.	Airport Operation
EMERGENCY DESCENT	EMG	A controlled descent during any airborne phase in response to a perceived emergency situation.	**Non-Airport Operation**
UNCONTROLLED DESCENT	UND	A descent during any airborne phase in which the aircraft does not sustain controlled flight.	**Non-Airport Operation**
POST-IMPACT	PIM	Any of that portion of the flight which occurs after impact with a person, object, obstacle or terrain.	N/A
UNKNOWN	UNK	Phase of flight is not discernible from the information available.	N/A

Note: Phase of Flight categories were obtained from the ICAO Publication, *Phase of Flight: Definitions and Usage Notes* (3)

Table 3 summarizes the GA accidents from 2000 through 2007 by PoF, and Table 4 summarizes the number of GA accidents from 2008 through 2019 by PoF.* Table 5 collectively summarizes all GA accidents from 2000 through 2019 by ICAO PoF and Table 6 summarizes the same data by ANS 2.36 PoF groups. Figure 2 graphically illustrates the distribution of all GA accidents from 2000 through 2019 by ANS 2.36 PoF group.

* Accidents with a PoF designation of "Unknown" are not tabulated and therefore not reported in Table 3 or Table 4.

Table 3. Summary of All GA Accidents by Phase of Flight [2000-2007]

STANDING			**111**
	Standing	5	
	Standing – Engine(s) Not Operating	5	
	Standing – Engine(s) Operating	33	
	Standing – Idling Rotors	13	
	Standing – Preflight	12	
	Standing – Starting Engine(s)	43	
PUSHBACK / TOWING			**1**
	Taxi – Pushback / Towing	1	
TAXI			**304**
	Taxi	89	
	Taxi – Aerial	13	
	Taxi – From Landing	112	
	Taxi – To Takeoff	90	
TAKEOFF			**943**
	Takeoff	335	
	Takeoff – Aborted	137	
	Takeoff – Roll/Run	471	
INITIAL CLIMB			**1,462**
	Takeoff – Initial Climb	1,462	
EN ROUTE			**2,560**
	Climb	212	
	Climb – To Cruise	147	
	Cruise	1,393	
	Cruise – Normal	528	
	Descent	170	
	Descent – Normal	110	
MANEUVERING			**1,345**
	Hover	69	
	Hover – In Ground Effect	65	
	Hover – Out of Ground Effect	28	
	Maneuvering	1,099	
	Maneuvering – Aerial Application	8	
	Maneuvering – Holding (IFR)	1	
	Maneuvering – Turn to Landing Area (EMERGENCY)	5	
	Maneuvering – Turn to Reverse Direction	70	
APPROACH			**1,668**
	Approach	374	
	Approach – Circling (IFR)	13	
	Approach – FAF/Outer Marker to Threshold (IFR)	79	
	Approach – IAF to FAF/Outer Marker (IFR)	24	
	Approach – VFR Pattern – Base Leg/Base to Final	122	
	Approach – VFR Pattern – Base Turn	61	
	Approach – VFR Pattern – Downwind	129	
	Approach – VFR Pattern – Final Approach	559	
	Approach – VFR Pattern – Go Around	227	
	Missed Approach (IFR)	30	

Table 3. Summary of All GA Accidents by Phase of Flight [2000-2007] (continued)			
LANDING			**3,731**
	Emergency Landing	16	
	Emergency Landing After Takeoff	11	
	Landing	693	
	Landing – Aborted	164	
	Landing – Flare/Touchdown	1,261	
	Landing – Roll	1,586	
EMERGENCY DESCENT			**45**
	Descent – Emergency	16	
	Emergency Descent/Landing	29	
DESCENT UNCONTROLLED			**29**
	Descent – Uncontrolled	29	
POST-IMPACT			**--**
	Post-Impact	--	
ALL PHASES OF FLIGHT			**12,199**

Table 4. Summary of All GA Accidents by Phase of Flight [2008-2019]

STANDING			**164**
	Standing	10	
	Standing – Engine(s) Not Operating	17	
	Standing – Engine(s) Operating	55	
	Standing – Shutdown	3	
	Standing – Startup	79	
PUSHBACK / TOWING			**--**
	Taxi – Pushback / Towing	--	
TAXI			**411**
	Taxi	155	
	Taxi – From Runway	135	
	Taxi – Into Takeoff Position	26	
	Taxi – To Runway	95	
TAKEOFF			**1,722**
	Takeoff	1,540	
	Takeoff – Rejected Takeoff	182	
INITIAL CLIMB			**1,626**
	Takeoff – Initial Climb	1,626	
EN ROUTE			**2,486**
	Enroute	592	
	Enroute – Change of Cruise Level	21	
	Enroute – Climb to Cruise	259	
	Enroute – Cruise	1,377	
	Enroute – Descent	236	
	Enroute – Holding (IFR)	1	
MANEUVERING			**1,720**
	Autorotation	95	
	Maneuvering	785	
	Maneuvering – Acrobatics	98	
	Maneuvering – Hover	125	
	Maneuvering – Low-alt Flying	617	
APPROACH			**1,830**
	Approach	385	
	Approach – Circling (IFR)	15	
	Approach – IFR Final Approach	94	
	Approach – IFR Initial Approach	37	
	Approach – IFR Missed Approach	48	
	Approach – VFR Go-Around	304	
	Approach – VFR Pattern Base	164	
	Approach – VFR Pattern Crosswind	23	
	Approach – VFR Pattern Downwind	177	
	Approach – VFR Pattern Final	583	

Table 4. Summary of All GA Accidents by Phase of Flight [2008-2019] (continued)

LANDING			**5,215**
	Landing	1,397	
	Landing – Aborted After Touchdown	101	
	Landing – Flare/Touchdown	1,651	
	Landing – Roll	2,066	
EMERGENCY DESCENT			**87**
	Emergency Descent	87	
DESCENT UNCONTROLLED			**42**
	Uncontrolled Descent	42	
POST-IMPACT			**8**
	Post-Impact	8	
ALL PHASES OF FLIGHT			**15,311**

Table 5. Summary of All GA Accidents by Phase of Flight [2000-2019]

Broad ICAO Phase of Flight	ANS 2.36 Broad Operation Phase	2000-2007	2008-2019	TOTAL
STANDING	Ground Ops	111	164	275
PUSHBACK / TOWING	Ground Ops	1	--	1
TAXI	Ground Ops	304	411	715
TAKEOFF	Takeoff	943	1,722	2,665
INITIAL CLIMB	Takeoff	1,462	1,626	3,088
EN ROUTE	Non-Airport	2,560	2,486	5,046
MANEUVERING	Non-Airport	1,345	1,720	3,065
APPROACH	Landing	1,668	1,830	3,498
LANDING	Landing	3,731	5,215	8,946
EMERGENCY DESCENT	Non-Airport	45	87	132
DESCENT UNCONTROLLED	Non-Airport	29	42	71
POST-IMPACT	Other	--	8	8
TOTAL		**12,199**	**15,311**	**27,510**

Table 6. Summary of All GA Accidents by ANS 2.36 Operation Phase [2000-2019]

ANS 2.36 Operation Phase	Number of Accidents	Percent of Total
Ground Ops	991	3.6%
Takeoff	5,753	20.9%
Non-Airport	8,314	30.2%
Landing	12,444	45.2%
Other	8	0.0%
TOTAL	**27,510**	**100.0%**

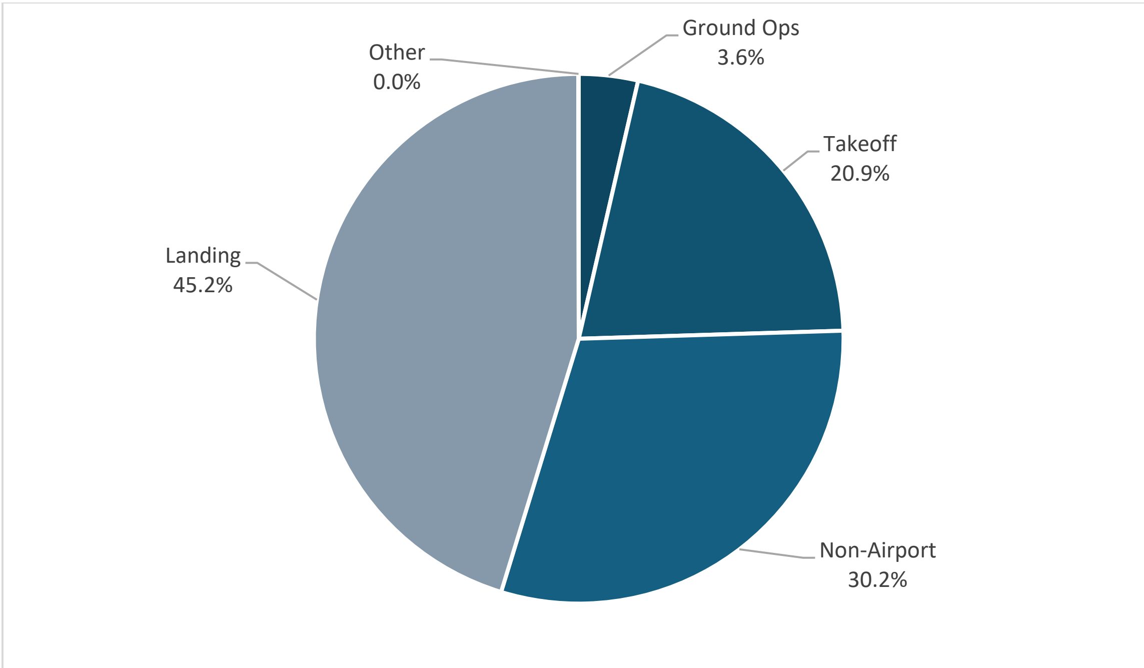

Figure 2. Distribution of all general aviation aircraft accidents by ANS 2.36 broad phase of operation

1.6 IDENTIFICATION OF NON-FIXED WING AIRCRAFT IN THE NTSB DATA SET

The following identifications were also annotated in the NTSB data set in preparation of the GA fixed-wing non-airport aircraft crash density analysis:

- Identify events associated with balloons, gliders, and powered parachutes.
- Identify duplicate events in the data set.
- Identify events associated with rotary wing aircraft.

The identification of gliders, balloons, powered parachutes, and duplicate entries in the NTSB data set was conducted so that subsequent filtering out of these instances could be done during preparation of data frames to be used for the crash density analysis. Also, aircraft wing types were annotated so that rotary wing accidents and fixed wing accidents can be evaluated separately.

1.7 PREPARATION OF CONUS NON-AIRPORT GA ACCIDENT DATA FRAMES

The annotated NTSB Data sets were then processed using an R programming code specifically developed for the creation of CONUS[†] Non-Airport GA Accident Data Frames to be used in the site-specific crash density analysis. The R code used in the preparation of the CONUS Non-Airport GA Accident Data Frames, "*GA crashes_NTSB 2022.R*" is provided in Appendix C of this report.

[†] CONUS: Contiguous United States, which consists of 48 adjoining U.S. states and the Federal District of Columbia

The following data filtering is performed within the code:

- Removal of events identified as Incidents.
- Removal any identified duplicate events.
- Removal of events associated with balloons, gliders, and powered parachutes.
- Removal of events that occurred outside of the CONUS
- Removal of events with no reported latitude/longitude data

The remaining data after the above filtering comprised All CONUS Non-Airport GA Accidents 2000-2019. This filtered data set is then directly used to create the following output data to be used in the crash density analysis for the time period of 2000-2019:

- 2000_2019 GA Nonairport Crash Data.csv
- 2000_2019 GA NonAirport Crash Data_No Rotary.csv
- 2000_2019 GA NonAirport Crash Data_Rotary.csv

A truncated output data was similarly created by filtering out all pre-2010 accidents from the 2000-2019 data set of All CONUS Non-Airport GA Accidents, thus yielding the following output data sets to be used in the crash density analysis for the time period of 2010-2019:

- 2010_2019 GA NonAirport Crash Data.csv
- 2010_2019 GA NonAirport Crash Data_No Rotary.csv
- 2010_2019 GA NonAirport Crash Data_Rotary.csv

1.8 CREATION OF CONSOLIDATED NON-AIRPORT GA ACCIDENT DATABASE

Table 7 summarizes the number of CONUS Non-Airport GA Accidents for the twenty-year period (2000-2019), the recent ten-year period (2010-2019) and the eight-year ACRAM data collection period for GA accidents (1986-1993).

Table 7. Comparison of GA Crash Rates: ACRAM [1986-1993] and Recent NTSB Data [2000-2019] and [2010-2019]

Data Set Time Period	Aircraft in Data Set(1)	Number of Accidents	Percentage of Data Set [%]	Annualized GA CONUS Non-Airport Crash Rate [crashes/yr]	Mean CONUS Crash Density(2) [crashes/yr/mi^2]
2000 – 2019	FW & RW	7,639	100.0%	382.0	1.2E-04
	FW only	6,520	85.4%	326.0	1.0E-04
	RW only	1,119	14.6%	56.0	1.8E-05
2010 – 2019	FW & RW	3,274	100.0%	327.4	1.0E-04
	FW only	2,787	64.8%	278.7	8.9E-05
	RW only	487	14.9%	48.7	1.6E-05
ACRAM (1986 – 1993)	--	4,181	--	522.6	1.7E-04

Notes: (1) FW: Fixed Wing; RW: Rotary Wing
(2) CONUS Area is 3,119,885 mi^2

Observations from Table 7 include the following:

- DOE-STD-3014 states that "*based on an analysis of historical helicopter crash data, the contribution to impact frequencies associated with nonlocal helicopter overflights is insignificant and need not be considered in the impact frequency calculation.*" A review of the data from Table 7 notes that the relative percentage of Rotary Wing accidents in the NTSB data set (~15%) is not insignificant. As such, the inclusion of nonlocal helicopter overflight crash density estimates is recommended to be included in ANS 2.36 standard crash frequency methodology.

- The 10-year NTSB data set has 3,274 GA CONUS Non Airport Accidents (fixed wing and rotary wing). The 10-year NTSB data set has 907 fewer crashes than the ACRAM data set (approximately 21.7% less than the ACRAM GA CONUS accident data set).

    - The reduction of total GA accidents does not adversely affect an analysis of the 10-year [2010-2019] data set. The methodology employed in the GA crash density estimate utilizes a Gaussian distribution model that evaluates the radial-distance to every crash in the data set relative to the evaluated site. The 10-year [2010-2019] data set contains a sufficient quantity of input data to support the use of the selected methodology.

    - The ACRAM report does not provide a detailed uncertainty analysis associated with the calculation of site-specific crash density values. DOE-STD-3014 addresses the relative uncertainty associated with the calculated site-specific data by only reporting non-airport crash density values to one-significant digit in Table B-15 of the standard. The uncertainty associated with the analysis of the 10-year [2010-2019] data set is expected to be bounded by similarly only reporting the updated crash density values to one-significant digit. Therefore, the 10 year period [2010-2019] of GA CONUS Non Airport Accidents are assessed to be statistically acceptable for analysis using the same methodology as was used in the ACRAM report.

1.9 DATA FILTERING SUMMARY

Appendix E contains a data summary report of the filtering of NTSB raw data for the creation of the GA CONUS Non-Airport Accident files used for the calculation of site specific crash density values.

Figure 3 illustrates the distribution of CONUS non-airport fixed-wing GA aircraft events incurring substantial damage or destroyed using the filtered GA accident data. The data was plotted using a software application called QGIS.[‡]

Individual GA crash events are illustrated as red dots, DOE sites are indicated as green dots, NRC regulated power generating sites are indicated as purple dots. The heat map (shaded red) areas are autogenerated by the QGIS software application and are presented for informational/illustrative purposes only (the heat map data is not used in calculations within this result).

[‡] QGIS is a geographic information system (GIS) software that is free and open-source, which enables users to visualize data using maps, charts, and diagrams.

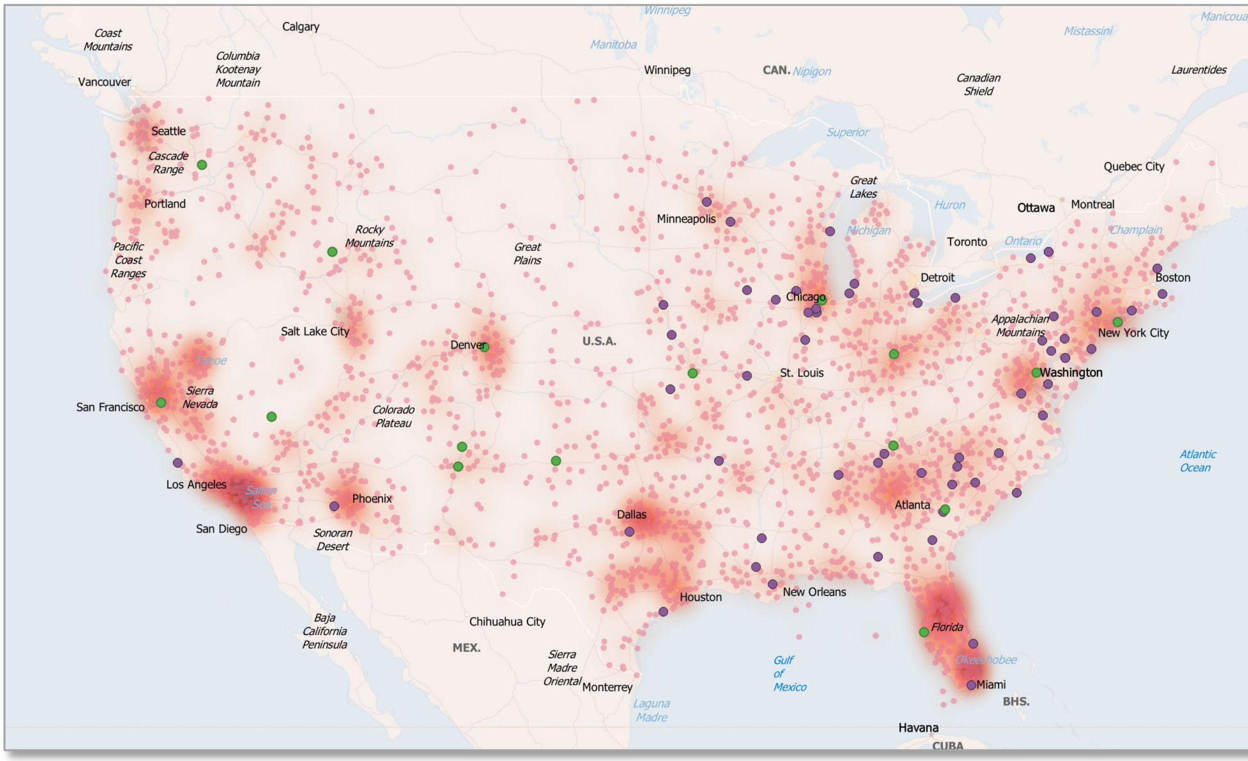

Figure 3. Illustration of Non-Airport General Aviation Accidents from 2000-2019: Fixed Wing only

2. ESTIMATING SITE SPECIFIC CRASH DENSITY

2.1 METHODOLOGY

The approach for general aviation was to develop a distribution of crash locations throughout the entire CONUS based on the historical data. This is a reasonable approach because there is a sizable database of crash locations derived from the NTSB database of aircraft crashes. This distribution spatially represents the relative frequencies of crashes throughout the CONUS given a crash. Then, given the expected frequency of general aviation crashes per year, this can be combined with the probability of a crash occurring in a specified 1-mi^2 area to estimate the product NPf(x, y).The calculation of the crash density is based on the following equation:

$$\rho_{GA,nonairport} = N * P * f(x,y) = \frac{f'(x,y)}{T} \qquad \text{Eqn. 1}$$

where

$\rho_{GA,nonairport}$	= Annualized Non-airport GA crash density [crashes/yr/mi^2]
N	= annualized aircraft operations [ops/yr]
P	= aircraft crash probability [crashes/op]
$f(x,y)$	= crash location conditional probability [mi^{-2}]
$f'(x,y)$	= Crash density probability for the evaluated time period [crashes/mi^2]
T	= Evaluated time period [yr]

The crash location conditional probability is modeled using a bivariate Gaussian probability distribution, expressed as follows (from the LANL Report, *ACRAM Modeling Technical Support Document*, LA-UR-96-2460. Sept. 1996): (4)

$$f'(x,y) = \frac{1}{2\pi n h_x h_y} \sum_{i=1}^{n} e^{\left(-\frac{(x-x_i)^2}{2h_x^2} - \frac{(y-y_i)^2}{2h_y^2}\right)} \qquad \text{Eqn. 2}$$

where

$f'(x,y)$	= Crash location conditional probability [crashes/mi^2]
(x_i, y_i)	= Cartesian coordinate location of plane crash "i"
(h_x, h_y)	= bandwidth estimators (i.e., smoothing parameters) [mi]
n	= total number of crashes evaluated

As noted in the ACRAM Modeling Technical Support Document, since GA aircraft generally fly from point to point, the smoothing should be symmetrical in x and y, hence, $h_x = h_y$. Since the bivariate probability is specified to be symmetrical, Equation 2 can be simplified as follows by letting $h_x = h_y = s$:

$$f(s) = \frac{1}{2\pi n h_s^2} \sum_{i=1}^{n} e^{\left(-\frac{{s_i}^2}{2{h_s}^2}\right)} \quad \text{Eqn. 3}$$

where

$f(s)$	= Crash density probability for the evaluated time period [crashes/mi^2]
(s_i)	= Distance of plane crash "i" from the site
(h_s)	= bandwidth estimators (i.e., smoothing parameters) [mi]
n	= total number of crashes evaluated

The shortest distance between two points (P_1 and P_2) on the surface of the Earth is represented as a "geodesic." A geodesic is a minor arc of a great-circle that passes through points P_1 and P_2, as illustrated in Figure 4.

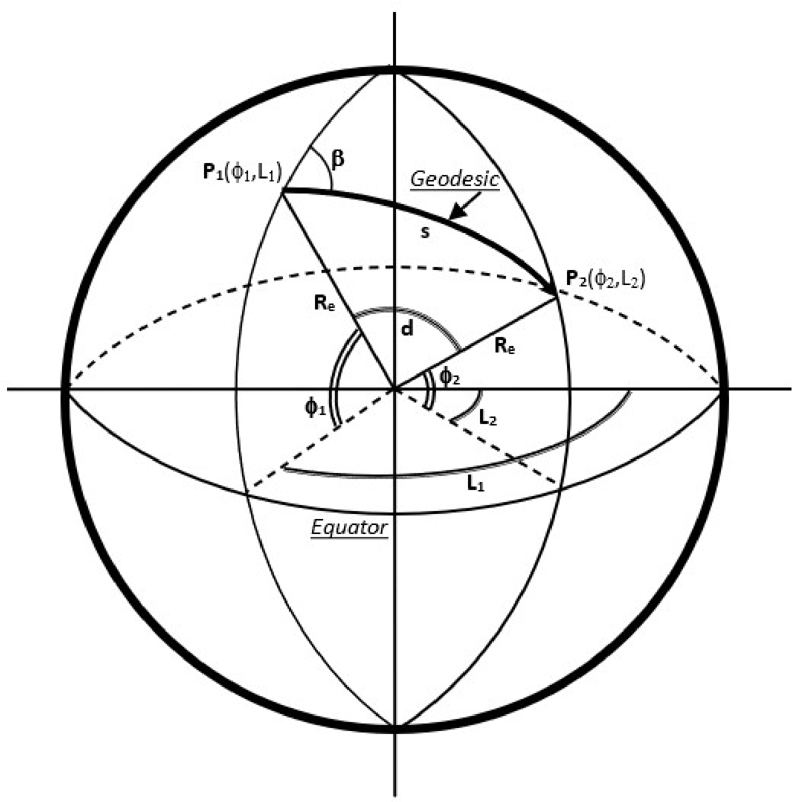

Figure 4. Geodesic (great-circle minor arc) between points P_1 and P_2

The standard convention for identifying the location of a specific point on the surface of the Earth is based on a geographic coordinate system. The geographic coordinate system utilizes two specific values to specify the unique location of a specific point on the surface of the Earth, the longitude and latitude:

- The latitude (ϕ) is the angle between the equatorial plane and a straight line that passes through the point and through the center of the earth. The latitude is expressed in degrees and ranges from 0° to 90°. The 0° latitude is coincident with the equator and the 90° latitudes are coincident with the poles. A north (N) / south (S) designator is used to describe which side of the equator the point is located. In Figure 4, point P_1 is located along latitude ϕ_1 and point P_2 is located along latitude ϕ_2. By convention, northern latitudes are expressed as a positive value and southern latitudes are expressed as a negative value.

- The longitude (L) of a point is the angle east or west of the Prime Meridian (i.e., the 0° reference longitude). The longitude is expressed in degrees and ranges from 0° to 180°. An east (E) / west (W) designator is used to describe which side of the Prime Meridian the point is located. In Figure 4, point P_1 is located along longitude L_1 and point P_2 is located along longitude L_2. By convention, western longitudes are expressed as a negative value, and eastern longitudes are expressed as a positive value.

If the Earth were representative of a perfect sphere, the angular distance (d) between two points, $P_1(\phi_1, L_1)$ and $P_2(\phi_2, L_2)$, can be calculated as follows:

$$\cos(d) = \sin(\phi_1) * \sin(\phi_2) + \cos(\phi_1) * \cos(\phi_2) * \cos(L_1 - L_2) \qquad \text{Eqn. 4}$$

with the resulting linear distance (s) between two points P_1 (L_1, ϕ_1) and P_2 (L_2, ϕ_2) expressed as:

$$s = R_e * \frac{\pi * d}{180} \qquad \text{Eqn. 5}$$

The assumption that the Earth can be modelled as a perfect sphere results in an inaccurate determination of the distance (s) between two points. The radius of the Earth (R_e) is actually slightly greater at the equator than at the poles. Essentially, the Earth is slightly flattened, with the bulge centered along the equatorial plane. In essence, the Earth is best represented as an oblate spheroid (i.e., a symmetrical 3-D representation of an ellipse).

The amount of flattening (i.e., the quantitative deviation from being a perfect sphere) of the Earth is expressed as follows:

$$f = \frac{R_{equator} - R_{pole}}{R_{equator}} \qquad \text{Eqn. 6}$$

where

f = spheroid flatness [unitless]

$R_{equator}$ = radius of the Earth along the equatorial plane [6378.14 km] [(5)]

R_{pole} = radius of the Earth to the poles [6356.76 km] [(5)]

Substituting the values for the radii into Equation 6 yields the flatness value of the Earth as:

$$f = \frac{6378.14 - 6356.76}{6378.14} = 0.003353$$

The algorithm for determining the distance between two points on the surface of an oblate spheroid is documented in *Astronomical Algorithms*, Second Edition [(5)] and only requires the following input values:

$P_1\ (L_1, \phi_1)$	= location of point 1 (in terms of longitude and latitude)
$P_1\ (L_1, \phi_1)$	= location of point 2 (in terms of longitude and latitude)
f	= flatness coefficient of the Earth [0.003353]
$R_{equator}$	= radius of the Earth along the equatorial plane [6378.14 km]

Using the above input values, the distance between two points on the Earth's surface can be calculated as follows using Equation 7 through Equation 17:

$$F = \frac{\phi_1 + \phi_2}{2} \qquad \text{Eqn. 7}$$

$$G = \frac{\phi_1 - \phi_2}{2} \qquad \text{Eqn. 8}$$

$$\lambda = \frac{L_1 - L_2}{2} \qquad \text{Eqn. 9}$$

$$S = sin^2(G) * cos^2(\lambda) + cos^2(F) * sin^2(\lambda) \qquad \text{Eqn. 10}$$

$$C = cos^2(G) * cos^2(\lambda) + sin^2(F) * sin^2(\lambda) \qquad \text{Eqn. 11}$$

$$\tan(\omega) = \sqrt{\frac{S}{C}} \qquad \text{Eqn. 12}$$

where ω is expressed in radians

$$\mathrm{R} = \frac{\sqrt{SC}}{\omega} \qquad \text{Eqn. 13}$$

$$D = 2 * \omega * R_{equator} \qquad \text{Eqn. 14}$$

$$H_1 = \frac{3R - 1}{2C} \qquad \text{Eqn. 15}$$

$$H_2 = \frac{3R + 1}{2S} \qquad \text{Eqn. 16}$$

And finally, the calculated distance (in units of km) between two points is determined using the following equation:

$$s = D[1 + f * H_1 * sin^2(F) * cos^2(G) - f * H_2 * cos^2(F) * sin^2(G)] \qquad \text{Eqn. 17}$$

The calculated distance "s" can subsequently be converted to units of miles by multiplying Eq. 17 by 0.62137119 mi/km.

In the application of the above methodology, a standard convention is employed which specified point P_1 as the facility of concern and point P_2 as the evaluated aircraft accident location.

The following distance function in the R code (see Appendix C) employs Equation 7 through Equation 17 for calculating the distance between two points on the Earth.

```
distance <- function(lat1,long1,lat2,long2){

  F <- ((lat1+lat2)/2)*(pi/180)
  G <- ((lat1-lat2)/2)*(pi/180)
  lamda <- ((long1-long2)/2)*(pi/180)
  S <- sin(G)^2*cos(lamda)^2+cos(F)^2*sin(lamda)^2
  C <- cos(G)^2*cos(lamda)^2+sin(F)^2*sin(lamda)^2
  tan_w <- (S/C)^0.5
  w <- atan(tan_w)
  R <- ((S*C)^0.5)/w
  D <- 2*w*R_equator
  H1 <- (3*R - 1)/(2*C)
  H2 <- (3*R + 1)/(2*C)
  s <- D*(1+f*H1*sin(F)^2*cos(G)^2-f*H2*cos(F)^2*sin(G)^2)
  s <- s*km_mi                  #Converts from km to miles

  return(s)
}
```

Figure 5. Distance function from R code

2.2 SITE-SPECIFIC CRASH DENSITY CALCULATION

The CONUS non-airport GA accident data set was used to calculate the following site-specific crash density estimates:

- All GA (FW +RW)
- Fixed-Wing only
- Rotary-Wing only

The sites include all significant DOE sites and all U.S. NRC regulated nuclear power-generating stations within the CONUS.

2.3 RESULTS

Appendix A documents crash density estimates for the DOE and NRC sites for the twenty year period of 2000 through 2019 and the ten year period of 2010 through 2019. As discussed in Section 2 of this report, the crash location conditional probability is calculated using cumulative bivariate Gaussian probability distribution. The bandwidth estimator (h_s) is defined as the distance from the site to the 3rd closest crash. As such, sites with crashes clustered closer to the site will have a smaller bandwidth value than sites that have crashes further spread out from the site.

The 99.9-percentile crash listed in the Appendix A tables refer to the number of crashes (and the radial distance that encompasses these set of crashes) closest to the site location that represents at least 99.9% of the cumulative crash density value. Cumulatively, all the crashes beyond the 99.9-percentile distance only contribute an additional 0.1% to the overall crash density value assigned to the site.

Appendix B documents a sensitivity analysis for the $f(s)$ values for various bandwidths. The sensitivity analysis is a comparative analysis for each site which calculates the estimated crash density for defined smoothing parameter values. The smoothing parameters analysis are in 10-mile increments, starting at 10 miles, up to a smoothing parameter value of 100-miles. The purpose of the smoothing parameter sensitivity analysis is to illustrate the potentially large variability in the calculated crash density when the bandwidth estimator is much lower the distance to the 3rd closest crash to the site. And in some instances, the sensitivity analysis also demonstrates the convergence with the CONUS average when the crash density smoothing parameter is much larger than the distance to the 3rd closest crash to the site.

Appendix C documents the R programming code that was utilized in the generation of this report.

3. REFERENCES

1. **Lawrence Livermore National Laboratory.** *Data Development Technical Standard Support Document For The Aircraft Crash Risk Analysis Methodology (ACRAM) Standard.* August 1996. UCRL-ID-124837.

2. **U. S. Department of Energy.** *Accident Analysis for Aircraft Crash into Hazardous Facilities.* 2006. DOE-STD-3014-2006.

3. **International Civil Aviation Organization.** *Phases of Flight: Definition and Usage Notes.* April 2013. Commercial Aviation Safety Team, Version 1.3.

4. **Sanzo, D., et al.** *ACRAM Modeling Technical Support Document.* 1996. LA-UR-96-2460, TSA-11-95-R112.

5. **Meeus, Jean.** *Astronomical Algorithms.* Second Edition: Williams-Bell, Inc., March 2000. 2nd Printing.

APPENDIX A. CRASH DENSITY RESULTS

APPENDIX A. CRASH DENSITY RESULTS[§]

Table A.1 - Non-airport general aviation crash density estimates for DOE/NRC sites; 20-year data set [2000-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
DEPARTMENT OF ENERGY SITES												
Argonne National Laboratory	**7E-04**	7.7	32	27.7	**7E-04**	7.7	27	27.7	**5E-05**	26.4	12	93.5
Brookhaven National Laboratory	**2E-03**	3.7	17	13.1	**1E-03**	5.9	17	19.8	**2E-04**	13.2	11	36.1
DOE Headquarters	**2E-04**	11.0	46	43.8	**3E-04**	18.4	79	65.3	**5E-05**	27.9	19	94.6
Hanford	**2E-04**	23.9	52	86.0	**1E-04**	24.1	42	86.2	**4E-05**	27.7	13	91.8
Idaho National Engineering Laboratory	**7E-05**	37.6	79	134.9	**7E-05**	37.6	71	134.8	**9E-06**	106.6	96	387.5
Kansas City Plant	**7E-04**	7.0	13	20.8	**7E-04**	7.0	12	20.8	**2E-05**	39.0	10	114.8
Los Alamos National Laboratory	**1E-04**	22.0	52	76.1	**1E-04**	22.0	46	75.4	**1E-05**	49.7	18	178.8
Lawrence Livermore National Laboratory	**2E-03**	3.7	14	13.2	**2E-03**	3.7	13	12.7	**9E-05**	22.8	21	75.9
Nevada Test Site	**7E-05**	53.1	321	216.0	**5E-05**	56.4	368	232.2	**2E-05**	62.6	83	247.2
Oak Ridge National Laboratory	**2E-04**	20.1	59	73.6	**1E-04**	20.1	50	73.4	**2E-05**	42.2	27	145.7
Pantex	**1E-04**	18.4	19	61.1	**1E-04**	18.4	17	61.1	**7E-06**	78.3	65	313.4
Sandia National Laboratories	**3E-04**	12.8	29	46.8	**3E-04**	12.8	27	46.9	**1E-05**	44.1	17	156.1
Savannah River Site	**1E-04**	21.1	50	80.7	**1E-04**	21.1	48	80.5	**1E-05**	102.4	135	381.1
Waste Isolation Pilot Plant	**3E-05**	51.5	105	195.0	**2E-05**	51.5	86	196.4	**7E-06**	88.3	73	353.1
NUCLEAR REGULATORY COMMISSION / AGREEMENT STATES REGULATED POWER GENERATING STATIONS												
Arkansas Nuclear 1/2	**8E-05**	20.1	37	77.9	**6E-05**	25.9	59	98.9	**2E-05**	42.0	15	155.3

[§] The 99.9% refers the number of crashes closest to the site location that represents at least 99.9% of the cumulative crash density value. For example in Table A.1 for all GA accidents (fixed wing + rotary wing) the 99.9th percentile crash is crash number 32 for Argonne National Laboratory. This means the 32 closest crashes to yield at least 99.9% of the overall crash density value and all crashes beyond the closest 32 crashes only contribute < 0.1% to the overall crash density value. The 99.9 percentile distance refers to the distance that encompasses the 99.9 percentile crashes. In this case, the 32 crashes which comprise at least 99.9% of the overall crash density value for Argonne National Laboratory reside within 27.7 miles of the site.

Table A.1 - Non-airport general aviation crash density estimates for DOE/NRC sites; 20-year data set [2000-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
Beaver Valley 1/2	**2E-04**	18.8	65	68.2	**2E-04**	20.5	66	77.0	**4E-05**	28.4	15	97.9
Braidwood 1/2	**3E-04**	14.9	61	52.3	**3E-04**	14.9	54	52.3	**2E-05**	41.6	24	146.6
Browns Ferry 1/2/3	**2E-04**	10.6	17	39.0	**2E-04**	10.6	15	39.0	**2E-05**	40.5	25	146.4
Brunswick 1/2	**2E-04**	13.2	29	43.2	**2E-04**	19.4	34	64.4	**1E-04**	13.2	4	34.5
Byron 1/2	**2E-04**	14.1	46	53.1	**2E-04**	14.1	44	51.9	**2E-05**	58.2	36	203.2
Callaway	**2E-04**	13.1	20	50.3	**1E-04**	13.5	18	50.9	**2E-05**	48.5	22	154.4
Calvert Cliffs 1/2	**2E-04**	10.6	15	38.8	**2E-04**	10.6	13	38.2	**2E-05**	46.5	39	166.0
Catawba 1/2	**4E-04**	9.5	19	33.4	**3E-04**	9.5	14	33.4	**4E-05**	29.1	11	96.6
Clinton	**1E-04**	14.7	20	53.5	**1E-04**	14.7	20	53.5	**1E-05**	70.8	59	260.8
Columbia Generating Station	**4E-04**	8.3	11	26.7	**2E-04**	14.3	17	49.8	**6E-05**	19.9	7	56.8
Comanche Peak 1/2	**6E-04**	6.9	13	24.7	**6E-04**	6.9	10	23.9	**5E-05**	24.7	35	87.1
Cooper	**6E-05**	34.3	71	129.2	**5E-05**	34.3	65	129.2	**6E-06**	85.7	58	329.1
D.C. Cook 1/2	**2E-04**	15.8	41	58.4	**2E-04**	15.8	33	58.3	**3E-05**	44.5	33	161.7
Davis-Besse	**7E-05**	20.1	52	77.9	**8E-05**	29.8	111	116.6	**2E-05**	55.4	51	208.2
Diablo Canyon 1/2	**2E-04**	13.4	21	45.6	**2E-04**	13.4	21	45.6	**2E-05**	102.0	143	336.3
Dresden 2/3	**5E-04**	10.1	43	36.9	**5E-04**	10.1	40	35.6	**3E-05**	39.6	23	132.6
Duane Arnold	**1E-04**	16.1	21	58.1	**9E-05**	26.2	40	97.3	**9E-06**	58.1	32	224.7
Farley 1/2	**1E-04**	26.6	77	98.9	**8E-05**	26.6	67	100.4	**2E-05**	38.6	16	134.6
Fermi 2	**2E-04**	10.6	15	39.7	**2E-04**	10.6	12	39.7	**2E-05**	33.4	19	128.9
FitzPatrick	**9E-05**	21.2	26	78.6	**6E-05**	21.2	22	80.7	**2E-05**	34.5	7	100.8
Fort Calhoun	**1E-04**	19.2	27	68.1	**9E-05**	22.5	32	79.6	**6E-06**	77.2	36	295.4
Ginna	**9E-05**	25.9	41	94.8	**8E-05**	25.9	32	94.8	**1E-05**	57.9	30	231.4
Grand Gulf 1	**6E-05**	24.6	34	96.0	**6E-05**	24.6	31	96.0	**7E-06**	67.6	60	266.0
Hatch 1/2	**9E-05**	27.7	88	106.0	**8E-05**	27.7	85	106.0	**9E-06**	87.3	127	329.1
Hope Creek 1	**2E-04**	11.5	33	44.7	**2E-04**	11.5	27	44.5	**5E-05**	36.3	47	124.8
Indian Point 2/3	**3E-04**	10.1	42	36.6	**3E-04**	10.1	34	35.8	**7E-05**	29.3	33	99.3

Table A.1 - Non-airport general aviation crash density estimates for DOE/NRC sites; 20-year data set [2000-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
La Salle 1/2	**3E-04**	11.8	38	44.8	**2E-04**	11.8	37	44.8	**2E-05**	57.3	45	208.6
Limerick 1/2	**3E-04**	12.3	47	46.2	**2E-04**	12.3	33	46.2	**1E-04**	16.4	19	58.1
McGuire 1/2	**4E-04**	12.8	40	43.2	**3E-04**	15.1	39	54.6	**1E-04**	14.1	7	43.1
Millstone 2/3	**2E-04**	18.7	77	69.3	**2E-04**	18.7	64	68.4	**4E-05**	44.4	48	150.6
Monticello	**3E-04**	11.3	38	42.1	**3E-04**	11.3	33	42.1	**2E-05**	36.0	9	116.1
Nine Mile Point 1/2	**9E-05**	21.5	27	79.6	**6E-05**	21.5	23	82.6	**2E-05**	34.2	7	100.5
North Anna 1/2	**2E-04**	14.7	58	51.3	**2E-04**	14.7	55	51.3	**2E-05**	49.6	37	180.4
Oconee 1/2/3	**2E-04**	19.2	79	72.0	**2E-04**	19.2	74	72.0	**2E-05**	50.2	33	188.6
Oyster Creek	**3E-04**	9.8	31	37.5	**3E-04**	9.8	27	37.1	**5E-05**	35.2	44	119.6
Palisades	**2E-04**	13.2	22	49.6	**2E-04**	14.1	26	54.1	**2E-05**	54.4	45	199.0
Palo Verde 1/2/3	**3E-04**	10.9	22	39.0	**3E-04**	10.9	20	39.0	**6E-05**	43.9	54	143.7
Peach Bottom 2/3	**3E-04**	17.0	59	59.3	**2E-04**	17.0	45	63.5	**1E-04**	19.9	20	72.6
Perry 1	**1E-04**	23.5	54	90.2	**8E-05**	23.5	45	90.6	**2E-05**	53.2	39	179.0
Pilgrim 1	**2E-04**	14.5	29	51.5	**1E-04**	26.3	51	88.5	**1E-04**	14.5	10	51.5
Point Beach 1/2	**8E-05**	32.6	109	123.9	**7E-05**	32.6	95	123.4	**1E-05**	58.8	38	214.8
Prairie Island 1/2	**3E-04**	11.6	32	44.0	**2E-04**	12.5	32	46.0	**2E-05**	44.0	13	143.1
Quad Cities 1/2	**1E-04**	16.5	17	59.1	**1E-04**	16.5	15	59.1	**1E-05**	64.6	47	234.3
River Bend 1	**1E-04**	17.1	23	63.3	**9E-05**	17.1	18	63.3	**2E-05**	52.7	36	178.4
Robinson 2	**1E-04**	19.3	43	72.4	**1E-04**	19.3	39	72.1	**1E-05**	46.0	23	153.1
Saint Lucie 1/2	**7E-04**	9.8	36	34.9	**6E-04**	9.8	26	34.9	**2E-04**	12.5	13	43.6
Salem 1/2	**2E-04**	11.7	35	44.9	**2E-04**	11.7	29	44.7	**5E-05**	36.6	47	125.0
Seabrook 1	**2E-04**	16.5	44	60.2	**2E-04**	16.5	33	59.7	**5E-05**	34.7	22	106.4
Sequoyah 1/2	**3E-04**	10.5	26	38.6	**2E-04**	13.3	32	47.2	**2E-05**	58.6	45	213.5
Shearon Harris 1	**1E-04**	19.1	39	67.8	**1E-04**	19.1	35	67.8	**1E-05**	44.7	23	164.1
South Texas 1/2	**1E-04**	25.3	96	95.3	**9E-05**	25.3	70	95.6	**4E-05**	41.6	50	151.3
Summer	**1E-04**	14.3	29	53.2	**1E-04**	14.3	29	53.2	**1E-05**	70.5	48	262.6

Table A.1 - Non-airport general aviation crash density estimates for DOE/NRC sites; 20-year data set [2000-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
Surry 1/2	**4E-04**	9.3	22	33.8	**3E-04**	12.4	28	44.4	**3E-05**	30.1	9	103.2
Susquehanna 1/2	**1E-04**	20.6	62	77.5	**1E-04**	30.3	131	116.7	**6E-05**	21.9	16	81.7
Three Mile Island 1	**2E-04**	16.7	48	61.8	**1E-04**	24.4	85	93.5	**6E-05**	22.8	22	75.7
Turkey Point 3/4	**1E-03**	4.0	8	14.4	**5E-04**	7.8	20	26.5	**1E-04**	14.7	10	48.2
Vogtle 1/2	**1E-04**	19.4	39	72.3	**1E-04**	19.4	38	72.3	**1E-05**	106.2	144	400.0
Waterford 3	**2E-04**	14.8	30	55.1	**1E-04**	15.0	23	56.6	**4E-05**	27.7	19	93.5
Watts Bar 1/2	**3E-04**	11.3	21	40.1	**2E-04**	11.3	19	40.9	**2E-05**	37.3	26	135.6
Wolf Creek 1	**7E-05**	29.7	86	114.2	**6E-05**	29.7	78	114.2	**9E-06**	73.2	41	277.5

Table A.2- Non-airport general aviation crash density estimates for DOE/NRC sites; 10-year data set [2010-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
DEPARTMENT OF ENERGY SITES												
Argonne National Laboratory	**8E-04**	7.7	19	29.1	**8E-04**	7.7	15	29.1	**7E-05**	26.4	7	90.4
Brookhaven National Laboratory	**1E-03**	7.5	12	19.8	**1E-03**	7.5	11	19.8	**5E-05**	29.9	15	102.3
DOE Headquarters	**3E-04**	25.7	55	84.6	**3E-04**	25.7	49	83.1	**3E-05**	41.2	17	146.8
Hanford	**1E-04**	27.7	28	98.6	**7E-05**	35.7	43	136.8	**6E-05**	27.7	10	91.8
Idaho National Engineering Laboratory	**7E-05**	39.0	43	148.1	**7E-05**	39.0	37	148.1	**1E-05**	126.3	64	477.4
Kansas City Plant	**2E-04**	13.3	12	47.5	**1E-04**	18.2	14	61.7	**1E-05**	59.0	12	219.1
Los Alamos National Laboratory	**9E-05**	30.0	31	101.0	**8E-05**	37.4	36	132.7	**8E-06**	91.7	40	354.8
Lawrence Livermore National Laboratory	**2E-03**	6.0	18	22.0	**2E-03**	6.0	16	19.2	**5E-05**	24.0	8	79.6
Nevada Test Site	**6E-05**	62.6	263	254.4	**4E-05**	69.1	286	274.7	**2E-05**	69.8	54	265.4
Oak Ridge National Laboratory	**2E-04**	23.2	29	87.3	**1E-04**	23.2	25	87.3	**2E-05**	71.0	23	247.8
Pantex	**7E-05**	28.5	17	98.3	**7E-05**	28.5	16	98.3	**8E-06**	154.6	132	599.3
Sandia National Laboratories	**2E-04**	20.2	18	70.8	**2E-04**	20.2	15	56.9	**1E-05**	73.2	13	281.3
Savannah River Site	**9E-05**	40.6	103	157.3	**9E-05**	40.6	96	156.6	**1E-05**	134.1	82	489.7
Waste Isolation Pilot Plant	**3E-05**	78.9	110	305.1	**3E-05**	78.9	89	301.3	**6E-06**	156.2	124	588.8
NUCLEAR REGULATORY COMMISSION / AGREEMENT STATES REGULATED POWER GENERATING STATIONS												
Arkansas Nuclear 1/2	**9E-05**	32.9	45	122.9	**7E-05**	37.0	54	138.6	**2E-05**	42.0	5	131.1
Beaver Valley 1/2	**1E-04**	26.8	41	92.5	**1E-04**	28.6	40	102.0	**1E-05**	67.4	26	244.0
Braidwood 1/2	**3E-04**	14.9	32	52.1	**3E-04**	14.9	27	49.9	**3E-05**	41.6	15	128.1
Browns Ferry 1/2/3	**1E-04**	18.6	25	66.8	**1E-04**	18.6	22	66.8	**2E-05**	65.5	19	222.7
Brunswick 1/2	**2E-04**	18.9	14	60.8	**8E-05**	31.5	28	116.6	**2E-05**	53.5	8	154.8
Byron 1/2	**2E-04**	16.1	28	61.0	**2E-04**	16.1	26	59.8	**2E-05**	68.3	30	249.5
Callaway	**1E-04**	27.0	33	95.1	**8E-05**	27.0	24	95.1	**3E-05**	48.5	15	154.4
Calvert Cliffs 1/2	**2E-04**	15.5	21	61.6	**1E-04**	25.5	52	93.7	**2E-05**	74.5	38	241.7

Table A.2- Non-airport general aviation crash density estimates for DOE/NRC sites; 10-year data set [2010-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
Catawba 1/2	**2E-04**	25.6	52	94.2	**1E-04**	25.6	48	94.6	**3E-05**	37.2	8	127.6
Clinton	**1E-04**	23.3	20	84.5	**1E-04**	23.3	17	84.5	**2E-05**	70.8	29	245.6
Columbia Generating Station	**1E-04**	32.0	42	115.8	**6E-05**	37.5	43	142.1	**4E-05**	40.3	18	140.6
Comanche Peak 1/2	**3E-04**	20.9	62	74.0	**2E-04**	21.5	50	76.7	**6E-05**	45.0	33	151.9
Cooper	**6E-05**	39.2	46	146.7	**5E-05**	39.2	42	144.9	**6E-06**	118.4	55	462.3
D.C. Cook 1/2	**1E-04**	23.9	48	91.1	**1E-04**	23.9	40	92.1	**3E-05**	50.6	19	177.3
Davis-Besse	**1E-04**	29.8	53	112.8	**8E-05**	35.0	68	131.0	**1E-05**	82.3	33	283.7
Diablo Canyon 1/2	**1E-04**	16.8	6	45.6	**1E-04**	16.8	6	45.6	**2E-05**	102.3	63	339.7
Dresden 2/3	**6E-04**	11.9	28	42.4	**6E-04**	11.9	24	40.0	**3E-05**	39.6	15	132.6
Duane Arnold	**6E-05**	30.6	37	113.0	**6E-05**	30.6	33	111.5	**9E-06**	104.7	46	385.6
Farley 1/2	**7E-05**	38.6	65	143.3	**6E-05**	50.0	113	197.8	**2E-05**	50.4	9	174.4
Fermi 2	**2E-04**	22.2	19	77.0	**1E-04**	22.2	16	77.0	**1E-05**	61.7	24	233.1
FitzPatrick	**4E-05**	46.3	69	181.1	**4E-05**	46.3	59	179.0	**1E-05**	133.1	61	432.2
Fort Calhoun	**1E-04**	22.8	17	79.6	**7E-05**	22.8	16	80.9	**6E-06**	130.3	60	497.3
Ginna	**4E-05**	45.6	53	176.7	**4E-05**	45.6	43	177.6	**9E-06**	84.5	48	311.6
Grand Gulf 1	**5E-05**	64.5	182	255.0	**4E-05**	66.4	168	257.6	**1E-05**	140.7	118	504.4
Hatch 1/2	**8E-05**	43.9	109	172.3	**8E-05**	43.9	101	172.3	**1E-05**	143.6	80	490.2
Hope Creek 1	**2E-04**	36.3	114	134.9	**1E-04**	38.3	99	142.9	**5E-05**	44.3	31	142.5
Indian Point 2/3	**3E-04**	17.9	53	66.3	**3E-04**	17.9	42	66.3	**7E-05**	35.8	22	123.3
La Salle 1/2	**3E-04**	18.0	36	64.3	**3E-04**	18.0	30	64.2	**2E-05**	62.5	27	213.4
Limerick 1/2	**2E-04**	16.4	28	59.3	**2E-04**	27.1	54	99.6	**9E-05**	26.9	24	90.9
McGuire 1/2	**3E-04**	15.3	21	55.6	**2E-04**	22.8	37	84.3	**8E-05**	21.7	4	43.1
Millstone 2/3	**2E-04**	18.7	31	67.1	**2E-04**	18.7	28	65.9	**3E-05**	71.3	34	231.3
Monticello	**3E-04**	21.8	24	74.6	**3E-04**	21.8	22	74.6	**6E-06**	116.1	34	423.3
Nine Mile Point 1/2	**4E-05**	46.8	70	181.6	**4E-05**	46.8	61	181.5	**1E-05**	132.7	61	432.0
North Anna 1/2	**3E-04**	23.4	48	83.1	**3E-04**	23.4	45	81.9	**1E-05**	93.1	54	325.2

Table A.2- Non-airport general aviation crash density estimates for DOE/NRC sites; 10-year data set [2010-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi²]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
Oconee 1/2/3	**2E-04**	20.2	41	74.4	**2E-04**	20.2	38	73.6	**1E-05**	80.8	32	286.3
Oyster Creek	**3E-04**	17.4	31	65.9	**2E-04**	17.4	20	64.2	**7E-05**	41.6	27	140.1
Palisades	**1E-04**	26.3	53	102.8	**1E-04**	26.3	42	102.8	**2E-05**	61.3	23	205.2
Palo Verde 1/2/3	**2E-04**	22.8	56	82.8	**2E-04**	22.8	40	77.5	**5E-05**	53.3	31	175.3
Peach Bottom 2/3	**2E-04**	19.9	29	75.1	**1E-04**	36.9	97	135.2	**1E-04**	19.9	8	63.6
Perry 1	**8E-05**	29.6	31	106.0	**8E-05**	29.6	28	98.7	**1E-05**	120.9	77	447.7
Pilgrim 1	**1E-04**	26.5	22	91.0	**6E-05**	29.1	25	115.6	**4E-05**	34.7	8	108.9
Point Beach 1/2	**1E-04**	38.8	71	142.1	**1E-04**	38.8	66	141.7	**9E-06**	111.1	41	411.8
Prairie Island 1/2	**2E-04**	15.1	20	57.0	**2E-04**	24.3	34	87.4	**7E-06**	103.6	35	401.3
Quad Cities 1/2	**7E-05**	28.0	44	111.7	**8E-05**	47.8	110	180.7	**1E-05**	81.5	36	286.1
River Bend 1	**1E-04**	17.1	12	63.3	**1E-04**	17.1	9	63.3	**2E-05**	54.3	17	178.5
Robinson 2	**2E-04**	19.3	22	69.5	**2E-04**	19.3	21	69.5	**1E-05**	86.5	21	303.1
Saint Lucie 1/2	**5E-04**	12.1	27	45.4	**3E-04**	12.1	19	46.2	**1E-04**	22.9	15	77.5
Salem 1/2	**2E-04**	36.6	116	135.2	**1E-04**	38.5	99	143.3	**5E-05**	44.7	31	142.6
Seabrook 1	**1E-04**	38.1	52	139.2	**9E-05**	38.1	45	139.3	**2E-05**	60.5	15	220.4
Sequoyah 1/2	**4E-04**	10.5	9	38.6	**2E-04**	20.1	25	75.6	**2E-05**	67.1	24	237.8
Shearon Harris 1	**1E-04**	23.7	30	88.4	**1E-04**	23.7	29	88.4	**9E-06**	122.7	75	464.1
South Texas 1/2	**1E-04**	33.6	64	125.6	**9E-05**	33.6	50	126.9	**5E-05**	41.6	22	141.5
Summer	**1E-04**	29.0	61	107.5	**1E-04**	29.0	55	107.5	**1E-05**	82.5	26	309.9
Surry 1/2	**2E-04**	12.5	9	41.3	**1E-04**	28.7	34	110.9	**1E-05**	139.0	73	476.0
Susquehanna 1/2	**2E-04**	25.5	48	96.4	**1E-04**	30.4	57	115.7	**6E-05**	27.4	18	105.0
Three Mile Island 1	**2E-04**	28.8	72	107.9	**1E-04**	29.6	59	110.3	**5E-05**	39.9	31	139.1
Turkey Point 3/4	**3E-03**	4.0	5	8.2	**1E-03**	7.8	17	26.5	**2E-05**	58.9	28	215.8
Vogtle 1/2	**9E-05**	37.1	82	145.2	**8E-05**	37.1	78	143.7	**1E-05**	136.6	83	498.6
Waterford 3	**2E-04**	26.7	30	84.9	**1E-04**	26.7	23	84.9	**2E-05**	56.0	14	165.1
Watts Bar 1/2	**2E-04**	24.2	41	92.1	**1E-04**	24.2	35	92.1	**2E-05**	70.4	25	250.7

Table A.2- Non-airport general aviation crash density estimates for DOE/NRC sites; 10-year data set [2010-2019]

	All CONUS GA (Fixed wing + Rotary wing)				*CONUS GA (Fixed wing only)*				*CONUS GA (Rotary wing only)*			
Site	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**	**NPf(xy), [crashes/yr /mi^2]**	**Dist to 3rd Crash, [mi]**	**99.9% Crash**	**Dist to 99.9% crash, [mi]**
Wolf Creek 1	**5E-05**	31.9	45	124.7	**5E-05**	31.9	40	124.6	**7E-06**	88.5	36	340.8

Table A.3 - Non-airport general aviation crash density estimates for DOE/NRC sites

Site	2000-2019 NPf(x,y) [crashes/yr/mi^2]	2010-2019 NPf(x,y) [crashes/yr/mi^2]	2000-2019 NPf(x,y) [crashes/yr/mi^2]	2010-2019 NPf(x,y) [crashes/yr/mi^2]
	Fixed-Wing Aircraft		*Rotary-Wing Aircraft*	
DEPARTMENT OF ENERGY SITES				
Argonne National Laboratory	7E-04	**8E-04**	5E-05	**7E-05**
Brookhaven National Laboratory	1E-03	**1E-03**	2E-04	**5E-05**
DOE Headquarters	3E-04	**3E-04**	5E-05	**3E-05**
Hanford	1E-04	**7E-05**	4E-05	**6E-05**
Idaho National Engineering Laboratory	7E-05	**7E-05**	9E-06	**1E-05**
Kansas City Plant	7E-04	**1E-04**	2E-05	**1E-05**
Los Alamos National Laboratory	1E-04	**8E-05**	1E-05	**8E-06**
Lawrence Livermore National Laboratory	2E-03	**2E-03**	9E-05	**5E-05**
Nevada Test Site	5E-05	**4E-05**	2E-05	**2E-05**
Oak Ridge National Laboratory	1E-04	**1E-04**	2E-05	**2E-05**
Pantex	1E-04	**7E-05**	7E-06	**8E-06**
Sandia National Laboratories	3E-04	**2E-04**	1E-05	**1E-05**
Savannah River Site	1E-04	**9E-05**	1E-05	**1E-05**
Waste Isolation Pilot Plant	2E-05	**3E-05**	7E-06	**6E-06**
NUCLEAR REGULATORY COMMISSION / AGREEMENT STATES REGULATED POWER GENERATING STATIONS				
Arkansas Nuclear 1/2	6E-05	**7E-05**	2E-05	**2E-05**
Beaver Valley 1/2	2E-04	**1E-04**	4E-05	**1E-05**
Braidwood 1/2	3E-04	**3E-04**	2E-05	**3E-05**
Browns Ferry 1/2/3	2E-04	**1E-04**	2E-05	**2E-05**
Brunswick 1/2	2E-04	**8E-05**	1E-04	**2E-05**
Byron 1/2	2E-04	**2E-04**	2E-05	**2E-05**
Callaway	1E-04	**8E-05**	2E-05	**3E-05**
Calvert Cliffs 1/2	2E-04	**1E-04**	2E-05	**2E-05**
Catawba 1/2	3E-04	**1E-04**	4E-05	**3E-05**
Clinton	1E-04	**1E-04**	1E-05	**2E-05**
Columbia Generating Station	2E-04	**6E-05**	6E-05	**4E-05**
Comanche Peak 1/2	6E-04	**2E-04**	5E-05	**6E-05**
Cooper	5E-05	**5E-05**	6E-06	**6E-06**
D.C. Cook 1/2	2E-04	**1E-04**	3E-05	**3E-05**
Davis-Besse	8E-05	**8E-05**	2E-05	**1E-05**
Diablo Canyon 1/2	2E-04	**1E-04**	2E-05	**2E-05**
Dresden 2/3	5E-04	**6E-04**	3E-05	**3E-05**
Duane Arnold	9E-05	**6E-05**	9E-06	**9E-06**

Table A.3 - Non-airport general aviation crash density estimates for DOE/NRC sites

Site	2000-2019 NPf(x,y) [crashes/yr/mi²]	2010-2019 NPf(x,y) [crashes/yr/mi²]	2000-2019 NPf(x,y) [crashes/yr/mi²]	2010-2019 NPf(x,y) [crashes/yr/mi²]
	Fixed-Wing Aircraft		*Rotary-Wing Aircraft*	
Farley 1/2	8E-05	**6E-05**	2E-05	**2E-05**
Fermi 2	2E-04	**1E-04**	2E-05	**1E-05**
FitzPatrick	6E-05	**4E-05**	2E-05	**1E-05**
Fort Calhoun	9E-05	**7E-05**	6E-06	**6E-06**
Ginna	8E-05	**4E-05**	1E-05	**9E-06**
Grand Gulf 1	6E-05	**4E-05**	7E-06	**1E-05**
Hatch 1/2	8E-05	**8E-05**	9E-06	**1E-05**
Hope Creek 1	2E-04	**1E-04**	5E-05	**5E-05**
Indian Point 2/3	3E-04	**3E-04**	7E-05	**7E-05**
La Salle 1/2	2E-04	**3E-04**	2E-05	**2E-05**
Limerick 1/2	2E-04	**2E-04**	1E-04	**9E-05**
McGuire 1/2	3E-04	**2E-04**	1E-04	**8E-05**
Millstone 2/3	2E-04	**2E-04**	4E-05	**3E-05**
Monticello	3E-04	**3E-04**	2E-05	**6E-06**
Nine Mile Point 1/2	6E-05	**4E-05**	2E-05	**1E-05**
North Anna 1/2	2E-04	**3E-04**	2E-05	**1E-05**
Oconee 1/2/3	2E-04	**2E-04**	2E-05	**1E-05**
Oyster Creek	3E-04	**2E-04**	5E-05	**7E-05**
Palisades	2E-04	**1E-04**	2E-05	**2E-05**
Palo Verde 1/2/3	3E-04	**2E-04**	6E-05	**5E-05**
Peach Bottom 2/3	2E-04	**1E-04**	1E-04	**1E-04**
Perry 1	8E-05	**8E-05**	2E-05	**1E-05**
Pilgrim 1	1E-04	**6E-05**	1E-04	**4E-05**
Point Beach 1/2	7E-05	**1E-04**	1E-05	**9E-06**
Prairie Island 1/2	2E-04	**2E-04**	2E-05	**7E-06**
Quad Cities 1/2	1E-04	**8E-05**	1E-05	**1E-05**
River Bend 1	9E-05	**1E-04**	2E-05	**2E-05**
Robinson 2	1E-04	**2E-04**	1E-05	**1E-05**
Saint Lucie 1/2	6E-04	**3E-04**	2E-04	**1E-04**
Salem 1/2	2E-04	**1E-04**	5E-05	**5E-05**
Seabrook 1	2E-04	**9E-05**	5E-05	**2E-05**
Sequoyah 1/2	2E-04	**2E-04**	2E-05	**2E-05**
Shearon Harris 1	1E-04	**1E-04**	1E-05	**9E-06**
South Texas 1/2	9E-05	**9E-05**	4E-05	**5E-05**

Table A.3 - Non-airport general aviation crash density estimates for DOE/NRC sites

Site	2000-2019 NPf(x,y) [crashes/yr/mi^2]	2010-2019 NPf(x,y) [crashes/yr/mi^2]	2000-2019 NPf(x,y) [crashes/yr/mi^2]	2010-2019 NPf(x,y) [crashes/yr/mi^2]
	Fixed-Wing Aircraft		*Rotary-Wing Aircraft*	
Summer	1E-04	**1E-04**	1E-05	**1E-05**
Surry 1/2	3E-04	**1E-04**	3E-05	**1E-05**
Susquehanna 1/2	1E-04	**1E-04**	6E-05	**6E-05**
Three Mile Island 1	1E-04	**1E-04**	6E-05	**5E-05**
Turkey Point 3/4	5E-04	**1E-03**	1E-04	**2E-05**
Vogtle 1/2	1E-04	**8E-05**	1E-05	**1E-05**
Waterford 3	1E-04	**1E-04**	4E-05	**2E-05**
Watts Bar 1/2	2E-04	**1E-04**	2E-05	**2E-05**
Wolf Creek 1	6E-05	**5E-05**	9E-06	**7E-06**

Table A.4 – Location of DOE/NRC sites

Site	Latitude	Longitude
DEPARTMENT OF ENERGY SITES		
Argonne National Laboratory	41.7092	-87.982
Brookhaven National Laboratory	40.875	-72.877
DOE Headquarters	38.8869	-77.0261
Hanford	46.6475	-119.599
Idaho National Engineering Laboratory	43.5333	-112.945
Kansas City Plant	38.862	-94.5527
Los Alamos National Laboratory	35.8756	-106.324
Lawrence Livermore National Laboratory	37.69	-121.71
Mound	39.6291	-84.2863
Nevada National Security Site	37.1167	-116.05
Oak Ridge National Laboratory	35.93	-84.31
Pantex	35.3116	-101.56
Pinellas	27.8738	-82.7485
Rocky Flats	39.89	-105.2
Sandia National Laboratories	35.0507	-106.543
Savannah River Site	33.2464	-81.6679
Waste Isolation Pilot Plant	32.37167	-103.794
NUCLEAR REGULATORY COMMISSION / AGREEMENT STATES REGULATED POWER GENERATING STATIONS		
Arkansas Nuclear 1/2	35.31028	-93.2314
Beaver Valley 1/2	40.62333	-80.4306
Braidwood 1/2	41.24361	-88.2292
Browns Ferry 1/2/3	34.70389	-87.1186
Brunswick 1/2	33.95833	-78.0103
Byron 1/2	42.07417	-89.2819
Callaway	38.76167	-91.78
Calvert Cliffs 1/2	38.43194	-76.4422
Catawba 1/2	35.05167	-81.07
Clinton	40.17222	-88.835
Columbia Generating Station	46.47111	-119.334
Comanche Peak 1/2	32.29833	-97.785
Cooper	40.36194	-95.6414
D.C. Cook 1/2	41.97539	-86.5659
Davis-Besse	41.59667	-83.0864
Diablo Canyon 1/2	35.21083	-120.856
Dresden 2/3	41.38972	-88.2681
Duane Arnold	42.10056	-91.7772
Farley 1/2	31.22306	-85.1117
Fermi 2	41.96278	-83.2575
FitzPatrick	43.52333	-76.3983
Fort Calhoun	41.52028	-96.0772
Ginna	43.27778	-77.31
Grand Gulf 1	32.00667	-91.0483
Hatch 1/2	31.93417	-82.3439
Hope Creek 1	39.46778	-75.5381
Indian Point 2/3	41.26972	-73.9522
La Salle 1/2	41.24556	-88.6692
Limerick 1/2	40.22667	-75.5872
McGuire 1/2	35.4325	-80.9483
Millstone 2/3	41.31194	-72.1686
Monticello	45.33361	-93.8492

Table A.4 – Location of DOE/NRC sites

Site	Latitude	Longitude
Nine Mile Point 1/2	43.52083	-76.4069
North Anna 1/2	38.06056	-77.7894
Oconee 1/2/3	34.79389	-82.8981
Oyster Creek	39.81472	-74.205
Palisades	42.32278	-86.3144
Palo Verde 1/2/3	33.38917	-112.865
Peach Bottom 2/3	39.75833	-76.2681
Perry 1	41.80083	-81.1433
Pilgrim 1	41.945	-70.5783
Point Beach 1/2	44.28111	-87.5367
Prairie Island 1/2	44.62167	-92.6331
Quad Cities 1/2	41.72639	-90.31
River Bend 1	30.75667	-91.3333
Robinson 2	34.40278	-80.1583
Saint Lucie 1/2	27.34861	-80.2464
Salem 1/2	39.46278	-75.5356
Seabrook 1	42.89889	-70.8508
Sequoyah 1/2	35.22639	-85.0917
Shearon Harris 1	35.63333	-78.955
South Texas 1/2	28.79556	-96.0489
Summer	34.29861	-81.3147
Surry 1/2	37.16556	-76.6978
Susquehanna 1/2	41.08889	-76.1489
Three Mile Island 1	40.15389	-76.7247
Turkey Point 3/4	25.43417	-80.3306
Vogtle 1/2	33.14333	-81.7606
Waterford 3	29.99528	-90.4711
Watts Bar 1/2	35.60278	-84.7894
Wolf Creek 1	38.23889	-95.6889

APPENDIX B. f(s) SENSITIVITY RESULTS

APPENDIX B. f(s) SENSITIVITY RESULTS

Table B.1 - 20-year f(s) sensitivity analysis for DOE sites [2000-2019]; fixed wing + rotary wing

Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	7E-04	1E-03	2E-04	4E-05	1E-06	5E-04	9E-05	1E-03	2E-08	2E-04	1E-04	3E-04	6E-05	6E-06
20	5E-04	5E-04	3E-04	1E-04	4E-05	3E-04	1E-04	8E-04	6E-06	2E-04	1E-04	2E-04	1E-04	2E-05
30	4E-04	4E-04	3E-04	2E-04	7E-05	2E-04	1E-04	6E-04	3E-05	2E-04	1E-04	2E-04	1E-04	2E-05
40	3E-04	3E-04	3E-04	1E-04	7E-05	1E-04	1E-04	5E-04	5E-05	2E-04	8E-05	1E-04	1E-04	2E-05
50	3E-04	3E-04	3E-04	1E-04	7E-05	1E-04	1E-04	4E-04	6E-05	2E-04	7E-05	1E-04	1E-04	3E-05
60	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	1E-04	3E-04	7E-05	2E-04	6E-05	1E-04	1E-04	3E-05
70	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	1E-04	3E-04	8E-05	2E-04	6E-05	9E-05	1E-04	4E-05
80	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	9E-05	3E-04	9E-05	2E-04	5E-05	8E-05	1E-04	4E-05
90	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	8E-05	2E-04	1E-04	2E-04	5E-05	7E-05	2E-04	4E-05
100	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	8E-05	2E-04	1E-04	2E-04	6E-05	7E-05	2E-04	4E-05
Distance to 3rd Crash [mi]	8	4	11	24	38	7	22	4	53	20	18	13	21	52

Table B.2 – 20-year f(s) sensitivity analysis for DOE sites [2000-2019]; fixed wing only

Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	7E-04	1E-03	2E-04	4E-05	1E-06	5E-04	9E-05	1E-03	2E-08	2E-04	1E-04	3E-04	6E-05	6E-06
20	5E-04	5E-04	3E-04	1E-04	4E-05	3E-04	1E-04	8E-04	6E-06	2E-04	1E-04	2E-04	1E-04	2E-05
30	4E-04	4E-04	3E-04	2E-04	7E-05	2E-04	1E-04	6E-04	3E-05	2E-04	1E-04	2E-04	1E-04	2E-05
40	3E-04	3E-04	3E-04	1E-04	7E-05	1E-04	1E-04	5E-04	5E-05	2E-04	8E-05	1E-04	1E-04	2E-05
50	3E-04	3E-04	3E-04	1E-04	7E-05	1E-04	1E-04	4E-04	6E-05	2E-04	7E-05	1E-04	1E-04	2E-05
60	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	1E-04	3E-04	7E-05	2E-04	6E-05	1E-04	1E-04	3E-05
70	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	1E-04	3E-04	8E-05	2E-04	6E-05	9E-05	1E-04	3E-05
80	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	9E-05	3E-04	9E-05	2E-04	5E-05	8E-05	1E-04	3E-05
90	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	8E-05	2E-04	1E-04	2E-04	5E-05	7E-05	2E-04	3E-05
100	2E-04	2E-04	2E-04	1E-04	7E-05	1E-04	8E-05	2E-04	1E-04	2E-04	6E-05	7E-05	2E-04	3E-05
Distance to 3rd Crash [mi]	8	6	18	24	38	7	22	4	56	20	18	13	21	52

Table B.3 – 20-year f(s) sensitivity analysis for DOE sites [2000-2019]; rotary wing only

Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	3E-05	2E-04	7E-05	1E-05	2E-10	3E-05	5E-06	8E-05	2E-08	9E-06	6E-06	2E-05	1E-13	6E-18
20	6E-05	1E-04	5E-05	4E-05	8E-07	2E-05	1E-05	1E-04	3E-06	2E-05	1E-05	2E-05	1E-07	2E-08
30	4E-05	8E-05	5E-05	4E-05	2E-06	2E-05	2E-05	8E-05	9E-06	2E-05	1E-05	2E-05	1E-06	7E-07
40	3E-05	6E-05	4E-05	3E-05	3E-06	2E-05	1E-05	6E-05	1E-05	2E-05	9E-06	1E-05	2E-06	2E-06
50	3E-05	5E-05	3E-05	3E-05	4E-06	1E-05	1E-05	5E-05	2E-05	2E-05	8E-06	1E-05	4E-06	4E-06
60	2E-05	5E-05	3E-05	3E-05	4E-06	1E-05	1E-05	4E-05	2E-05	2E-05	7E-06	1E-05	5E-06	5E-06
70	2E-05	4E-05	3E-05	2E-05	6E-06	1E-05	1E-05	4E-05	2E-05	2E-05	7E-06	1E-05	7E-06	6E-06
80	2E-05	4E-05	3E-05	2E-05	7E-06	1E-05	1E-05	3E-05	2E-05	2E-05	7E-06	1E-05	8E-06	7E-06
90	2E-05	3E-05	3E-05	2E-05	8E-06	1E-05	1E-05	3E-05	2E-05	2E-05	7E-06	1E-05	9E-06	7E-06
100	2E-05	3E-05	2E-05	2E-05	9E-06	1E-05	1E-05	3E-05	2E-05	2E-05	8E-06	1E-05	1E-05	7E-06
Distance to 3rd Crash [mi]	26	13	28	28	107	39	50	23	63	42	78	44	102	88

Table B.4 – 10-year f(s) sensitivity analysis for DOE sites [2010-2019]; fixed wing + rotary wing

Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	7E-04	1E-03	6E-05	3E-05	1E-06	3E-04	2E-05	1E-03	2E-10	1E-04	2E-05	3E-04	4E-05	1E-15
20	6E-04	6E-04	3E-04	1E-04	5E-05	2E-04	7E-05	7E-04	3E-06	2E-04	7E-05	2E-04	6E-05	1E-07
30	4E-04	4E-04	3E-04	1E-04	7E-05	1E-04	9E-05	5E-04	2E-05	1E-04	7E-05	2E-04	8E-05	3E-06
40	3E-04	3E-04	3E-04	1E-04	7E-05	1E-04	9E-05	4E-04	4E-05	1E-04	6E-05	1E-04	9E-05	1E-05
50	3E-04	3E-04	2E-04	1E-04	7E-05	1E-04	9E-05	3E-04	5E-05	1E-04	6E-05	1E-04	1E-04	2E-05
60	2E-04	2E-04	2E-04	1E-04	7E-05	9E-05	8E-05	3E-04	6E-05	1E-04	5E-05	9E-05	1E-04	2E-05
70	2E-04	2E-04	2E-04	1E-04	7E-05	9E-05	8E-05	2E-04	6E-05	1E-04	5E-05	8E-05	1E-04	2E-05
80	2E-04	2E-04	2E-04	1E-04	7E-05	9E-05	7E-05	2E-04	7E-05	1E-04	5E-05	7E-05	1E-04	3E-05
90	2E-04	2E-04	2E-04	1E-04	7E-05	9E-05	7E-05	2E-04	8E-05	1E-04	5E-05	7E-05	1E-04	3E-05
100	2E-04	2E-04	2E-04	1E-04	7E-05	8E-05	7E-05	2E-04	9E-05	1E-04	5E-05	6E-05	1E-04	3E-05
Distance to 3rd Crash [mi]	8	7	26	28	39	13	30	6	63	23	29	20	41	79

Table B.5 – 10-year f(s) sensitivity analysis for DOE sites [2010-2019]; fixed wing only														
Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	7E-04	1E-03	6E-05	5E-06	1E-06	2E-04	8E-06	1E-03	2E-10	1E-04	2E-05	3E-04	4E-05	1E-15
20	5E-04	5E-04	3E-04	5E-05	5E-05	1E-04	5E-05	7E-04	2E-06	2E-04	7E-05	2E-04	6E-05	1E-07
30	4E-04	3E-04	3E-04	7E-05	7E-05	1E-04	8E-05	5E-04	1E-05	1E-04	6E-05	1E-04	8E-05	3E-06
40	3E-04	3E-04	3E-04	7E-05	7E-05	1E-04	8E-05	4E-04	2E-05	1E-04	6E-05	1E-04	9E-05	1E-05
50	2E-04	2E-04	2E-04	7E-05	7E-05	9E-05	8E-05	3E-04	3E-05	1E-04	5E-05	9E-05	1E-04	2E-05
60	2E-04	2E-04	2E-04	7E-05	7E-05	8E-05	7E-05	2E-04	4E-05	1E-04	5E-05	8E-05	1E-04	2E-05
70	2E-04	2E-04	2E-04	7E-05	7E-05	8E-05	7E-05	2E-04	4E-05	1E-04	5E-05	7E-05	1E-04	2E-05
80	2E-04	2E-04	2E-04	7E-05	6E-05	8E-05	6E-05	2E-04	5E-05	1E-04	4E-05	6E-05	1E-04	3E-05
90	2E-04	1E-04	1E-04	8E-05	6E-05	8E-05	6E-05	2E-04	6E-05	1E-04	4E-05	6E-05	1E-04	3E-05
100	1E-04	1E-04	1E-04	8E-05	6E-05	8E-05	6E-05	2E-04	7E-05	1E-04	4E-05	5E-05	1E-04	3E-05
Distance to 3rd Crash [mi]	8	7	26	36	39	18	37	6	69	23	29	20	41	79

Table B.6 – 10-year f(s) sensitivity analysis for DOE sites [2010-2019]; rotary wing only

Bandwidth [mi]	Argonne National Laboratory	Brookhaven National Laboratory	DOE Headquarters	Hanford	Idaho National Engineering Laboratory	Kansas City Plant	Los Alamos National Laboratory	Lawrence Livermore National Laboratory	Nevada Test Site	Oak Ridge National Laboratory	Pantex	Sandia	Savannah River Site	Waste Isolation Pilot Plant
10	4E-05	7E-05	6E-06	2E-05	4E-25	7E-05	9E-06	3E-05	5E-13	3E-08	4E-19	5E-07	6E-19	5E-41
20	8E-05	6E-05	3E-05	7E-05	3E-10	4E-05	2E-05	6E-05	5E-07	7E-06	9E-09	1E-05	1E-08	3E-14
30	6E-05	5E-05	4E-05	6E-05	1E-07	3E-05	1E-05	5E-05	7E-06	1E-05	4E-07	2E-05	5E-07	2E-09
40	4E-05	4E-05	3E-05	5E-05	9E-07	2E-05	1E-05	4E-05	1E-05	1E-05	1E-06	1E-05	2E-06	7E-08
50	3E-05	4E-05	3E-05	4E-05	2E-06	2E-05	1E-05	3E-05	2E-05	2E-05	2E-06	1E-05	3E-06	4E-07
60	3E-05	4E-05	3E-05	4E-05	4E-06	1E-05	9E-06	3E-05	2E-05	2E-05	3E-06	1E-05	4E-06	1E-06
70	2E-05	4E-05	3E-05	3E-05	5E-06	1E-05	9E-06	3E-05	2E-05	2E-05	3E-06	1E-05	5E-06	2E-06
80	2E-05	3E-05	2E-05	3E-05	7E-06	1E-05	8E-06	3E-05	2E-05	1E-05	4E-06	9E-06	7E-06	2E-06
90	2E-05	3E-05	2E-05	3E-05	8E-06	1E-05	8E-06	2E-05	2E-05	1E-05	4E-06	8E-06	7E-06	3E-06
100	2E-05	3E-05	2E-05	3E-05	9E-06	9E-06	7E-06	2E-05	2E-05	1E-05	5E-06	8E-06	8E-06	4E-06
Distance to 3rd Crash [mi]	26	30	41	28	126	59	92	24	70	71	155	73	134	156

Table B.7 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing + rotary wing

Bandwidth [mi]	**Arkansas Nuclear 1/2**	**Beaver Valley 1/2**	**Braidwood 1/2**	**Browns Ferry 1/2/3**	**Brunswick 1/2**	**Byron 1/2**	**Callaway**	**Calvert Cliffs 1/2**	**Catawba 1/2**	**Clinton**	**Columbia Generating Station**	**Comanche Peak 1/2**	**Cooper**	**D.C. Cook 1/2**	**Davis-Besse**	**Diablo Canyon 1/2**	**Dresden 2/3**	**Duane Arnold**
10	4E-05	1E-04	2E-04	3E-04	2E-04	2E-04	2E-04	3E-04	3E-04	9E-05	3E-04	4E-04	3E-05	2E-04	4E-05	3E-04	5E-04	1E-04
20	8E-05	2E-04	4E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-04	9E-05	2E-04	3E-04	4E-05	2E-04	7E-05	2E-04	5E-04	1E-04
30	9E-05	2E-04	3E-04	2E-04	2E-04	2E-04	1E-04	2E-04	2E-04	9E-05	1E-04	3E-04	5E-05	2E-04	9E-05	1E-04	4E-04	9E-05
40	9E-05	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	6E-05	2E-04	1E-04	1E-04	3E-04	9E-05
50	1E-04	2E-04	2E-04	2E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	7E-05	2E-04	1E-04	1E-04	3E-04	8E-05
60	1E-04	2E-04	2E-04	2E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	7E-05	2E-04	1E-04	1E-04	2E-04	8E-05
70	1E-04	2E-04	2E-04	2E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	7E-05	2E-04	1E-04	1E-04	2E-04	9E-05
80	1E-04	2E-04	2E-04	2E-04	9E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	2E-04	7E-05	2E-04	1E-04	1E-04	2E-04	9E-05
90	1E-04	1E-04	2E-04	2E-04	9E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	2E-04	7E-05	2E-04	1E-04	1E-04	2E-04	1E-04
100	1E-04	1E-04	2E-04	2E-04	8E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	2E-04	7E-05	2E-04	1E-04	2E-04	2E-04	1E-04
Distance to 3rd Crash [mi]	20	19	15	11	13	14	13	11	10	15	8	7	34	16	20	13	10	20

Table B.7 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	**Farley 1/2**	**Fermi 2**	**FitzPatrick**	**Fort Calhoun**	**Ginna**	**Grand Gulf 1**	**Hatch 1/2**	**Hope Creek 1**	**Indian Point 2/3**	**La Salle 1/2**	**Limerick 1/2**	**McGuire 1/2**	**Millstone 2/3**	**Monticello**	**Nine Mile Point 1/2**	**North Anna 1/2**	**Oconee 1/2/3**	**Oyster Creek**
10	6E-05	2E-04	1E-04	1E-04	4E-05	3E-05	6E-05	2E-04	3E-04	3E-04	3E-04	4E-04	2E-04	2E-04	1E-04	2E-04	1E-04	3E-04
20	1E-04	2E-04	9E-05	1E-04	8E-05	6E-05	8E-05	2E-04	4E-04	3E-04	3E-04	4E-04	2E-04	3E-04	9E-05	3E-04	2E-04	3E-04
30	1E-04	1E-04	8E-05	9E-05	9E-05	6E-05	9E-05	3E-04	4E-04	3E-04	3E-04	3E-04	2E-04	3E-04	8E-05	3E-04	2E-04	3E-04
40	1E-04	1E-04	7E-05	8E-05	8E-05	6E-05	1E-04	2E-04	4E-04	2E-04	3E-04	2E-04	2E-04	2E-04	7E-05	3E-04	2E-04	3E-04
50	1E-04	1E-04	7E-05	8E-05	7E-05	7E-05	1E-04	2E-04	3E-04	2E-04	3E-04	2E-04	2E-04	2E-04	7E-05	2E-04	2E-04	2E-04
60	1E-04	1E-04	7E-05	7E-05	7E-05	7E-05	1E-04	2E-04	3E-04	2E-04	3E-04	2E-04	2E-04	1E-04	7E-05	2E-04	2E-04	2E-04
70	1E-04	1E-04	7E-05	7E-05	7E-05	7E-05	1E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	1E-04	7E-05	2E-04	2E-04	2E-04
80	1E-04	1E-04	7E-05	6E-05	7E-05	8E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	7E-05	2E-04	2E-04	2E-04
90	1E-04	1E-04	7E-05	6E-05	7E-05	8E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	7E-05	2E-04	2E-04	2E-04
100	1E-04	1E-04	7E-05	6E-05	7E-05	9E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	7E-05	2E-04	2E-04	2E-04
Distance to 3rd Crash [mi]	16	27	11	21	19	26	25	28	11	10	12	12	13	19	11	22	15	19

Table B.7 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	Palisades	Palo Verde 1/2/3	Peach Bottom 2/3	Perry 1	Pilgrim 1	Point Beach 1/2	Prairie Island 1/2	Quad Cities 1/2	River Bend 1	Robinson 2	Saint Lucie 1/2	Salem 1/2	Seabrook 1	Sequoyah 1/2	Shearon Harris 1	South Texas 1/2	Summer	Surry 1/2
10	3E-04	3E-04	2E-04	1E-04	2E-04	3E-05	3E-04	1E-04	1E-04	1E-04	7E-04	2E-04	2E-04	3E-04	1E-04	3E-05	1E-04	4E-04
20	2E-04	2E-04	3E-04	1E-04	2E-04	6E-05	3E-04	1E-04	1E-04	1E-04	5E-04	2E-04	2E-04	3E-04	1E-04	1E-04	1E-04	3E-04
30	2E-04	3E-04	2E-04	1E-04	2E-04	8E-05	2E-04	1E-04	1E-04	1E-04	4E-04	3E-04	2E-04	2E-04	1E-04	1E-04	1E-04	2E-04
40	2E-04	3E-04	2E-04	1E-04	1E-04	9E-05	2E-04	1E-04	1E-04	1E-04	4E-04	2E-04	2E-04	2E-04	1E-04	1E-04	2E-04	2E-04
50	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	2E-04	1E-04	1E-04	1E-04	4E-04	2E-04	2E-04	2E-04	1E-04	2E-04	2E-04	2E-04
60	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	2E-04	1E-04	1E-04	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
70	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
80	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
90	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
100	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	1E-04	2E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
Distance to 3rd Crash [mi]	13	11	17	23	14	33	12	16	17	19	10	12	17	10	19	25	14	9

Table B.7 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	**Susquehanna 1/2**	**Three Mile Island 1**	**Turkey Point 3/4**	**Vogtle 1/2**	**Waterford 3**	**Watts Bar 1/2**	**Wolf Creek 1**
10	9E-05	1E-04	6E-04	9E-05	1E-04	3E-04	5E-05
20	1E-04	2E-04	5E-04	1E-04	2E-04	2E-04	6E-05
30	2E-04	2E-04	4E-04	1E-04	2E-04	2E-04	7E-05
40	2E-04	2E-04	3E-04	1E-04	1E-04	2E-04	8E-05
50	2E-04	2E-04	3E-04	1E-04	1E-04	2E-04	9E-05
60	2E-04	2E-04	2E-04	1E-04	1E-04	2E-04	1E-04
70	2E-04	2E-04	2E-04	1E-04	9E-05	2E-04	1E-04
80	2E-04	2E-04	2E-04	1E-04	8E-05	2E-04	1E-04
90	2E-04	2E-04	2E-04	1E-04	8E-05	2E-04	1E-04
100	2E-04	2E-04	2E-04	2E-04	7E-05	2E-04	1E-04
Distance to 3rd Crash [mi]	21	17	4	19	15	11	30

Table B.8 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing only

Bandwidth [mi]	Arkansas Nuclear 1/2	Beaver Valley 1/2	Braidwood 1/2	Browns Ferry 1/2/3	Brunswick 1/2	Byron 1/2	Callaway	Calvert Cliffs 1/2	Catawba 1/2	Clinton	Columbia Generating Station	Comanche Peak 1/2	Cooper	D.C. Cook 1/2	Davis-Besse	Diablo Canyon 1/2	Dresden 2/3	Duane Arnold
10	3E-05	1E-04	2E-04	3E-04	7E-05	2E-04	1E-04	2E-04	3E-04	9E-05	2E-04	4E-04	3E-05	2E-04	2E-05	3E-04	5E-04	7E-05
20	6E-05	2E-04	3E-04	2E-04	2E-04	2E-04	1E-04	2E-04	2E-04	9E-05	1E-04	3E-04	4E-05	2E-04	6E-05	2E-04	4E-04	9E-05
30	7E-05	2E-04	3E-04	1E-04	1E-04	2E-04	1E-04	2E-04	2E-04	9E-05	1E-04	3E-04	5E-05	2E-04	8E-05	1E-04	3E-04	8E-05
40	8E-05	2E-04	2E-04	1E-04	1E-04	2E-04	1E-04	2E-04	2E-04	9E-05	9E-05	3E-04	6E-05	2E-04	1E-04	1E-04	3E-04	8E-05
50	8E-05	2E-04	2E-04	1E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	9E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	7E-05
60	9E-05	1E-04	2E-04	1E-04	9E-05	2E-04	1E-04	2E-04	2E-04	1E-04	8E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	8E-05
70	9E-05	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	2E-04	2E-04	1E-04	9E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	8E-05
80	9E-05	1E-04	2E-04	1E-04	8E-05	2E-04	9E-05	2E-04	2E-04	1E-04	9E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	8E-05
90	1E-04	1E-04	2E-04	1E-04	8E-05	1E-04	9E-05	2E-04	2E-04	1E-04	9E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	9E-05
100	1E-04	1E-04	2E-04	1E-04	7E-05	1E-04	9E-05	1E-04	2E-04	1E-04	9E-05	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	9E-05
Distance to 3rd Crash [mi]	26	20	15	11	19	14	14	11	10	15	14	7	34	16	30	13	10	26

Table B.8 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing only (continued)

Bandwidth [mi]	**Farley 1/2**	**Fermi 2**	**FitzPatrick**	**Fort Calhoun**	**Ginna**	**Grand Gulf 1**	**Hatch 1/2**	**Hope Creek 1**	**Indian Point 2/3**	**La Salle 1/2**	**Limerick 1/2**	**McGuire 1/2**	**Millstone 2/3**	**Monticello**	**Nine Mile Point 1/2**	**North Anna 1/2**	**Oconee 1/2/3**	**Oyster Creek**
10	5E-05	2E-04	1E-04	6E-05	4E-05	3E-05	6E-05	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	2E-04	1E-04	3E-04
20	8E-05	1E-04	7E-05	9E-05	8E-05	5E-05	7E-05	2E-04	3E-04	3E-04	2E-04	3E-04	2E-04	3E-04	7E-05	3E-04	2E-04	3E-04
30	8E-05	1E-04	6E-05	8E-05	8E-05	6E-05	9E-05	2E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	6E-05	3E-04	2E-04	2E-04
40	9E-05	1E-04	6E-05	8E-05	7E-05	6E-05	1E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	6E-05	2E-04	2E-04	2E-04
50	9E-05	1E-04	6E-05	7E-05	6E-05	6E-05	1E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	6E-05	2E-04	2E-04	2E-04
60	1E-04	1E-04	6E-05	6E-05	6E-05	6E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	6E-05	2E-04	2E-04	2E-04
70	1E-04	1E-04	6E-05	6E-05	6E-05	7E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	6E-05	2E-04	2E-04	2E-04
80	1E-04	1E-04	6E-05	6E-05	6E-05	7E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	1E-04	6E-05	2E-04	2E-04	2E-04
90	1E-04	1E-04	6E-05	6E-05	6E-05	7E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	1E-04	6E-05	2E-04	2E-04	1E-04
100	1E-04	1E-04	6E-05	5E-05	6E-05	7E-05	1E-04	2E-04	2E-04	1E-04	2E-04	1E-04	1E-04	9E-05	6E-05	1E-04	2E-04	1E-04
Distance to 3rd Crash [mi]	27	11	21	23	26	25	28	11	10	12	12	15	19	11	22	15	19	10

Table B.8 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing only (continued)

Bandwidth [mi]	Palisades	Palo Verde 1/2/3	Peach Bottom 2/3	Perry 1	Pilgrim 1	Point Beach 1/2	Prairie Island 1/2	Quad Cities 1/2	River Bend 1	Robinson 2	Saint Lucie 1/2	Salem 1/2	Seabrook 1	Sequoyah 1/2	Shearon Harris 1	South Texas 1/2	Summer	Surry 1/2
10	2E-04	3E-04	1E-04	1E-04	3E-05	3E-05	2E-04	1E-04	1E-04	1E-04	6E-04	2E-04	2E-04	2E-04	1E-04	3E-05	1E-04	3E-04
20	2E-04	2E-04	2E-04	8E-05	1E-04	5E-05	2E-04	1E-04	9E-05	1E-04	4E-04	2E-04	2E-04	2E-04	1E-04	8E-05	1E-04	2E-04
30	2E-04	2E-04	2E-04	9E-05	1E-04	7E-05	2E-04	9E-05	8E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	1E-04	2E-04
40	2E-04	2E-04	2E-04	9E-05	1E-04	8E-05	2E-04	1E-04	8E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	2E-04
50	2E-04	2E-04	2E-04	9E-05	1E-04	9E-05	2E-04	1E-04	8E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
60	2E-04	2E-04	2E-04	9E-05	9E-05	9E-05	1E-04	1E-04	7E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
70	2E-04	2E-04	2E-04	9E-05	9E-05	9E-05	1E-04	1E-04	7E-05	1E-04	2E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
80	2E-04	1E-04	2E-04	1E-04	9E-05	9E-05	1E-04	1E-04	7E-05	1E-04	2E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
90	2E-04	1E-04	2E-04	1E-04	8E-05	1E-04	1E-04	1E-04	7E-05	1E-04	2E-04	2E-04	9E-05	2E-04	1E-04	1E-04	2E-04	1E-04
100	1E-04	1E-04	2E-04	1E-04	8E-05	1E-04	1E-04	1E-04	7E-05	1E-04	2E-04	2E-04	9E-05	2E-04	1E-04	1E-04	2E-04	1E-04
Distance to 3rd Crash [mi]	14	11	17	23	26	33	13	16	17	19	10	12	17	13	19	25	14	12

Table B.8 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; fixed wing only (continued)

Bandwidth [mi]	Susquehanna 1/2	Three Mile Island 1	Turkey Point 3/4	Vogtle 1/2	Waterford 3	Watts Bar 1/2	Wolf Creek 1
10	2E-05	8E-05	4E-04	9E-05	1E-04	2E-04	5E-05
20	9E-05	1E-04	4E-04	1E-04	1E-04	2E-04	6E-05
30	1E-04	1E-04	3E-04	1E-04	1E-04	2E-04	6E-05
40	1E-04	1E-04	3E-04	1E-04	1E-04	2E-04	7E-05
50	1E-04	2E-04	2E-04	1E-04	8E-05	2E-04	8E-05
60	1E-04	2E-04	2E-04	1E-04	7E-05	2E-04	9E-05
70	1E-04	2E-04	2E-04	1E-04	7E-05	2E-04	9E-05
80	1E-04	2E-04	2E-04	1E-04	6E-05	2E-04	9E-05
90	1E-04	2E-04	1E-04	1E-04	6E-05	2E-04	9E-05
100	1E-04	2E-04	1E-04	1E-04	6E-05	2E-04	9E-05
Distance to 3rd Crash [mi]	30	24	8	19	15	11	30

Table B.9 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; rotary wing only

Bandwidth [mi]	Arkansas Nuclear 1/2	Beaver Valley 1/2	Braidwood 1/2	Browns Ferry 1/2/3	Brunswick 1/2	Byron 1/2	Callaway	Calvert Cliffs 1/2	Catawba 1/2	Clinton	Columbia Generating Station	Comanche Peak 1/2	Cooper	D.C. Cook 1/2	Davis-Besse	Diablo Canyon 1/2	Dresden 2/3	Duane Arnold
10	1E-05	2E-05	3E-06	2E-06	2E-04	1E-06	5E-05	2E-05	2E-05	8E-15	1E-04	2E-05	1E-14	2E-06	1E-05	1E-19	5E-06	2E-05
20	2E-05	5E-05	2E-05	2E-05	6E-05	8E-06	3E-05	2E-05	5E-05	1E-07	6E-05	5E-05	1E-07	2E-05	1E-05	4E-09	3E-05	2E-05
30	2E-05	4E-05	3E-05	2E-05	3E-05	1E-05	2E-05	2E-05	4E-05	2E-06	4E-05	6E-05	2E-06	2E-05	1E-05	4E-07	3E-05	1E-05
40	2E-05	3E-05	2E-05	2E-05	2E-05	1E-05	2E-05	2E-05	3E-05	5E-06	3E-05	6E-05	4E-06	3E-05	2E-05	3E-06	3E-05	9E-06
50	1E-05	3E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	9E-06	2E-05	6E-05	5E-06	3E-05	2E-05	6E-06	2E-05	9E-06
60	1E-05	2E-05	2E-05	2E-05	1E-05	2E-05	2E-05	2E-05	2E-05	1E-05	2E-05	6E-05	5E-06	2E-05	2E-05	1E-05	2E-05	9E-06
70	1E-05	2E-05	2E-05	2E-05	1E-05	2E-05	2E-05	2E-05	2E-05	1E-05	2E-05	5E-05	6E-06	2E-05	2E-05	1E-05	2E-05	9E-06
80	1E-05	2E-05	2E-05	2E-05	1E-05	2E-05	2E-05	2E-05	2E-05	1E-05	2E-05	5E-05	6E-06	2E-05	2E-05	2E-05	2E-05	9E-06
90	1E-05	2E-05	2E-05	2E-05	1E-05	2E-05	1E-05	2E-05	2E-05	1E-05	2E-05	4E-05	6E-06	2E-05	2E-05	2E-05	2E-05	9E-06
100	1E-05	2E-05	2E-05	2E-05	9E-06	1E-05	1E-05	2E-05	1E-05	1E-05	2E-05	4E-05	6E-06	2E-05	2E-05	2E-05	2E-05	9E-06
Distance to 3rd Crash [mi]	42	28	42	41	13	58	49	47	29	71	20	25	86	44	55	102	40	58

Table B.9 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; rotary wing only (continued)

Bandwidth [mi]	Farley 1/2	Fermi 2	FitzPatrick	Fort Calhoun	Ginna	Grand Gulf 1	Hatch 1/2	Hope Creek 1	Indian Point 2/3	La Salle 1/2	Limerick 1/2	McGuire 1/2	Millstone 2/3	Monticello	Nine Mile Point 1/2	North Anna 1/2	Oconee 1/2/3	Oyster Creek
10	1E-06	2E-06	5E-06	7E-05	4E-07	6E-07	1E-07	9E-07	1E-05	4E-05	7E-05	1E-04	1E-06	2E-06	5E-06	1E-05	3E-09	2E-05
20	2E-05	2E-05	2E-05	2E-05	8E-06	6E-06	4E-06	3E-05	6E-05	2E-05	1E-04	8E-05	2E-05	2E-05	2E-05	2E-05	4E-06	4E-05
30	2E-05	2E-05	2E-05	1E-05	1E-05	7E-06	5E-06	5E-05	7E-05	2E-05	9E-05	5E-05	3E-05	3E-05	2E-05	2E-05	1E-05	5E-05
40	2E-05	2E-05	2E-05	8E-06	1E-05	7E-06	5E-06	5E-05	7E-05	2E-05	8E-05	3E-05	4E-05	2E-05	2E-05	2E-05	1E-05	5E-05
50	2E-05	2E-05	1E-05	7E-06	1E-05	6E-06	5E-06	5E-05	6E-05	2E-05	7E-05	3E-05	4E-05	2E-05	1E-05	2E-05	2E-05	5E-05
60	2E-05	2E-05	1E-05	6E-06	1E-05	7E-06	6E-06	5E-05	5E-05	2E-05	6E-05	2E-05	4E-05	1E-05	1E-05	2E-05	2E-05	5E-05
70	1E-05	2E-05	1E-05	6E-06	1E-05	8E-06	7E-06	4E-05	5E-05	2E-05	5E-05	2E-05	3E-05	1E-05	1E-05	2E-05	2E-05	4E-05
80	1E-05	2E-05	1E-05	6E-06	1E-05	9E-06	8E-06	4E-05	4E-05	2E-05	5E-05	2E-05	3E-05	1E-05	1E-05	2E-05	2E-05	4E-05
90	1E-05	2E-05	1E-05	6E-06	1E-05	9E-06	9E-06	4E-05	4E-05	2E-05	4E-05	2E-05	3E-05	1E-05	1E-05	2E-05	2E-05	4E-05
100	1E-05	2E-05	1E-05	6E-06	1E-05	1E-05	1E-05	3E-05	3E-05	2E-05	4E-05	1E-05	3E-05	9E-06	1E-05	2E-05	2E-05	3E-05
Distance to 3rd Crash [mi]	39	33	34	77	58	68	87	36	29	57	16	14	44	36	34	50	50	35

Table B.9 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; rotary wing only (continued)

Bandwidth [mi]	**Palisades**	**Palo Verde 1/2/3**	**Peach Bottom 2/3**	**Perry 1**	**Pilgrim 1**	**Point Beach 1/2**	**Prairie Island 1/2**	**Quad Cities 1/2**	**River Bend 1**	**Robinson 2**	**Saint Lucie 1/2**	**Salem 1/2**	**Seabrook 1**	**Sequoyah 1/2**	**Shearon Harris 1**	**South Texas 1/2**	**Summer**	**Surry 1/2**
10	6E-05	4E-06	6E-05	7E-07	2E-04	3E-11	4E-05	3E-06	1E-05	6E-07	2E-04	8E-07	1E-05	9E-05	1E-05	3E-07	1E-13	8E-05
20	2E-05	2E-05	1E-04	1E-05	8E-05	1E-06	3E-05	1E-05	2E-05	9E-06	1E-04	3E-05	4E-05	3E-05	2E-05	2E-05	2E-07	4E-05
30	2E-05	4E-05	8E-05	2E-05	6E-05	6E-06	2E-05	1E-05	2E-05	1E-05	1E-04	5E-05	5E-05	2E-05	1E-05	3E-05	3E-06	3E-05
40	2E-05	5E-05	7E-05	2E-05	5E-05	9E-06	2E-05	1E-05	2E-05	1E-05	8E-05	5E-05	4E-05	2E-05	1E-05	4E-05	7E-06	2E-05
50	2E-05	6E-05	6E-05	2E-05	4E-05	1E-05	2E-05	1E-05	2E-05	1E-05	7E-05	5E-05	4E-05	2E-05	1E-05	4E-05	9E-06	2E-05
60	2E-05	5E-05	5E-05	2E-05	3E-05	1E-05	1E-05	1E-05	2E-05	1E-05	6E-05	5E-05	3E-05	2E-05	1E-05	4E-05	1E-05	1E-05
70	2E-05	5E-05	4E-05	2E-05	3E-05	1E-05	1E-05	1E-05	2E-05	1E-05	6E-05	4E-05	3E-05	2E-05	1E-05	4E-05	1E-05	1E-05
80	2E-05	4E-05	4E-05	2E-05	2E-05	1E-05	1E-05	1E-05	2E-05	1E-05	5E-05	4E-05	2E-05	2E-05	1E-05	4E-05	1E-05	1E-05
90	2E-05	4E-05	4E-05	2E-05	2E-05	1E-05	1E-05	1E-05	2E-05	1E-05	5E-05	4E-05	2E-05	2E-05	1E-05	3E-05	1E-05	1E-05
100	2E-05	3E-05	3E-05	2E-05	2E-05	1E-05	1E-05	1E-05	2E-05	1E-05	4E-05	3E-05	2E-05	2E-05	1E-05	3E-05	1E-05	1E-05
Distance to 3rd Crash [mi]	54	44	20	53	14	59	44	65	53	46	12	37	35	59	45	42	70	30

Table B.9 – 20-year f(s) sensitivity analysis for NRC sites [2000-2019]; rotary wing only (continued)

Bandwidth [mi]	Susquehanna 1/2	Three Mile Island 1	Turkey Point 3/4	Vogtle 1/2	Waterford 3	Watts Bar 1/2	Wolf Creek 1
10	7E-05	5E-05	2E-04	2E-11	4E-05	1E-05	4E-11
20	6E-05	7E-05	1E-04	5E-07	5E-05	2E-05	9E-07
30	5E-05	6E-05	7E-05	2E-06	4E-05	2E-05	4E-06
40	4E-05	5E-05	5E-05	3E-06	4E-05	2E-05	7E-06
50	4E-05	5E-05	4E-05	4E-06	3E-05	2E-05	8E-06
60	4E-05	4E-05	4E-05	5E-06	3E-05	2E-05	9E-06
70	4E-05	4E-05	3E-05	6E-06	2E-05	2E-05	9E-06
80	4E-05	4E-05	3E-05	8E-06	2E-05	2E-05	9E-06
90	3E-05	3E-05	3E-05	9E-06	2E-05	2E-05	9E-06
100	3E-05	3E-05	2E-05	1E-05	2E-05	2E-05	9E-06
Distance to 3rd Crash [mi]	22	23	15	106	28	37	73

Table B.10 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing + rotary wing

Bandwidth [mi]	Arkansas Nuclear 1/2	Beaver Valley 1/2	Braidwood 1/2	Browns Ferry 1/2/3	Brunswick 1/2	Byron 1/2	Callaway	Calvert Cliffs 1/2	Catawba 1/2	Clinton	Columbia Generating Station	Comanche Peak 1/2	Cooper	D.C. Cook 1/2	Davis-Besse	Diablo Canyon 1/2	Dresden 2/3	Duane Arnold
10	6E-05	1E-04	3E-04	1E-04	3E-04	2E-04	2E-04	2E-04	1E-04	1E-04	2E-04	3E-04	5E-07	7E-05	5E-05	2E-04	6E-04	1E-05
20	8E-05	1E-04	4E-04	1E-04	2E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	3E-05	1E-04	9E-05	1E-04	5E-04	6E-05
30	9E-05	1E-04	3E-04	1E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	5E-05	2E-04	1E-04	7E-05	4E-04	6E-05
40	1E-04	1E-04	3E-04	1E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	6E-05	2E-04	1E-04	7E-05	3E-04	7E-05
50	1E-04	1E-04	2E-04	1E-04	9E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	6E-05	2E-04	1E-04	8E-05	2E-04	7E-05
60	1E-04	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	3E-04	6E-05	2E-04	1E-04	9E-05	2E-04	8E-05
70	1E-04	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	2E-04	2E-04	1E-04	1E-04	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	8E-05
80	1E-04	1E-04	2E-04	1E-04	7E-05	2E-04	9E-05	2E-04	2E-04	1E-04	1E-04	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	9E-05
90	1E-04	1E-04	2E-04	1E-04	7E-05	1E-04	9E-05	1E-04	2E-04	1E-04	1E-04	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	9E-05
100	1E-04	1E-04	2E-04	1E-04	7E-05	1E-04	9E-05	1E-04	1E-04	1E-04	1E-04	2E-04	6E-05	2E-04	1E-04	1E-04	2E-04	9E-05
Distance to 3rd Crash [mi]	33	27	15	19	19	16	27	15	26	23	32	21	39	24	30	17	12	31

Table B.10 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	Farley 1/2	Fermi 2	FitzPatrick	Fort Calhoun	Ginna	Grand Gulf 1	Hatch 1/2	Hope Creek 1	Indian Point 2/3	La Salle 1/2	Limerick 1/2	McGuire 1/2	Millstone 2/3	Monticello	Nine Mile Point 1/2	North Anna 1/2	Oconee 1/2/3	Oyster Creek
10	2E-06	2E-04	8E-05	2E-04	8E-07	3E-10	4E-06	1E-04	3E-04	2E-04	2E-04	3E-04	1E-04	2E-04	8E-05	1E-04	2E-04	2E-04
20	4E-05	2E-04	4E-05	1E-04	2E-05	2E-06	3E-05	1E-04	4E-04	3E-04	2E-04	3E-04	2E-04	3E-04	4E-05	2E-04	2E-04	3E-04
30	6E-05	1E-04	4E-05	9E-05	3E-05	1E-05	5E-05	2E-04	4E-04	3E-04	2E-04	2E-04	2E-04	2E-04	4E-05	3E-04	2E-04	3E-04
40	7E-05	1E-04	4E-05	8E-05	4E-05	2E-05	7E-05	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	4E-05	2E-04	2E-04	2E-04
50	7E-05	1E-04	4E-05	7E-05	4E-05	3E-05	8E-05	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	1E-04	4E-05	2E-04	2E-04	2E-04
60	8E-05	1E-04	5E-05	7E-05	5E-05	4E-05	9E-05	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	1E-04	5E-05	2E-04	2E-04	2E-04
70	9E-05	1E-04	5E-05	6E-05	5E-05	5E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	5E-05	2E-04	2E-04	2E-04
80	9E-05	1E-04	6E-05	6E-05	5E-05	6E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	9E-05	6E-05	2E-04	2E-04	2E-04
90	1E-04	1E-04	6E-05	6E-05	6E-05	6E-05	1E-04	2E-04	2E-04	2E-04	2E-04	1E-04	1E-04	9E-05	6E-05	1E-04	2E-04	2E-04
100	1E-04	1E-04	6E-05	6E-05	6E-05	7E-05	1E-04	2E-04	2E-04	1E-04	2E-04	1E-04	1E-04	8E-05	6E-05	1E-04	2E-04	2E-04
Distance to 3rd Crash [mi]	39	22	46	23	46	65	44	36	18	18	16	15	19	22	47	23	20	17

Table B.10 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	**Palisades**	**Palo Verde 1/2/3**	**Peach Bottom 2/3**	**Perry 1**	**Pilgrim 1**	**Point Beach 1/2**	**Prairie Island 1/2**	**Quad Cities 1/2**	**River Bend 1**	**Robinson 2**	**Saint Lucie 1/2**	**Salem 1/2**	**Seabrook 1**	**Sequoyah 1/2**	**Shearon Harris 1**	**South Texas 1/2**	**Summer**	**Surry 1/2**
10	2E-04	2E-04	1E-04	2E-05	8E-05	6E-05	2E-04	6E-05	2E-04	2E-04	5E-04	1E-04	4E-05	4E-04	7E-05	1E-05	7E-05	3E-04
20	1E-04	2E-04	2E-04	7E-05	1E-04	8E-05	2E-04	7E-05	1E-04	2E-04	4E-04	1E-04	8E-05	2E-04	1E-04	1E-04	1E-04	2E-04
30	1E-04	3E-04	2E-04	8E-05	1E-04	1E-04	2E-04	7E-05	1E-04	2E-04	4E-04	2E-04	1E-04	2E-04	1E-04	1E-04	1E-04	1E-04
40	1E-04	3E-04	2E-04	8E-05	9E-05	1E-04	2E-04	8E-05	1E-04	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	2E-04	2E-04	1E-04
50	2E-04	2E-04	2E-04	8E-05	9E-05	1E-04	1E-04	1E-04	1E-04	2E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
60	2E-04	2E-04	2E-04	8E-05	9E-05	1E-04	1E-04	1E-04	1E-04	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
70	2E-04	2E-04	2E-04	9E-05	8E-05	1E-04	1E-04	1E-04	9E-05	1E-04	3E-04	2E-04	1E-04	2E-04	1E-04	1E-04	2E-04	1E-04
80	2E-04	2E-04	2E-04	9E-05	8E-05	1E-04	1E-04	1E-04	9E-05	1E-04	2E-04	2E-04	9E-05	2E-04	1E-04	1E-04	2E-04	1E-04
90	2E-04	2E-04	2E-04	9E-05	8E-05	1E-04	1E-04	1E-04	8E-05	1E-04	2E-04	2E-04	9E-05	2E-04	1E-04	1E-04	1E-04	1E-04
100	2E-04	1E-04	2E-04	9E-05	8E-05	1E-04	9E-05	1E-04	8E-05	1E-04	2E-04	2E-04	8E-05	2E-04	1E-04	1E-04	1E-04	1E-04
Distance to 3rd Crash [mi]	26	23	20	30	27	39	15	28	17	19	12	37	38	10	24	34	29	12

Table B.10 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing + rotary wing (continued)

Bandwidth [mi]	**Susquehanna 1/2**	**Three Mile Island 1**	**Turkey Point 3/4**	**Vogtle 1/2**	**Waterford 3**	**Watts Bar 1/2**	**Wolf Creek 1**
10	5E-05	3E-05	9E-04	8E-05	8E-05	2E-04	7E-06
20	2E-04	1E-04	6E-04	6E-05	2E-04	2E-04	4E-05
30	2E-04	2E-04	4E-04	8E-05	2E-04	2E-04	5E-05
40	2E-04	2E-04	3E-04	9E-05	1E-04	2E-04	6E-05
50	2E-04	2E-04	3E-04	1E-04	1E-04	2E-04	7E-05
60	2E-04	2E-04	2E-04	1E-04	1E-04	2E-04	8E-05
70	2E-04	2E-04	2E-04	1E-04	9E-05	2E-04	8E-05
80	2E-04	2E-04	2E-04	1E-04	8E-05	2E-04	8E-05
90	2E-04	2E-04	1E-04	1E-04	8E-05	2E-04	8E-05
100	2E-04	2E-04	1E-04	1E-04	7E-05	1E-04	8E-05
Distance to 3rd Crash [mi]	26	29	4	37	27	24	32

Table B.11 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing only

Bandwidth [mi]	Arkansas Nuclear 1/2	Beaver Valley 1/2	Braidwood 1/2	Browns Ferry 1/2/3	Brunswick 1/2	Byron 1/2	Callaway	Calvert Cliffs 1/2	Catawba 1/2	Clinton	Columbia Generating Station	Comanche Peak 1/2	Cooper	D.C. Cook 1/2	Davis-Besse	Diablo Canyon 1/2	Dresden 2/3	Duane Arnold
10	3E-05	1E-04	3E-04	1E-04	5E-05	2E-04	8E-05	2E-04	1E-04	1E-04	1E-06	2E-04	5E-07	7E-05	2E-05	2E-04	6E-04	1E-05
20	5E-05	1E-04	3E-04	1E-04	9E-05	2E-04	9E-05	1E-04	1E-04	1E-04	3E-05	2E-04	3E-05	1E-04	6E-05	1E-04	5E-04	6E-05
30	6E-05	1E-04	3E-04	1E-04	8E-05	2E-04	8E-05	1E-04	2E-04	1E-04	5E-05	2E-04	5E-05	1E-04	8E-05	7E-05	3E-04	6E-05
40	7E-05	1E-04	2E-04	1E-04	7E-05	2E-04	7E-05	2E-04	2E-04	9E-05	6E-05	2E-04	5E-05	1E-04	9E-05	6E-05	3E-04	6E-05
50	8E-05	1E-04	2E-04	1E-04	7E-05	2E-04	7E-05	2E-04	2E-04	9E-05	6E-05	2E-04	6E-05	1E-04	1E-04	7E-05	2E-04	6E-05
60	8E-05	1E-04	2E-04	1E-04	6E-05	2E-04	7E-05	2E-04	2E-04	9E-05	6E-05	2E-04	6E-05	2E-04	1E-04	8E-05	2E-04	7E-05
70	8E-05	1E-04	2E-04	1E-04	6E-05	2E-04	7E-05	1E-04	2E-04	1E-04	7E-05	2E-04	6E-05	2E-04	1E-04	8E-05	2E-04	7E-05
80	9E-05	1E-04	2E-04	1E-04	6E-05	1E-04	7E-05	1E-04	1E-04	1E-04	7E-05	2E-04	6E-05	1E-04	1E-04	9E-05	2E-04	8E-05
90	9E-05	1E-04	1E-04	1E-04	6E-05	1E-04	7E-05	1E-04	1E-04	1E-04	7E-05	2E-04	6E-05	1E-04	1E-04	1E-04	1E-04	8E-05
100	9E-05	1E-04	1E-04	1E-04	6E-05	1E-04	8E-05	1E-04	1E-04	1E-04	7E-05	2E-04	6E-05	1E-04	1E-04	1E-04	1E-04	9E-05
Distance to 3rd Crash [mi]	37	29	15	19	31	16	27	25	26	23	37	22	39	24	35	17	12	31

Table B.11 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing only (continued)

Bandwidth [mi]	Farley 1/2	Fermi 2	FitzPatrick	Fort Calhoun	Ginna	Grand Gulf 1	Hatch 1/2	Hope Creek 1	Indian Point 2/3	La Salle 1/2	Limerick 1/2	McGuire 1/2	Millstone 2/3	Monticello	Nine Mile Point 1/2	North Anna 1/2	Oconee 1/2/3	Oyster Creek
10	1E-07	2E-04	8E-05	5E-05	8E-07	3E-10	4E-06	1E-04	3E-04	2E-04	9E-05	1E-04	1E-04	2E-04	8E-05	1E-04	2E-04	2E-04
20	1E-05	1E-04	4E-05	8E-05	2E-05	2E-06	3E-05	9E-05	3E-04	3E-04	1E-04	2E-04	2E-04	3E-04	4E-05	2E-04	2E-04	2E-04
30	3E-05	1E-04	3E-05	7E-05	3E-05	1E-05	5E-05	1E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	3E-05	3E-04	2E-04	2E-04
40	4E-05	9E-05	4E-05	6E-05	3E-05	2E-05	7E-05	1E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	4E-05	2E-04	2E-04	2E-04
50	6E-05	9E-05	4E-05	6E-05	4E-05	3E-05	8E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	4E-05	2E-04	2E-04	2E-04
60	6E-05	1E-04	4E-05	6E-05	4E-05	4E-05	9E-05	1E-04	2E-04	2E-04	2E-04	2E-04	2E-04	1E-04	4E-05	2E-04	2E-04	1E-04
70	7E-05	1E-04	5E-05	6E-05	4E-05	5E-05	1E-04	1E-04	2E-04	2E-04	2E-04	1E-04	1E-04	1E-04	5E-05	2E-04	2E-04	1E-04
80	8E-05	1E-04	5E-05	5E-05	4E-05	5E-05	1E-04	1E-04	2E-04	1E-04	1E-04	1E-04	1E-04	9E-05	5E-05	1E-04	2E-04	1E-04
90	8E-05	1E-04	5E-05	5E-05	5E-05	6E-05	1E-04	1E-04	2E-04	1E-04	1E-04	1E-04	1E-04	8E-05	5E-05	1E-04	2E-04	1E-04
100	9E-05	1E-04	5E-05	5E-05	5E-05	6E-05	1E-04	1E-04	1E-04	1E-04	1E-04	1E-04	1E-04	7E-05	5E-05	1E-04	2E-04	1E-04
Distance to 3rd Crash [mi]	50	22	46	23	46	66	44	38	18	18	27	23	19	22	47	23	20	17

Table B.11 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing only (continued)

Bandwidth [mi]	Palisades	Palo Verde 1/2/3	Peach Bottom 2/3	Perry 1	Pilgrim 1	Point Beach 1/2	Prairie Island 1/2	Quad Cities 1/2	River Bend 1	Robinson 2	Saint Lucie 1/2	Salem 1/2	Seabrook 1	Sequoyah 1/2	Shearon Harris 1	South Texas 1/2	Summer	Surry 1/2
10	2E-04	2E-04	2E-05	2E-05	1E-05	6E-05	2E-04	6E-05	1E-04	2E-04	4E-04	1E-04	4E-05	2E-04	7E-05	1E-05	7E-05	2E-04
20	1E-04	2E-04	7E-05	7E-05	5E-05	8E-05	2E-04	6E-05	1E-04	2E-04	3E-04	9E-05	7E-05	2E-04	1E-04	7E-05	1E-04	1E-04
30	1E-04	2E-04	1E-04	8E-05	6E-05	1E-04	2E-04	6E-05	9E-05	2E-04	3E-04	1E-04	9E-05	2E-04	1E-04	9E-05	1E-04	1E-04
40	1E-04	2E-04	1E-04	8E-05	6E-05	1E-04	2E-04	7E-05	8E-05	1E-04	2E-04	1E-04	9E-05	2E-04	1E-04	1E-04	1E-04	1E-04
50	1E-04	2E-04	1E-04	8E-05	6E-05	1E-04	1E-04	8E-05	8E-05	1E-04	2E-04	1E-04	9E-05	2E-04	1E-04	1E-04	1E-04	1E-04
60	1E-04	2E-04	1E-04	8E-05	6E-05	1E-04	1E-04	9E-05	8E-05	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	1E-04	1E-04	1E-04
70	1E-04	1E-04	1E-04	8E-05	7E-05	1E-04	1E-04	1E-04	7E-05	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	1E-04	1E-04	1E-04
80	1E-04	1E-04	1E-04	8E-05	7E-05	1E-04	1E-04	1E-04	7E-05	1E-04	2E-04	1E-04	8E-05	2E-04	1E-04	1E-04	1E-04	1E-04
90	1E-04	1E-04	1E-04	8E-05	7E-05	1E-04	9E-05	1E-04	7E-05	1E-04	2E-04	1E-04	7E-05	1E-04	1E-04	9E-05	1E-04	1E-04
100	1E-04	1E-04	1E-04	8E-05	7E-05	1E-04	9E-05	1E-04	7E-05	1E-04	2E-04	1E-04	7E-05	1E-04	1E-04	9E-05	1E-04	9E-05
Distance to 3rd Crash [mi]	26	23	37	30	29	39	24	48	17	19	12	38	38	20	24	34	29	29

Table B.11 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; fixed wing only (continued)

Bandwidth [mi]	Susquehanna 1/2	Three Mile Island 1	Turkey Point 3/4	Vogtle 1/2	Waterford 3	Watts Bar 1/2	Wolf Creek 1
10	2E-05	2E-05	8E-04	8E-05	8E-05	2E-04	7E-06
20	1E-04	9E-05	5E-04	6E-05	1E-04	1E-04	4E-05
30	1E-04	1E-04	4E-04	7E-05	1E-04	1E-04	5E-05
40	1E-04	1E-04	3E-04	9E-05	1E-04	1E-04	6E-05
50	1E-04	1E-04	2E-04	1E-04	1E-04	1E-04	7E-05
60	1E-04	1E-04	2E-04	1E-04	9E-05	1E-04	7E-05
70	1E-04	1E-04	2E-04	1E-04	8E-05	1E-04	8E-05
80	1E-04	1E-04	1E-04	1E-04	7E-05	1E-04	8E-05
90	1E-04	1E-04	1E-04	1E-04	6E-05	1E-04	8E-05
100	1E-04	1E-04	1E-04	1E-04	6E-05	1E-04	8E-05
Distance to 3rd Crash [mi]	30	30	8	37	27	24	32

Table B.12 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; rotary wing only

Bandwidth [mi]	Arkansas Nuclear 1/2	Beaver Valley 1/2	Braidwood 1/2	Browns Ferry 1/2/3	Brunswick 1/2	Byron 1/2	Callaway	Calvert Cliffs 1/2	Catawba 1/2	Clinton	Columbia Generating Station	Comanche Peak 1/2	Cooper	D.C. Cook 1/2	Davis-Besse	Diablo Canyon 1/2	Dresden 2/3	Duane Arnold
10	2E-05	6E-06	9E-08	2E-09	3E-04	8E-12	1E-04	5E-05	6E-06	2E-14	2E-04	3E-05	1E-15	9E-09	2E-05	2E-19	2E-07	2E-11
20	3E-05	2E-05	2E-05	3E-06	8E-05	1E-06	5E-05	3E-05	4E-05	3E-07	8E-05	6E-05	7E-08	9E-06	3E-05	8E-09	2E-05	8E-07
30	3E-05	2E-05	3E-05	9E-06	4E-05	7E-06	4E-05	2E-05	4E-05	4E-06	5E-05	6E-05	1E-06	3E-05	2E-05	6E-07	4E-05	4E-06
40	2E-05	2E-05	3E-05	1E-05	2E-05	1E-05	3E-05	2E-05	3E-05	8E-06	4E-05	6E-05	3E-06	3E-05	2E-05	3E-06	3E-05	6E-06
50	2E-05	1E-05	3E-05	1E-05	2E-05	2E-05	3E-05	2E-05	2E-05	1E-05	4E-05	6E-05	4E-06	3E-05	1E-05	7E-06	3E-05	7E-06
60	1E-05	1E-05	3E-05	2E-05	1E-05	2E-05	3E-05	2E-05	2E-05	2E-05	3E-05	6E-05	5E-06	3E-05	1E-05	1E-05	3E-05	7E-06
70	1E-05	1E-05	2E-05	2E-05	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	3E-05	5E-05	5E-06	3E-05	1E-05	1E-05	2E-05	8E-06
80	1E-05	1E-05	2E-05	2E-05	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	3E-05	5E-05	6E-06	2E-05	1E-05	1E-05	2E-05	8E-06
90	1E-05	1E-05	2E-05	1E-05	1E-05	2E-05	2E-05	2E-05	1E-05	2E-05	3E-05	4E-05	6E-06	2E-05	1E-05	2E-05	2E-05	9E-06
100	1E-05	1E-05	2E-05	1E-05	9E-06	1E-05	2E-05	2E-05	1E-05	2E-05	2E-05	4E-05	6E-06	2E-05	1E-05	2E-05	2E-05	9E-06
Distance to 3rd Crash [mi]	42	67	42	65	53	68	49	75	37	71	40	45	118	51	82	102	40	105

Table B.12 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; rotary wing only (continued)

Bandwidth [mi]	Farley 1/2	Fermi 2	FitzPatrick	Fort Calhoun	Ginna	Grand Gulf 1	Hatch 1/2	Hope Creek 1	Indian Point 2/3	La Salle 1/2	Limerick 1/2	McGuire 1/2	Millstone 2/3	Monticello	Nine Mile Point 1/2	North Anna 1/2	Oconee 1/2/3	Oyster Creek
10	2E-06	3E-06	5E-10	1E-04	3E-18	1E-13	2E-34	5E-07	3E-06	2E-11	9E-05	2E-04	8E-09	2E-07	4E-10	1E-15	1E-09	4E-05
20	2E-05	2E-05	2E-06	4E-05	3E-08	2E-07	1E-12	3E-05	5E-05	2E-06	1E-04	9E-05	4E-06	8E-06	2E-06	8E-08	3E-06	6E-05
30	3E-05	2E-05	4E-06	2E-05	1E-06	2E-06	1E-08	5E-05	7E-05	1E-05	9E-05	5E-05	1E-05	9E-06	4E-06	2E-06	8E-06	7E-05
40	2E-05	2E-05	5E-06	1E-05	4E-06	3E-06	2E-07	5E-05	7E-05	2E-05	8E-05	3E-05	2E-05	8E-06	5E-06	5E-06	1E-05	7E-05
50	2E-05	2E-05	5E-06	9E-06	6E-06	4E-06	1E-06	5E-05	6E-05	2E-05	8E-05	3E-05	2E-05	7E-06	5E-06	8E-06	1E-05	6E-05
60	2E-05	1E-05	6E-06	7E-06	7E-06	5E-06	2E-06	5E-05	5E-05	2E-05	7E-05	2E-05	3E-05	7E-06	6E-06	1E-05	1E-05	6E-05
70	1E-05	1E-05	6E-06	7E-06	8E-06	6E-06	3E-06	5E-05	5E-05	2E-05	6E-05	2E-05	3E-05	6E-06	6E-06	1E-05	1E-05	5E-05
80	1E-05	1E-05	7E-06	6E-06	9E-06	7E-06	5E-06	4E-05	4E-05	2E-05	5E-05	2E-05	3E-05	6E-06	7E-06	1E-05	1E-05	4E-05
90	1E-05	1E-05	8E-06	6E-06	1E-05	8E-06	6E-06	4E-05	4E-05	2E-05	5E-05	1E-05	3E-05	6E-06	8E-06	1E-05	1E-05	4E-05
100	1E-05	1E-05	9E-06	6E-06	1E-05	9E-06	7E-06	3E-05	4E-05	2E-05	4E-05	1E-05	2E-05	6E-06	9E-06	1E-05	1E-05	3E-05
Distance to 3rd Crash [mi]	50	62	133	130	84	141	144	44	36	63	27	22	71	116	133	93	81	42

Table B.12 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; rotary wing only (continued)

Bandwidth [mi]	Palisades	Palo Verde 1/2/3	Peach Bottom 2/3	Perry 1	Pilgrim 1	Point Beach 1/2	Prairie Island 1/2	Quad Cities 1/2	River Bend 1	Robinson 2	Saint Lucie 1/2	Salem 1/2	Seabrook 1	Sequoyah 1/2	Shearon Harris 1	South Texas 1/2	Summer	Surry 1/2
10	6E-11	5E-07	9E-05	2E-13	7E-05	5E-12	8E-05	3E-06	3E-05	2E-08	1E-04	4E-07	8E-09	1E-04	7E-09	6E-07	4E-15	1E-04
20	2E-06	1E-05	1E-04	3E-07	6E-05	5E-07	4E-05	2E-05	3E-05	4E-06	1E-04	3E-05	6E-06	4E-05	3E-06	3E-05	1E-07	4E-05
30	1E-05	3E-05	8E-05	3E-06	4E-05	3E-06	2E-05	1E-05	2E-05	8E-06	1E-04	5E-05	2E-05	2E-05	6E-06	5E-05	2E-06	2E-05
40	2E-05	5E-05	6E-05	5E-06	3E-05	5E-06	2E-05	1E-05	2E-05	1E-05	9E-05	5E-05	2E-05	2E-05	6E-06	5E-05	6E-06	1E-05
50	2E-05	5E-05	6E-05	7E-06	3E-05	6E-06	1E-05	1E-05	2E-05	1E-05	7E-05	5E-05	2E-05	2E-05	7E-06	5E-05	9E-06	8E-06
60	2E-05	5E-05	5E-05	8E-06	2E-05	6E-06	1E-05	1E-05	2E-05	1E-05	6E-05	5E-05	2E-05	2E-05	8E-06	4E-05	1E-05	7E-06
70	2E-05	4E-05	5E-05	9E-06	2E-05	7E-06	8E-06	1E-05	2E-05	1E-05	5E-05	5E-05	2E-05	2E-05	8E-06	4E-05	1E-05	6E-06
80	2E-05	4E-05	4E-05	1E-05	2E-05	7E-06	8E-06	1E-05	2E-05	1E-05	5E-05	4E-05	1E-05	2E-05	9E-06	4E-05	1E-05	7E-06
90	2E-05	4E-05	4E-05	1E-05	1E-05	8E-06	7E-06	1E-05	2E-05	1E-05	4E-05	4E-05	1E-05	2E-05	9E-06	3E-05	1E-05	7E-06
100	2E-05	3E-05	3E-05	1E-05	1E-05	8E-06	7E-06	1E-05	2E-05	1E-05	4E-05	3E-05	1E-05	1E-05	9E-06	3E-05	1E-05	8E-06
Distance to 3rd Crash [mi]	61	53	20	121	35	111	104	81	54	87	23	45	61	67	123	42	83	139

Table B.12 – 10-year f(s) sensitivity analysis for NRC sites [2010-2019]; rotary wing only (continued)

Bandwidth [mi]	**Susquehanna 1/2**	**Three Mile Island 1**	**Turkey Point 3/4**	**Vogtle 1/2**	**Waterford 3**	**Watts Bar 1/2**	**Wolf Creek 1**
10	3E-05	5E-06	1E-04	1E-20	7E-08	4E-07	4E-16
20	6E-05	4E-05	5E-05	4E-09	8E-06	1E-05	7E-08
30	5E-05	5E-05	3E-05	3E-07	2E-05	2E-05	2E-06
40	5E-05	5E-05	3E-05	1E-06	2E-05	2E-05	4E-06
50	5E-05	5E-05	2E-05	2E-06	2E-05	2E-05	6E-06
60	5E-05	5E-05	2E-05	4E-06	2E-05	2E-05	7E-06
70	4E-05	4E-05	2E-05	5E-06	2E-05	2E-05	7E-06
80	4E-05	4E-05	2E-05	6E-06	2E-05	2E-05	7E-06
90	4E-05	4E-05	2E-05	7E-06	1E-05	2E-05	7E-06
100	4E-05	3E-05	2E-05	8E-06	1E-05	1E-05	7E-06
Distance to 3rd Crash [mi]	27	40	59	137	56	70	88

APPENDIX C. R PROGRAMMING CODE

APPENDIX C. R PROGRAMMING CODE

C.1 Description of R Software Application and RStudio Interface Application

R software application, also known as R: A Language and Environment for Statistical Computing was used as the base coding application. RStudio is a desktop interface software application used to access the R programming and code execution.

The following version of these software applications were utilized in the analysis of the NTSB GA data:

- R version 4.1.1 (2021-08-10) -- "Kick Things"
  - Organization: R Foundation for Statistical Computing
  - Location: Vienna, Austria
  - Application URL: https://www.R-project.org/

- RStudio 2022.07.2 Build 576
  - Organization: Posit, PBC
  - Location: Delaware, USA
  - Application URL: https://posit.co/

C.2 Summary Description of Developed R Codes

The following R code files associated with this analysis were developed and executed via the RStudio application.

Table C.1 – Description of R Code Files and Associated Input/Out Files		
R Code File	**Input Files (Read)**	**Output Files (Write)**
GA-crashes_NTSB-2022-data.R	• GA crashes ORNL_2000-2007.csv • GA crashes ORNL_2008-2019.csv	• 2000_2019 GA NonAirport Crash Data.csv • 2000_2019 GA NonAirport Crash Data_Rotary.csv • 2000_2019 GA NonAirport Crash Data_No Rotary.csv • 2010_2019 GA NonAirport Crash Data.csv • 2010_2019 GA NonAirport Crash Data_Rotary.csv • 2010_2019 GA NonAirport Crash Data_No Rotary.csv • NTSB Data Filter Report.csv • 2000_2007 GA PoF Accident Data.csv • 2008_2019 GA PoF Accident Data.csv

Table C.1 – Description of R Code Files and Associated Input/Out Files		
R Code File	**Input Files (Read)**	**Output Files (Write)**
GA-fxy-calc_20-yr.R	• DOE and NRC Site Locations.csv • 2000_2019 GA NonAirport Crash Data.csv • 2000_2019 GA NonAirport Crash Data_No Rotary.csv	• NPfxy Site Results_20yr.csv • NPfxy Site Results_20yr_rotary.csv • NPfxy Site Results_20yr_no rotary.csv • GA Site NPfs Sensitivity Results_20yr.csv • GA Site NPfs Sensitivity Results_20yr_rotary.csv • GA Site NPfs Sensitivity Results_20yr_no rotary.csv
GA-fxy-calc_10-yr.R	• DOE and NRC Site Locations.csv • 2010_2019 GA NonAirport Crash Data.csv • 2010_2019 GA NonAirport Crash Data_No Rotary.csv	• NPfxy Site Results_10yr.csv • NPfxy Site Results_10yr_rotary.csv • NPfxy Site Results_10yr_no rotary.csv • GA Site NPfs Sensitivity Results_10yr.csv • GA Site NPfs Sensitivity Results_10yr_rotary.csv • GA Site NPfs Sensitivity Results_10yr_no rotary.csv

C.2.1 GA-crashes_NTSB-2022-data.R

The code reads the two annotated NTSB data files. The code then filters out GA events not associated with CONUS Non-Airport Accidents. The filtered data is then consolidated into data frames and written to four output files:

- Two files containing both fixed-wing aircraft and rotary-wing aircraft CONUS Non-Airport Accidents. One file includes accidents for a twenty year period of 2000 2010. The other file contains accidents for the ten-year period 2010-2019.

- Two files containing only fixed-wing aircraft CONUS Non-Airport Accidents. One file includes accidents for a twenty year period of 2000 2010. The other file contains accidents for the ten-year period 2010-2019.

Additionally, two report files are produced. One file is a tabulation of the number of accidents by Phase of Flight, and a second file is a summary report of the data filtering performed to produce the data frame .csv files that will be used in the crash density calculations.

C.2.2 GA-fxy-calc_20-yr.R

The code reads the selected input site data (DOE or NRC) and the selected twenty-year accident data set (FW+RW data set or FW only data set). The code then calculates the site specific crash density value for the site using the methodology described in this report. The results of the crash density calculations are consolidated into data frames and written to two output files:

- A file containing a summary of the site-specific Non-Airport GA Accidents.
    - Site Name
    - Crash Density Value, [crashes/yr/mi^2]
    - Distance to the 3rd closest crash, [mi]
    - Crash associated with the 99th percentile of overall crash density value

  - Distance to 99th percentile crash
- A file containing a parametric sensitivity analysis of the site specific
  - Site Name
  - Crash Density Values evaluated with band-width valuations of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100-miles.

The following example illustrates how the code is setup to evaluate the Rotary Wing only data set (Line 14). The data sets containing both Fixed Wing and Rotary Wing aircraft (Line 12) and the data set containing only the Fixed Wing data set (Line 13) are commented out using the # sign since the code can only run a single data set at one time.

```
9  setwd("W:/ANS 2.36 Folder/NTSB Data/Input Data")
10
11 SiteData <- read.csv("DOE and NRC Site Locations.csv")
12 #NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data.csv", header=TRUE)
13 #NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data_No Rotary.csv", header=TRUE)
14 NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data_Rotary.csv", header=TRUE)
15
16 Crash_data <- data.frame(NTSBData$NTSB_ID,NTSBData$Lat,NTSBData$Long)
17
18 site_results <- data.frame(Site = character(),
19                           NPfxy3 = numeric(),
20                           Dist3rd = numeric(),
21                           Crash99th = numeric(),
22                           Dist99th = numeric(),
23                           stringsAsFactors = FALSE)
24
25 nsite <- nrow(SiteData)
26 site_NPfs <- array("",dim=c(10,(nsite+1)))
```

Figure C.1. Example code for selecting General Aviation input crash data sets

C.2.3 GA-fxy-calc_10-yr.R

The code reads the selected ten-year accident data set (All GA data set, or FW only data set, or RW only data set). The code then calculates the site specific crash density value for the sites using the methodology described in this report. The results of the crash density calculations are consolidated into data frames and written to two output files:

- A file containing a summary of the site-specific Non-Airport GA Accidents.
  - Site Name
  - Crash Density Value, [crashes/yr/mi^2]
  - Distance to the 3rd closest crash, [mi]
  - Crash associated with the 99th percentile of overall crash density value
  - Distance to 99th percentile crash
- A file containing a parametric sensitivity analysis of the site specific
  - Site Name
  - Crash Density Values evaluated with band-width valuations of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100-miles.

C.3 R Code for Preparing the NTSB GA Crash Data

The following R Code was used for organizing and consolidating the NTSB GA crash data:

GA-crashes_NTSB-2022-data.R

```
#--------------------Libraries Used--------------------
#Libraries Used

library(dplyr)
library(maps)
library(ggplot2)
library(ggmap)
library(ggthemes)
library(ggforce)
library(RColorBrewer)
myPalette <- brewer.pal(5,"Set1")

#--------------------Download NTSB GA Incident/Accident Data-----------------
---

setwd("W:/ANS 2.36 Folder/NTSB Data/2000_2019 GA Crash Data")
NTSBData1 <- read.csv("GA crashes ORNL_2000-2007.csv", header=TRUE)
NTSBData2 <- read.csv("GA crashes ORNL_2008-2019.csv", header=TRUE)

Count_NTSB1_all <- nrow(NTSBData1); Count_NTSB2_all <- nrow(NTSBData2)

#--------------------Remove Duplicate Records -------------------------------
--

a <- table(NTSBData1$Duplicate); b <- table(NTSBData2$Duplicate)

Count_NTSB1_Dup <- as.numeric(a[2]); Count_NTSB2_Dup <- as.numeric(b[2])

NTSBData1 <- NTSBData1  %>%
  filter(NTSBData1$Duplicate!='X')

NTSBData1 <- NTSBData1  %>%
  filter(NTSBData1$Duplicate!='X')

#--------------------Filter out GA Incident Data-----------------------------
---

a <- table(NTSBData1$EventType); b <- table(NTSBData2$EventType)

Count_NTSB1_Acc <- as.numeric(a[1]); Count_NTSB1_Inc <- as.numeric(a[2])

Count_NTSB2_Acc <- as.numeric(b[1]); Count_NTSB2_Inc <- as.numeric(b[2])

GA_Acc_00to07 <- filter(NTSBData1, NTSBData1$EventType=="ACC")
GA_Acc_08to19 <- filter(NTSBData2, NTSBData2$EventType=="ACC")

#--------------------Filter out Accident Damage Listed as "None" or "Minor"--
---
```

```
a <- table(GA_Acc_00to07$DamageLevel); b <- table(GA_Acc_08to19$DamageLevel)

Count_Acc_00to07_Des <- as.numeric(a[1])
Count_Acc_00to07_Min <- as.numeric(a[2])
Count_Acc_00to07_Non <- as.numeric(a[3])
Count_Acc_00to07_Sub <- as.numeric(a[4])

Count_Acc_08to19_Des <- as.numeric(b[2])
Count_Acc_08to19_Min <- as.numeric(b[3])
Count_Acc_08to19_Non <- as.numeric(b[4])
Count_Acc_08to19_Sub <- as.numeric(b[5])

GA_Acc_00to07 <- GA_Acc_00to07  %>%
  filter((GA_Acc_00to07$DamageLevel=="Destroyed")|
           (GA_Acc_00to07$DamageLevel=="Substantial"))

GA_Acc_08to19 <- GA_Acc_08to19  %>%
  filter((GA_Acc_08to19$DamageLevel=="Destroyed")|
           (GA_Acc_08to19$DamageLevel=="Substantial"))

#--------------------Create Data Frames for Non-Airport Accidents------------
---

a <- table(GA_Acc_00to07$Phase_of_Flight); b <-
table(GA_Acc_08to19$Phase_of_Flight)

Count_Acc_00to07_APR <- as.numeric(a[1])
Count_Acc_00to07_EMG <- as.numeric(a[2])
Count_Acc_00to07_ENR <- as.numeric(a[3])
Count_Acc_00to07_ICL <- as.numeric(a[4])
Count_Acc_00to07_LDG <- as.numeric(a[5])
Count_Acc_00to07_MNV <- as.numeric(a[6])
Count_Acc_00to07_PBT <- as.numeric(a[7])
Count_Acc_00to07_PIM <- 0 # No PIM Events in the 00to07 NTSB Data set
Count_Acc_00to07_STD <- as.numeric(a[8])
Count_Acc_00to07_TOF <- as.numeric(a[9])
Count_Acc_00to07_TXI <- as.numeric(a[10])
Count_Acc_00to07_UND <- as.numeric(a[11])
Count_Acc_00to07_UNK <- as.numeric(a[12])

Count_Acc_08to19_APR <- as.numeric(b[1])
Count_Acc_08to19_EMG <- as.numeric(b[2])
Count_Acc_08to19_ENR <- as.numeric(b[3])
Count_Acc_08to19_ICL <- as.numeric(b[4])
Count_Acc_08to19_LDG <- as.numeric(b[5])
Count_Acc_08to19_MNV <- as.numeric(b[6])
Count_Acc_08to19_PBT <- 0 # No PBT Events in the 08to19 NTSB Data set
Count_Acc_08to19_PIM <- as.numeric(b[7])
Count_Acc_08to19_STD <- as.numeric(b[8])
Count_Acc_08to19_TOF <- as.numeric(b[9])
Count_Acc_08to19_TXI <- as.numeric(b[10])
Count_Acc_08to19_UND <- as.numeric(b[11])
Count_Acc_08to19_UNK <- as.numeric(b[12])

Enroute_00to07 <- GA_Acc_00to07  %>%
  filter((GA_Acc_00to07$Phase_of_Flight=="ENR")|
           (GA_Acc_00to07$Phase_of_Flight=="MNV")|
```

```
           (GA_Acc_00to07$Phase_of_Flight=="EMG")|
           (GA_Acc_00to07$Phase_of_Flight=="UND"))

Enroute_08to19 <- GA_Acc_08to19  %>%
  filter((GA_Acc_08to19$Phase_of_Flight=="ENR")|
          (GA_Acc_08to19$Phase_of_Flight=="MNV")|
          (GA_Acc_08to19$Phase_of_Flight=="EMG")|
          (GA_Acc_08to19$Phase_of_Flight=="UND"))

#--------------------Remove Balloon, Glider, and Powered Parachute Accidents
---

a <- table(Enroute_00to07$Other); b <- table(Enroute_08to19$Other)

Count_Enr_00to07_BAL <- as.numeric(a[2])
Count_Enr_00to07_GLI <- as.numeric(a[3])
Count_Enr_00to07_PoP <- as.numeric(a[5])
Count_Enr_00to07_Pow <- as.numeric(a[1])+as.numeric(a[4])+as.numeric(a[6])

Count_Enr_08to19_BAL <- as.numeric(b[2])
Count_Enr_08to19_GLI <- as.numeric(b[3])
Count_Enr_08to19_PoP <- as.numeric(b[5])
Count_Enr_08to19_Pow <- as.numeric(b[1])+as.numeric(b[4])+as.numeric(b[6])

Enroute_00to07 <- Enroute_00to07  %>%
  filter(Enroute_00to07$Other!='Balloon'
         &Enroute_00to07$Other!='Glider'
         &Enroute_00to07$Other!='Powered Parachute')

Enroute_08to19 <- Enroute_08to19  %>%
  filter(Enroute_08to19$Other!='Balloon'
         &Enroute_08to19$Other!='Glider'
         &Enroute_08to19$Other!='Powered Parachute')

#--------------------Remove entries w/o Latitude-Longitude Data--------------
---

Enroute_00to07 <- Enroute_00to07  %>%
  filter((Enroute_00to07$Latitude!="NA"))

Enroute_08to19 <- Enroute_08to19  %>%
  filter((Enroute_08to19$Latitude!="NA"))

Count_Enroute_NoCoord_00to07 <- Count_Enr_00to07_Pow-nrow(Enroute_00to07)
Count_Enroute_NoCoord_08to19 <- Count_Enr_08to19_Pow-nrow(Enroute_08to19)

CONUS_00to07 <- filter(Enroute_00to07,StateOrRegion!='AK'
                       &StateOrRegion!='AO'
                       &StateOrRegion!='GM'
                       &StateOrRegion!='HI'
                       &StateOrRegion!='PO'
                       &StateOrRegion!='PI')

CONUS_08to19 <- filter(Enroute_08to19,StateOrRegion!='AK'
                       &StateOrRegion!='AO'
                       &StateOrRegion!='GM'
                       &StateOrRegion!='HI'
```

```
                        &StateOrRegion!='PO'
                        &StateOrRegion!='PI')

Count_CONUS_00to07 <- nrow(CONUS_00to07)
Count_nonCONUS_00to07 <- nrow(Enroute_00to07) - nrow(CONUS_00to07)

Count_CONUS_08to19 <- nrow(CONUS_00to07)
Count_nonCONUS_08to19 <- nrow(Enroute_08to19) - nrow(CONUS_08to19)

CONUS_10to19 <- CONUS_08to19  %>%
  filter(CONUS_08to19$EventYear >= 2010)

#--------------------Compile All GA Non-Airport Accidents--------------------
---

a_00to07 <- data.frame(CONUS_00to07$NTSBNumberFull,
                       CONUS_00to07$Latitude,
                       CONUS_00to07$Longitude)

a_08to19 <- data.frame(CONUS_08to19$NTSBNumberFull,
                       CONUS_08to19$Latitude,
                       CONUS_08to19$Longitude)

a_10to19 <- data.frame(CONUS_10to19$NTSBNumberFull,
                       CONUS_10to19$Latitude,
                       CONUS_10to19$Longitude)

#--------------------Compile Fixed-Wing Aircraft Data------------------------
---

CONUS_00to07_norotary <- CONUS_00to07  %>%
  filter(CONUS_00to07$Rotary.Wing!='Y')

CONUS_08to19_norotary <- CONUS_08to19  %>%
  filter(CONUS_08to19$Rotary.Wing!='Y')

CONUS_10to19_norotary <- CONUS_10to19  %>%
  filter(CONUS_10to19$Rotary.Wing!='Y')

Count_FW_CONUS_00to07 <- nrow(CONUS_00to07_norotary)
Count_RW_CONUS_00to07 <- nrow(CONUS_00to07)-nrow(CONUS_00to07_norotary)

Count_FW_CONUS_08to19 <- nrow(CONUS_08to19_norotary)
Count_RW_CONUS_08to19 <- nrow(CONUS_08to19)-nrow(CONUS_08to19_norotary)

a_00to07_norotary <- data.frame(CONUS_00to07_norotary$NTSBNumberFull,
                       CONUS_00to07_norotary$Latitude,
                       CONUS_00to07_norotary$Longitude)

a_08to19_norotary <- data.frame(CONUS_08to19_norotary$NTSBNumberFull,
                                CONUS_08to19_norotary$Latitude,
                                CONUS_08to19_norotary$Longitude)

a_10to19_norotary <- data.frame(CONUS_10to19_norotary$NTSBNumberFull,
                                CONUS_10to19_norotary$Latitude,
                                CONUS_10to19_norotary$Longitude)
```

```
#--------------------Compile Rotary-Wing Aircraft Data-----------------------
---

CONUS_00to07_rotary <- CONUS_00to07  %>%
  filter(CONUS_00to07$Rotary.Wing=='Y')

CONUS_08to19_rotary <- CONUS_08to19  %>%
  filter(CONUS_08to19$Rotary.Wing=='Y')

CONUS_10to19_rotary <- CONUS_10to19  %>%
  filter(CONUS_10to19$Rotary.Wing=='Y')

a_00to07_rotary <- data.frame(CONUS_00to07_rotary$NTSBNumberFull,
                                CONUS_00to07_rotary$Latitude,
                                CONUS_00to07_rotary$Longitude)

a_08to19_rotary <- data.frame(CONUS_08to19_rotary$NTSBNumberFull,
                                CONUS_08to19_rotary$Latitude,
                                CONUS_08to19_rotary$Longitude)

a_10to19_rotary <- data.frame(CONUS_10to19_rotary$NTSBNumberFull,
                                CONUS_10to19_rotary$Latitude,
                                CONUS_10to19_rotary$Longitude)

#--------------------Consolidate non-Airport Acc. Data Into A Single Data
Frame-

df_colnames <- c("NTSB_ID","Lat","Long")

colnames(a_00to07) <- df_colnames
colnames(a_08to19) <- df_colnames
colnames(a_10to19) <- df_colnames

colnames(a_00to07_norotary) <- df_colnames
colnames(a_08to19_norotary) <- df_colnames
colnames(a_10to19_norotary) <- df_colnames

colnames(a_00to07_rotary) <- df_colnames
colnames(a_08to19_rotary) <- df_colnames
colnames(a_10to19_rotary) <- df_colnames

#CONUS data - both Fixed Wing and Rotary Wing

CONUS_all <- data.frame(ID = numeric(),
                          Lat = numeric(),
                          Long = numeric(),
                          stringsAsFactors = FALSE)

CONUS_all_10yr <- data.frame(ID = numeric(),
                             Lat = numeric(),
                             Long = numeric(),
                             stringsAsFactors = FALSE)

n_00to07 <- nrow(CONUS_00to07)
n_08to19 <- nrow(CONUS_08to19)
n_10to19 <- nrow(CONUS_10to19)
```

```
for (i in 1:n_00to07){CONUS_all <- rbind(CONUS_all,a_00to07[i,])}
for (i in 1:n_08to19){CONUS_all <- rbind(CONUS_all,a_08to19[i,])}
for (i in 1:n_10to19){CONUS_all_10yr <- rbind(CONUS_all_10yr,a_10to19[i,])}

#CONUS data - Fixed Wing only

CONUS_all_norotary <- data.frame(ID = numeric(),
                          Lat = numeric(),
                          Long = numeric(),
                          stringsAsFactors = FALSE)

CONUS_all_norotary_10yr <- data.frame(ID = numeric(),
                             Lat = numeric(),
                             Long = numeric(),
                             stringsAsFactors = FALSE)

n_00to07_norotary <- nrow(CONUS_00to07_norotary)
n_08to19_norotary <- nrow(CONUS_08to19_norotary)
n_10to19_norotary <- nrow(CONUS_10to19_norotary)

for (i in 1:n_00to07_norotary){
  CONUS_all_norotary <- rbind(CONUS_all_norotary,a_00to07_norotary[i,])
  }

for (i in 1:n_08to19_norotary){
  CONUS_all_norotary <- rbind(CONUS_all_norotary,a_08to19_norotary[i,])
}

for (i in 1:n_10to19_norotary){
  CONUS_all_norotary_10yr <-
rbind(CONUS_all_norotary_10yr,a_10to19_norotary[i,])
}

#CONUS data - Rotary Wing only
CONUS_all_rotary <- data.frame(ID = numeric(),
                                 Lat = numeric(),
                                 Long = numeric(),
                                 stringsAsFactors = FALSE)

CONUS_all_rotary_10yr <- data.frame(ID = numeric(),
                                      Lat = numeric(),
                                      Long = numeric(),
                                      stringsAsFactors = FALSE)

n_00to07_rotary <- nrow(CONUS_00to07_rotary)
n_08to19_rotary <- nrow(CONUS_08to19_rotary)
n_10to19_rotary <- nrow(CONUS_10to19_rotary)

for (i in 1:n_00to07_rotary){
  CONUS_all_rotary <- rbind(CONUS_all_rotary,a_00to07_rotary[i,])
}

for (i in 1:n_08to19_rotary){
  CONUS_all_rotary <- rbind(CONUS_all_rotary,a_08to19_rotary[i,])
}

for (i in 1:n_10to19_rotary){
```

```
  CONUS_all_rotary_10yr <- rbind(CONUS_all_rotary_10yr,a_10to19_rotary[i,])
}

#--------------------Generate Results in a .csv file-------------------------
---

write.csv(CONUS_all,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2000_2019 GA NonAirport
Crash Data.csv",
          row.names=FALSE)

write.csv(CONUS_all_norotary,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2000_2019 GA NonAirport
Crash Data_No Rotary.csv",
          row.names=FALSE)

write.csv(CONUS_all_rotary,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2000_2019 GA NonAirport
Crash Data_Rotary.csv",
          row.names=FALSE)

write.csv(CONUS_all_10yr,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2010_2019 GA NonAirport
Crash Data.csv",
          row.names=FALSE)

write.csv(CONUS_all_norotary_10yr,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2010_2019 GA NonAirport
Crash Data_No Rotary.csv",
          row.names=FALSE)

write.csv(CONUS_all_rotary_10yr,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2010_2019 GA NonAirport
Crash Data_Rotary.csv",
          row.names=FALSE)

#--------------------Generate Data Filter Report ----------------------------
---

Label_00to07 <- c("NTSB GA Events 00-07","Duplicate GA Events 00-07",
                  "NTSB GA Acc 00-07","NTSB GA Incidents 00-07",
                  "Damage: None 00-07","Damage: Minor 00-07",
                  "Damage: Substantial 00-07","Damage: Destroyed 00-07",
                  "PoF: Approach 00-07","PoF: Emergency Descent 00-07",
                  "PoF: Enroute 00-07","PoF: Initial Climb 00-07",
                  "PoF: Landing 00-07","PoF: Maneuvering 00-07",
                  "PoF: Push Back/Towing 00-07","PoF: Post Impact 08-19",
                  "PoF: Standing 00-07","PoF: Takeoff 00-07","PoF: Taxi 00-
07",
                  "PoF: Uncontrolled Descent 00-07","PoF: Unknown 00-07",
                  "NonAirport: Balloon 00-07","NonAirport: Glider 00-07",
                  "NonAirport: Powered Parachute 00-07",
                  "NonAirport: Powered Aircraft 00-07",
                  "No Lat/Long Data 00-07","CONUS 00-07",
                  "Non CONUS 00-07","Fixed-Wing CONUS 00-07",
                  "Rotary-Wing CONUS 00-07")
Amount_00to07 <- c(Count_NTSB1_all,Count_NTSB1_Dup,Count_NTSB1_Acc,
```

```
                    Count_NTSB1_Inc,Count_Acc_00to07_Non,Count_Acc_00to07_Min,
                    Count_Acc_00to07_Sub,Count_Acc_00to07_Des,
                    Count_Acc_00to07_APR,Count_Acc_00to07_EMG,
                    Count_Acc_00to07_ENR,Count_Acc_00to07_ICL,
                    Count_Acc_00to07_LDG,Count_Acc_00to07_MNV,
                    Count_Acc_00to07_PBT,Count_Acc_00to07_PIM,
                    Count_Acc_00to07_STD,Count_Acc_00to07_TOF,
                    Count_Acc_00to07_TXI,Count_Acc_00to07_UND,
                    Count_Acc_00to07_UNK,Count_Enr_00to07_BAL,
                    Count_Enr_00to07_GLI,Count_Enr_00to07_PoP,
                    Count_Enr_00to07_Pow,Count_Enroute_NoCoord_00to07,
                    Count_CONUS_00to07,Count_nonCONUS_00to07,
                    Count_FW_CONUS_00to07,Count_RW_CONUS_00to07)
df3_00to07 <- data.frame(Label_00to07,Amount_00to07)

Label_08to19 <- c("NTSB GA Events 08-19","Duplicate GA Events 08-19",
                   "NTSB GA Acc 08-19","NTSB GA Incidents 08-19",
                   "Damage: None 08-19","Damage: Minor 08-19",
                   "Damage: Substantial 08-19","Damage: Destroyed 08-19",
                   "PoF: Approach 08-19","PoF: Emergency Descent 08-19",
                   "PoF: Enroute 08-19","PoF: Initial Climb 08-19",
                   "PoF: Landing 08-19","PoF: Maneuvering 08-19",
                   "PoF: Push Back/Towing 08-19","PoF: Post Impact 08-19",
                   "PoF: Standing 08-19","PoF: Takeoff 08-19","PoF: Taxi 08-
19",
                   "PoF: Uncontrolled Descent 08-19","PoF: Unknown 08-19",
                   "NonAirport: Balloon 08-19","NonAirport: Glider 08-19",
                   "NonAirport: Powered Parachute 08-19",
                   "NonAirport: Powered Aircraft 08-19",
                   "No Lat/Long Data 08-19","CONUS 08-19",
                   "Non CONUS 08-19","Fixed-Wing CONUS 08-19",
                   "Rotary-Wing CONUS 08-19")
Amount_08to19 <- c(Count_NTSB2_all,Count_NTSB2_Dup,Count_NTSB2_Acc,
                    Count_NTSB2_Inc,Count_Acc_08to19_Non,Count_Acc_08to19_Min,
                    Count_Acc_08to19_Sub,Count_Acc_08to19_Des,
                    Count_Acc_08to19_APR,Count_Acc_08to19_EMG,
                    Count_Acc_08to19_ENR,Count_Acc_08to19_ICL,
                    Count_Acc_08to19_LDG,Count_Acc_08to19_MNV,
                    Count_Acc_08to19_PBT,Count_Acc_08to19_PIM,
                    Count_Acc_08to19_STD,Count_Acc_08to19_TOF,
                    Count_Acc_08to19_TXI,Count_Acc_08to19_UND,
                    Count_Acc_08to19_UNK,Count_Enr_08to19_BAL,
                    Count_Enr_08to19_GLI,Count_Enr_08to19_PoP,
                    Count_Enr_08to19_Pow,Count_Enroute_NoCoord_08to19,
                    Count_CONUS_08to19,Count_nonCONUS_08to19,
                    Count_FW_CONUS_08to19,Count_RW_CONUS_08to19)
df3_08to19 <- data.frame(Label_08to19,Amount_08to19)

Label_All <- c("NTSB GA Events","Duplicate GA Events",
                   "NTSB GA Acc","NTSB GA Incidents",
                   "Damage: None","Damage: Minor",
                   "Damage: Substantial","Damage: Destroyed",
                   "PoF: Approach","PoF: Emergency Descent",
                   "PoF: Enroute","PoF: Initial Climb",
                   "PoF: Landing","PoF: Maneuvering",
                   "PoF: Push Back/Towing","PoF: Post Impact",
                   "PoF: Standing","PoF: Takeoff","PoF: Taxi",
```

```
                   "PoF: Uncontrolled Descent","PoF: Unknown",
                   "NonAirport: Balloon","Enroute: Glider",
                   "NonAirport: Powered Parachute",
                   "NonAirport: Powered Aircraft",
                   "No Lat/Long Data","CONUS",
                   "Non CONUS","Fixed-Wing CONUS",
                   "Rotary-Wing CONUS")

Report_colnames <- c("Parameter","2000-2007","2008-2019")

FilterReport <- data.frame(Label_All,df3_00to07[,2],df3_08to19[,2])
colnames(FilterReport) <- Report_colnames

write.csv(FilterReport,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/NTSB Data Filter
Report.csv",
          row.names=FALSE)

#------------------------Accident Count By Phase of Flight------------------
---

PoF_Accident_STD_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="STD")
PoF_Accident_STD_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="STD")

PoF_Accident_PBT_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="PBT")

PoF_Accident_PIM_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="PIM")

PoF_Accident_TXI_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="TXI")
PoF_Accident_TXI_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="TXI")

PoF_Accident_TOF_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="TOF")
PoF_Accident_TOF_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="TOF")

PoF_Accident_ICL_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="ICL")
PoF_Accident_ICL_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="ICL")

PoF_Accident_ENR_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="ENR")
PoF_Accident_ENR_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="ENR")

PoF_Accident_MAN_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="MNV")
PoF_Accident_MAN_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="MNV")
```

```
PoF_Accident_APR_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="APR")
PoF_Accident_APR_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="APR")

PoF_Accident_LDG_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="LDG")
PoF_Accident_LDG_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="LDG")

PoF_Accident_EMG_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="EMG")
PoF_Accident_EMG_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="EMG")

PoF_Accident_UND_00to07 <- GA_Acc_00to07  %>%
  filter(GA_Acc_00to07$Phase_of_Flight=="UND")
PoF_Accident_UND_08to19 <- GA_Acc_08to19  %>%
  filter(GA_Acc_08to19$Phase_of_Flight=="UND")

a_STD_00to07 <- table(PoF_Accident_STD_00to07$Phase_Meaning)
a_PBT_00to07 <- table(PoF_Accident_PBT_00to07$Phase_Meaning)
a_TXI_00to07 <- table(PoF_Accident_TXI_00to07$Phase_Meaning)
a_TOF_00to07 <- table(PoF_Accident_TOF_00to07$Phase_Meaning)
a_ICL_00to07 <- table(PoF_Accident_ICL_00to07$Phase_Meaning)
a_ENR_00to07 <- table(PoF_Accident_ENR_00to07$Phase_Meaning)
a_MAN_00to07 <- table(PoF_Accident_MAN_00to07$Phase_Meaning)
a_APR_00to07 <- table(PoF_Accident_APR_00to07$Phase_Meaning)
a_LDG_00to07 <- table(PoF_Accident_LDG_00to07$Phase_Meaning)
a_EMG_00to07 <- table(PoF_Accident_EMG_00to07$Phase_Meaning)
a_UND_00to07 <- table(PoF_Accident_UND_00to07$Phase_Meaning)

a_STD_08to19 <- table(PoF_Accident_STD_08to19$PhaseName)
a_PIM_08to19 <- table(PoF_Accident_PIM_08to19$PhaseName)
a_TXI_08to19 <- table(PoF_Accident_TXI_08to19$PhaseName)
a_TOF_08to19 <- table(PoF_Accident_TOF_08to19$PhaseName)
a_ICL_08to19 <- table(PoF_Accident_ICL_08to19$PhaseName)
a_ENR_08to19 <- table(PoF_Accident_ENR_08to19$PhaseName)
a_MAN_08to19 <- table(PoF_Accident_MAN_08to19$PhaseName)
a_APR_08to19 <- table(PoF_Accident_APR_08to19$PhaseName)
a_LDG_08to19 <- table(PoF_Accident_LDG_08to19$PhaseName)
a_EMG_08to19 <- table(PoF_Accident_EMG_08to19$PhaseName)
a_UND_08to19 <- table(PoF_Accident_UND_08to19$PhaseName)

PoF_Report_00to07 <- data.frame(V1 = numeric(),
                        stringsAsFactors = FALSE)
PoF_Report_08to19 <- data.frame(V1 = numeric(),
                                stringsAsFactors = FALSE)

aa <- as.matrix(a_STD_00to07); bb <- as.matrix(a_STD_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_PBT_00to07); PoF_Report_00to07 <-
rbind(PoF_Report_00to07,aa)

aa <- as.matrix(a_TXI_00to07); bb <- as.matrix(a_TXI_08to19)
```

```
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_TOF_00to07); bb <- as.matrix(a_TOF_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_ICL_00to07); bb <- as.matrix(a_ICL_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_ENR_00to07); bb <- as.matrix(a_ENR_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_MAN_00to07); bb <- as.matrix(a_MAN_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_APR_00to07)
bb <- as.matrix(a_APR_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_LDG_00to07); bb <- as.matrix(a_LDG_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_EMG_00to07); bb <- as.matrix(a_EMG_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

aa <- as.matrix(a_UND_00to07); bb <- as.matrix(a_UND_08to19)
PoF_Report_00to07 <- rbind(PoF_Report_00to07,aa)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

bb <- as.matrix(a_PIM_08to19)
PoF_Report_08to19 <- rbind(PoF_Report_08to19,bb)

write.csv(PoF_Report_00to07,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2000_2007 GA PoF Accident
Data.csv",
          row.names=TRUE)

write.csv(PoF_Report_08to19,
          "W:/ANS 2.36 Folder/NTSB Data/Input Data/2008_2019 GA PoF Accident
Data.csv",
          row.names=TRUE)

#--------------------Data Analysis of PoF Accident Data ---------------------
---

GA_pof <- c("STD","PBT","TXI","TOF","ICL","ENR","MNV",
            "APR","LDG","EMG","UND","PIM","UNK")

pof_color <- c("white","white","white","lightgoldenrodyellow",
               "lightgoldenrodyellow","blue","blue","linen","linen",
```

```
                "blue","blue","white","white")

n <- length(GA_pof)
ACC_00to07 <- c(); ACC_08to19 <- c()

for (i in 1:n){

  ACC_00to07[i] <- length(which(GA_Acc_00to07$Phase_of_Flight==GA_pof[i]))
  ACC_08to19[i] <- length(which(GA_Acc_08to19$Phase_of_Flight==GA_pof[i]))

}

df1 <- data.frame(GA_pof,ACC_00to07,ACC_08to19)

ggplot(df1, aes(x=GA_pof, y=ACC_00to07)) +
  geom_bar(stat = "identity", fill = pof_color, color = "slategray")

EnrouteSummary <- df1  %>%
  filter((df1$GA_pof == "ENR")|(df1$GA_pof == "MNV")|(df1$GA_pof == "EMG")
         |(df1$GA_pof == "UND"))

EnrouteTotal <- sum(EnrouteSummary$ACC_00to07)+
  sum(EnrouteSummary$ACC_08to19)

TakeoffSummary <- df1  %>%
  filter((df1$GA_pof == "TOF")|(df1$GA_pof == "ICL"))

TakeoffTotal <- sum(TakeoffSummary$ACC_00to07)+
  sum(TakeoffSummary$ACC_08to19)

LandingSummary <- df1  %>%
  filter((df1$GA_pof == "APR")|(df1$GA_pof == "LDG"))

LandingTotal <- sum(LandingSummary$ACC_00to07)+
  sum(LandingSummary$ACC_08to19)

GroundSummary <- df1  %>%
  filter((df1$GA_pof == "STD")|(df1$GA_pof == "PBT")|(df1$GA_pof == "TXI"))

GroundTotal <- sum(GroundSummary$ACC_00to07)+
  sum(GroundSummary$ACC_08to19)

OtherSummary <- df1  %>%
  filter((df1$GA_pof == "PIM")|(df1$GA_pof == "UNK"))

OtherTotal <- sum(OtherSummary$ACC_00to07)+
  sum(OtherSummary$ACC_08to19)

AllTotal <- TakeoffTotal+EnrouteTotal+LandingTotal+GroundTotal+OtherTotal

TakeoffPct <- TakeoffTotal/AllTotal
EnroutePct <- EnrouteTotal/AllTotal
LandingPct <- LandingTotal/AllTotal
GroundPct <- GroundTotal/AllTotal
OtherPct <- OtherTotal/AllTotal

PhaseLabel <- c("Takeoff","Enroute","Landing","Ground Ops","Other/Unknown")
```

```
PhaseTotal <- c(as.numeric(TakeoffTotal),
                as.numeric(EnrouteTotal),
                as.numeric(LandingTotal),
                as.numeric(GroundTotal),
                as.numeric(OtherTotal))

df2 <- data.frame(PhaseLabel,PhaseTotal)

pie(df2$PhaseTotal,labels = df2$PhaseLabel,col=myPalette,
    main="GA Accidents by Phase of Flight/Operation [2000-2019]")

State_00to07 <- table(Enroute_00to07$StateOrRegion)
```

C.4 R Code for Calculating the Twenty-Year Site-Specific GA Non-Airport Crash Density

The following R Code was used for calculating the twenty-year GA non-airport crash density:

GA-fxy-calc_20-yr.R

```
#--------------------Libraries Used--------------------

library(dplyr)
library(maps)
library(ggmap)
library(ggthemes)
library(ggforce)

setwd("W:/ANS 2.36 Folder/NTSB Data/Input Data")

SiteData <- read.csv("DOE and NRC Site Locations.csv")
#NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data.csv", header=TRUE)
#NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data_No Rotary.csv",
header=TRUE)
NTSBData <- read.csv("2000_2019 GA NonAirport Crash Data_Rotary.csv",
header=TRUE)

Crash_data <- data.frame(NTSBData$NTSB_ID,NTSBData$Lat,NTSBData$Long)

site_results <- data.frame(Site = character(),
                          NPfxy3 = numeric(),
                          Dist3rd = numeric(),
                          Crash99th = numeric(),
                          Dist99th = numeric(),
                          stringsAsFactors = FALSE)

nsite <- nrow(SiteData)
site_NPfs <- array("",dim=c(10,(nsite+1)))

for (a in 1:10){site_NPfs[a,1]<- a*10}

n <- nrow(Crash_data)

#--------Constants-------------------------------------------------------

R_equator <- 6378.14 #kilometers along the equatorial plane
f <- 0.003353 #Flatness of the earth
km_mi <- 0.62137119

#--------Function that Calculates Distance from Site to Crash----------------

distance <- function(lat1,long1,lat2,long2){

  F <- ((lat1+lat2)/2)*(pi/180)
  G <- ((lat1-lat2)/2)*(pi/180)
  lamda <- ((long1-long2)/2)*(pi/180)
  S <- sin(G)^2*cos(lamda)^2+cos(F)^2*sin(lamda)^2
  C <- cos(G)^2*cos(lamda)^2+sin(F)^2*sin(lamda)^2
  tan_w <- (S/C)^0.5
```

```
  w <- atan(tan_w)
  R <- ((S*C)^0.5)/w
  D <- 2*w*R_equator
  H1 <- (3*R - 1)/(2*C)
  H2 <- (3*R + 1)/(2*C)
  s <- D*(1+f*H1*sin(F)^2*cos(G)^2-f*H2*cos(F)^2*sin(G)^2)
  s <- s*km_mi              #Converts from km to miles

  return(s)
}

d <- c()
#--------Site Location----------------------------------------------------

for (SiteID in 1:nsite){

  name <- SiteData$Site[SiteID]
  lat_1 <- SiteData$Lat[SiteID]
  long_1 <- SiteData$Long[SiteID]

  #-------Calculate distance to each crash location--------------------------

  z <- 1
  dd <- c()
  d50lat <- c()
  d50long <- c()
  Acc_ID <- c()

  for (i in 1:n){

    lat_2 <- Crash_data$NTSBData.Lat[i]
    long_2 <- Crash_data$NTSBData.Long[i]
    d[i] <- distance(lat_1, long_1, lat_2, long_2)
    if(d[i]<=50){
      d50lat[z] <- lat_2
      d50long[z] <- long_2
      Acc_ID[z] <- Crash_data$NTSBData.NTSB_ID[i]
      dd[z] <- d[i]
      z <- z+1
    }
  }

  if(z>1){d50 <- data.frame(Acc_ID,d50lat,d50long,dd)}

  d <- sort(d,decreasing=FALSE)
  fs <- c()
  P <- c()
  NPfs3 <- c()


  #-------Calculate Distance to 3rd Closest Crash for Site-------------------

  for (j in 1:100){

    fs[j] <- 0
    hs <- j
```

```
    for (i in 1:n){fs[j] <- fs[j] + exp((-d[i]^2)/(2*hs^2))}

    fs[j] <- fs[j]/(2*pi*n*hs^2)

  }

  for (x in 1:10){site_NPfs[x,SiteID+1] <- n*fs[x*10]/20}

  #-------Calculate NPfs3 for site------------------------------------------

  fs3 <- 0

  for (i in 1:n){

    P[i] <- exp((-d[i]^2)/(2*d[3]^2))
    fs3 <- fs3 + P[i]
    NPfs3[i] <- (fs3/(2*pi*d[3]^2))/20
  }

  #-------Determine Number of Crashes at the 99.9 percentile-----------------

  latch <- 0

  for (i in 1:n){if(NPfs3[i]/max(NPfs3) > 0.999 && latch == 0){
    index = i
    latch <- 1
    }}

   #-------f(s) Sensitivity Analysis-----------------------------------------

  band_width <- c(1:100)
  plot_data <- data.frame(band_width,fs)
  radial_data <- data.frame(c(1:n),d)
  fs3_data <- data.frame(c(1:n),NPfs3)

  site_results <- rbind(site_results,c(name,max(NPfs3),d[3],index,d[index]))

}
colnames(site_results) <- c("Site","NPfxy3","Dist3rd","Crash99th","Dist99th")

#--------Generate Output Files---------------------------------------------

write.csv(site_results, "W:/ANS 2.36 Folder/NTSB Data/NPfxy Site 
Results_10yr.csv",
          row.names=FALSE)

site_NPfs <- data.frame(site_NPfs)
colnames(site_NPfs) <- c("Bandwidth",SiteData$Site)
write.csv(site_NPfs,
          "W:/ANS 2.36 Folder/NTSB Data/GA Site NPfs Sensitivity 
Results_10yr.csv",
          row.names=FALSE)
```

C.5 R Code for Calculating the Ten-Year Site-Specific GA Non-Airport Crash Density

The following R Code was used for calculating the ten-year GA non-airport crash density:

GA-fxy-calc_10-yr.R

```
#--------------------Libraries Used--------------------

library(dplyr)
library(maps)
library(ggmap)
library(ggthemes)
library(ggforce)
library(ggplot2)

setwd("W:/ANS 2.36 Folder/NTSB Data/Input Data")

SiteData <- read.csv("DOE and NRC Site Locations.csv")
#NTSBData <- read.csv("2010_2019 GA NonAirport Crash Data.csv", header=TRUE)
#NTSBData <- read.csv("2010_2019 GA NonAirport Crash Data_No Rotary.csv",
header=TRUE)
NTSBData <- read.csv("2010_2019 GA NonAirport Crash Data_Rotary.csv",
header=TRUE)

Crash_data <- data.frame(NTSBData$NTSB_ID,NTSBData$Lat,NTSBData$Long)

site_results <- data.frame(Site = character(),
                          NPfxy3 = numeric(),
                          Dist3rd = numeric(),
                          Crash99th = numeric(),
                          Dist99th = numeric(),
                          stringsAsFactors = FALSE)

nsite <- nrow(SiteData)
site_NPfs <- array("",dim=c(10,(nsite+1)))

for (a in 1:10){site_NPfs[a,1]<- a*10}

n <- nrow(Crash_data)

nU <- 100 # No. of crashes evaluated in the uniform crash density calc.
Ucrash <- data.frame(matrix(ncol=3*nsite,nrow=nU))

#--------Constants-----------------------------------------------------------

R_equator <- 6378.14 #kilometers along the equatorial plane
f <- 0.003353 #Flatness of the earth
km_mi <- 0.62137119

#--------Function that Calculates Distance from Site to Crash----------------

distance <- function(lat1,long1,lat2,long2){

  F <- ((lat1+lat2)/2)*(pi/180)
  G <- ((lat1-lat2)/2)*(pi/180)
```

```
  lamda <- ((long1-long2)/2)*(pi/180)
  S <- sin(G)^2*cos(lamda)^2+cos(F)^2*sin(lamda)^2
  C <- cos(G)^2*cos(lamda)^2+sin(F)^2*sin(lamda)^2
  tan_w <- (S/C)^0.5
  w <- atan(tan_w)
  R <- ((S*C)^0.5)/w
  D <- 2*w*R_equator
  H1 <- (3*R - 1)/(2*C)
  H2 <- (3*R + 1)/(2*C)
  s <- D*(1+f*H1*sin(F)^2*cos(G)^2-f*H2*cos(F)^2*sin(G)^2)
  s <- s*km_mi              #Converts from km to miles

  return(s)
}

d <- c()
Report_ID <- c()

#--------Site Location-------------------------------------------------------

for (SiteID in 1:nsite){

  name <- SiteData$Site[SiteID]
  lat_1 <- SiteData$Lat[SiteID]
  long_1 <- SiteData$Long[SiteID]

  #-------Calculate distance to each crash location--------------------------

  z <- 1
  dd <- c()
  d50lat <- c()
  d50long <- c()
  Acc_ID <- c()

  for (i in 1:n){

    lat_2 <- Crash_data$NTSBData.Lat[i]
    long_2 <- Crash_data$NTSBData.Long[i]
    Report_ID[i] <- Crash_data$NTSBData.NTSB_ID[i]

    d[i] <- distance(lat_1, long_1, lat_2, long_2)

    if(d[i]<=50){
      d50lat[z] <- lat_2
      d50long[z] <- long_2
      Acc_ID[z] <- Crash_data$NTSBData.NTSB_ID[i]
      dd[z] <- d[i]
      z <- z+1
    }
  }

  if(z>1){d50 <- data.frame(Acc_ID,d50lat,d50long,dd)}

  d_all <- data.frame(Report_ID,d)
  d_all <- d_all[order(d_all$d),]

  d <- sort(d,decreasing=FALSE)
```

```
  fs <- c()
  P <- c()
  NPfs3 <- c()


  #-------Calculate Distance to 3rd Closest Crash for Site-------------------

  for (j in 1:100){

    fs[j] <- 0
    hs <- j

    for (i in 1:n){fs[j] <- fs[j] + exp((-d[i]^2)/(2*hs^2))}

    fs[j] <- fs[j]/(2*pi*n*hs^2)

  }

  for (x in 1:10){site_NPfs[x,SiteID+1] <- n*fs[x*10]/10}

  #-------Calculate NPfs3 for site-------------------------------------------

  fs3 <- 0

  for (i in 1:n){

    P[i] <- exp((-d[i]^2)/(2*d[3]^2))
    fs3 <- fs3 + P[i]
    NPfs3[i] <- (fs3/(2*pi*d[3]^2))/10

  }

  #-------Determine Number of Crashes at the 99.9 percentile-----------------

  latch <- 0

  for (i in 1:n){if(NPfs3[i]/max(NPfs3) > 0.999 && latch == 0){
    index = i
    latch <- 1
    }}

  #-------f(s) Sensitivity Analysis------------------------------------------

  band_width <- c(1:100)
  plot_data <- data.frame(band_width,fs)
  radial_data <- data.frame(c(1:n),d)
  fs3_data <- data.frame(c(1:n),NPfs3)

  site_results <- rbind(site_results,c(name,max(NPfs3),d[3],index,d[index]))

}
colnames(site_results) <- c("Site","NPfxy3","Dist3rd","Crash99th","Dist99th")

#--------Generate Output Files---------------------------------------------

write.csv(site_results, "W:/ANS 2.36 Folder/NTSB Data/NPfxy Site
Results_10yr.csv",
```

```
          row.names=FALSE)

site_NPfs <- data.frame(site_NPfs)
colnames(site_NPfs) <- c("Bandwidth",SiteData$Site)
write.csv(site_NPfs,
          "W:/ANS 2.36 Folder/NTSB Data/GA Site NPfs Sensitivity
Results_10yr.csv",
          row.names=FALSE)
```

APPENDIX D. FLOWCHART OF PREPARATION OF NTSB GA ACCIDENT / INCIDENT DATA AND SUBSEQUENT CRASH DENSITY ANALYSIS

APPENDIX D. FLOWCHART OF PREPARATION OF NTSB GA ACCIDENT / INCIDENT DATA AND SUBSEQUENT CRASH DENSITY ANALYSIS

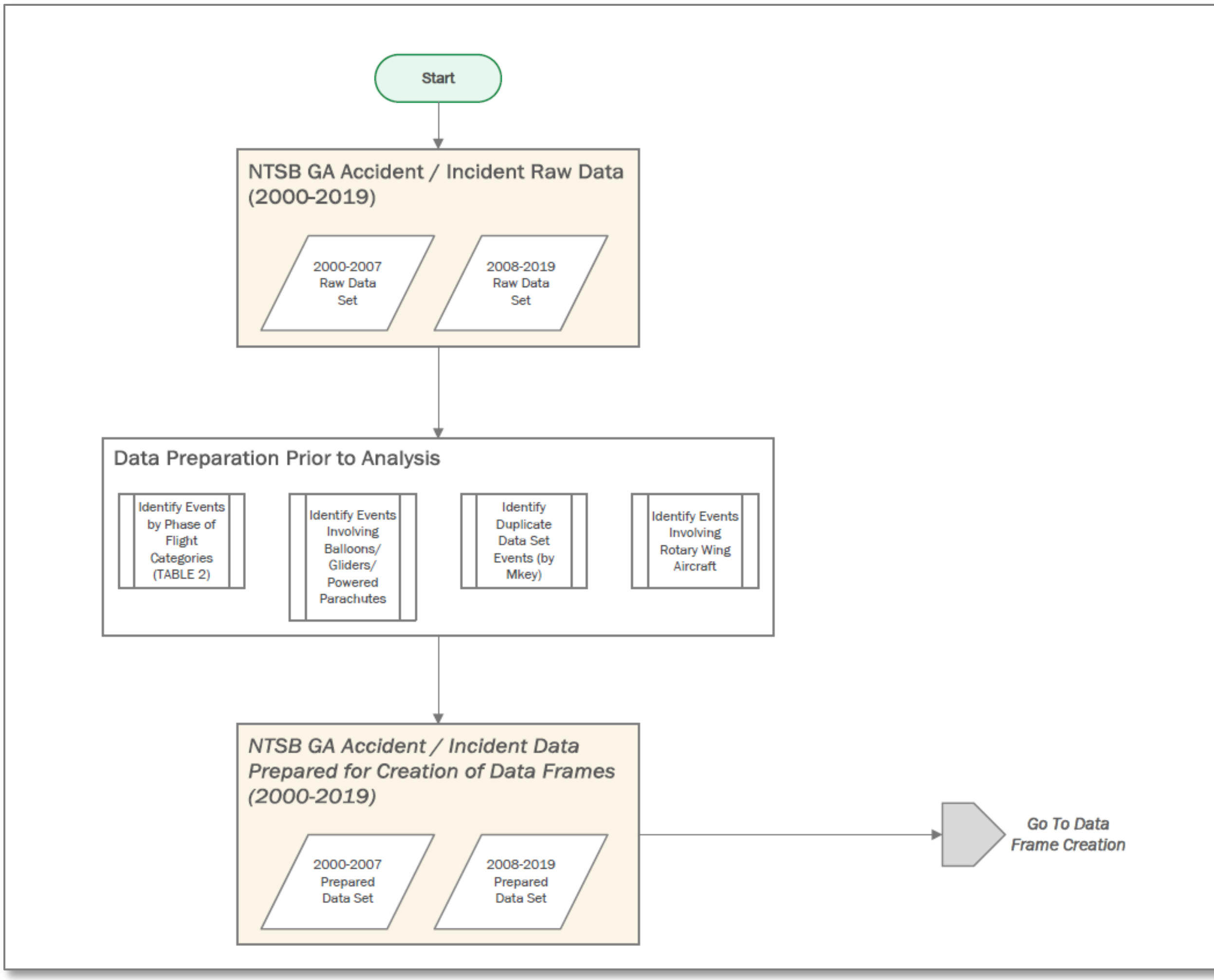

Figure D.1. Preparing the raw GA accident / incident data

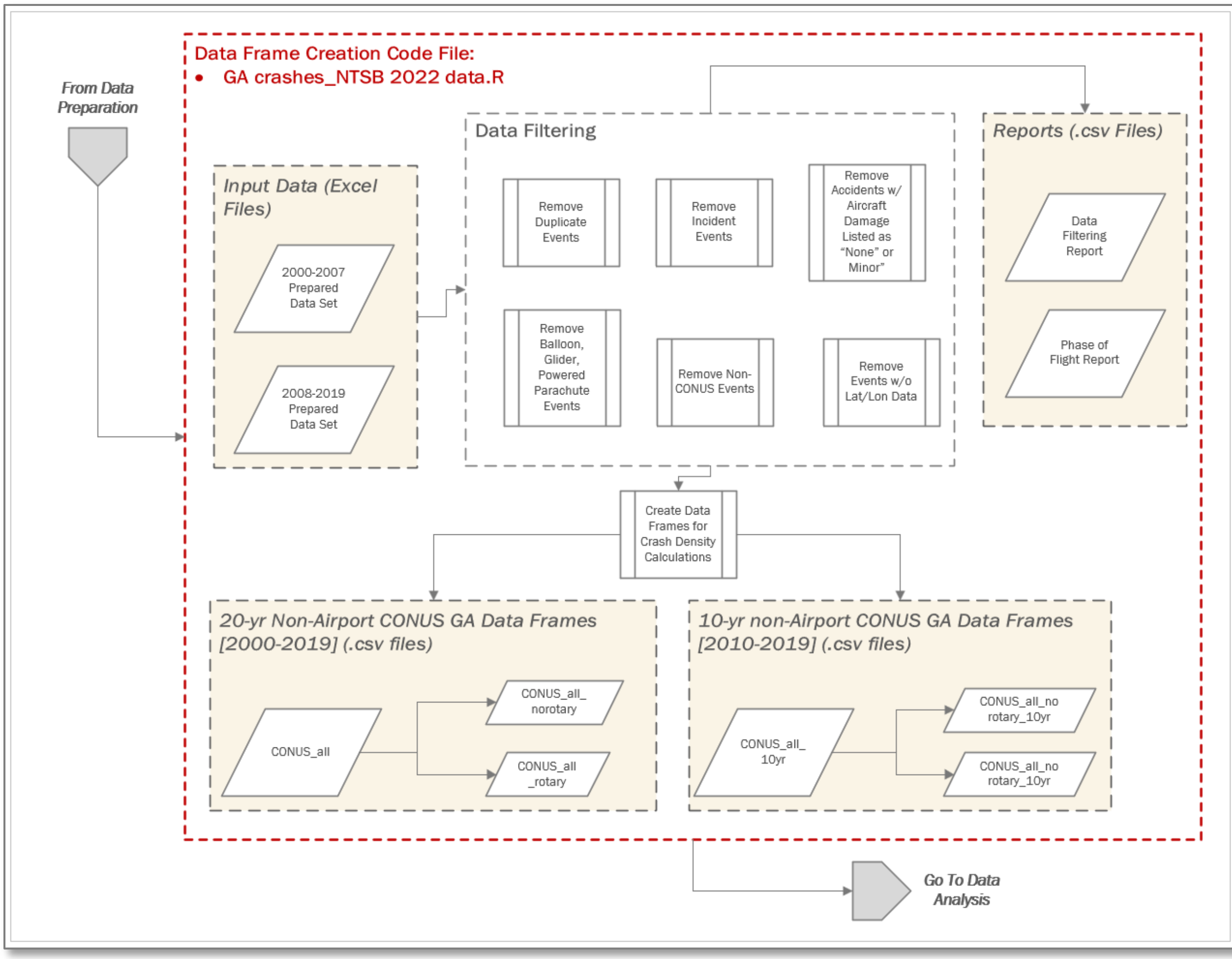

Figure D.2. Creating data frames for data analysis use

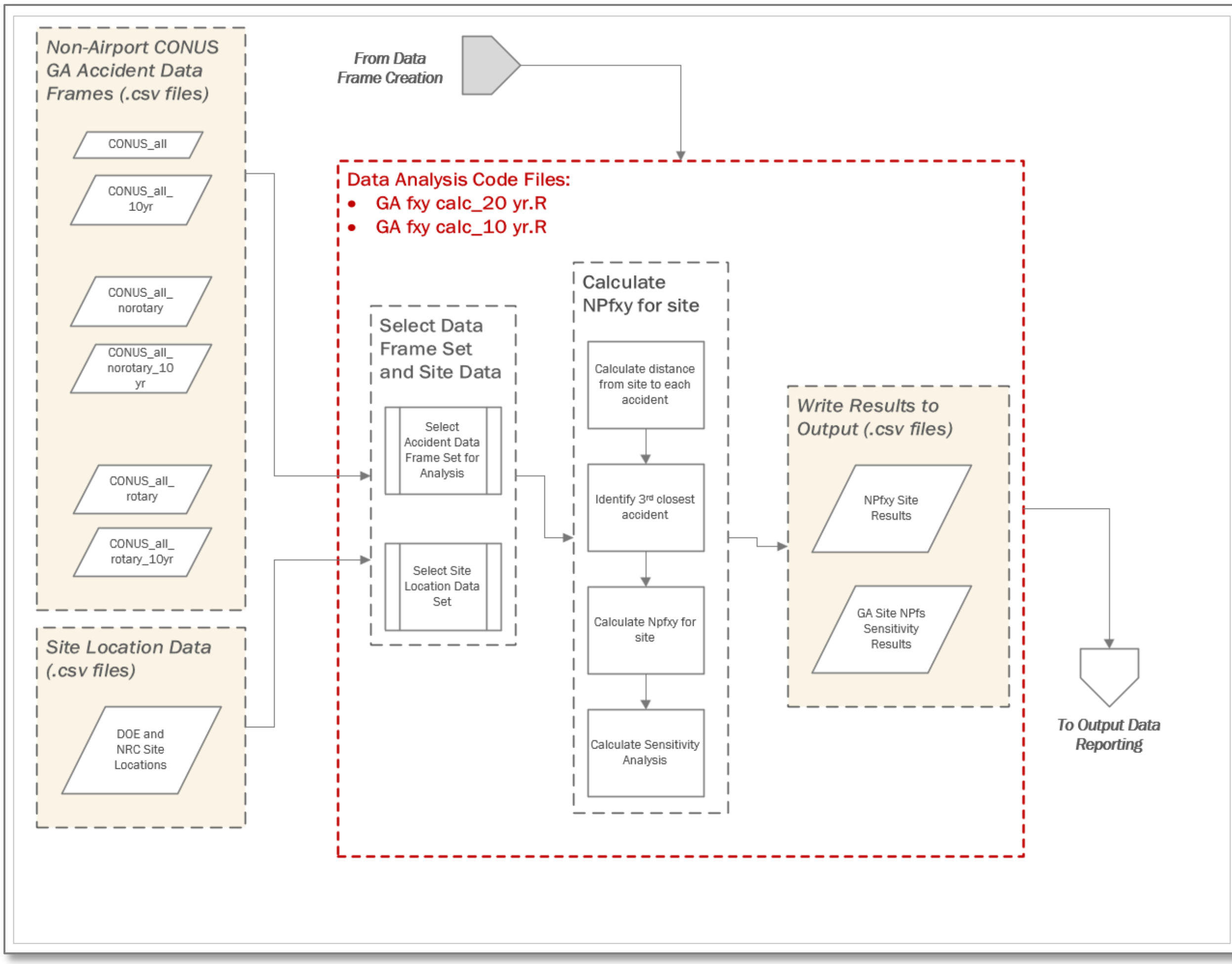

Figure D.3. Data analysis: estimate GA non-airport crash density for DOE and NRC sites

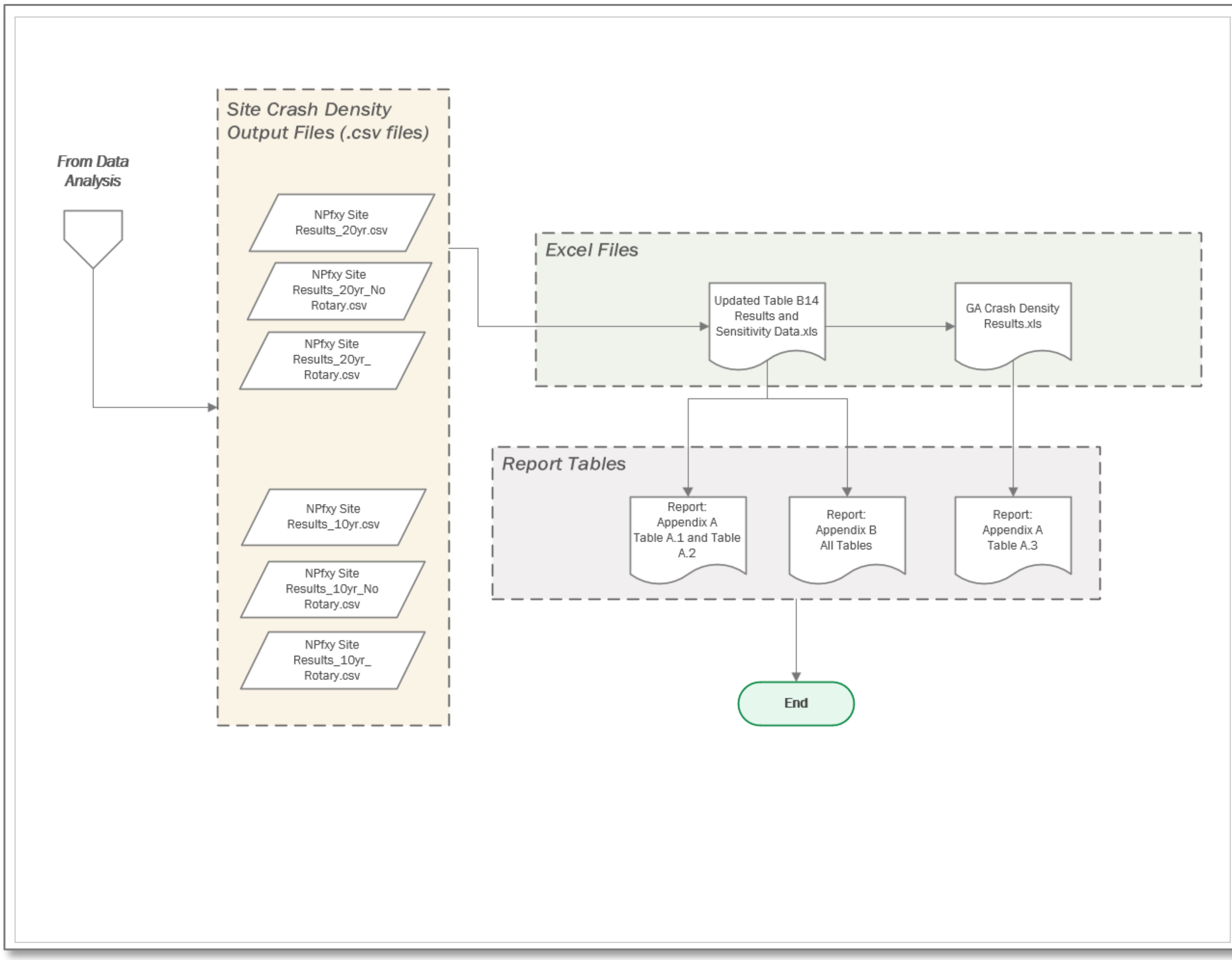

Figure D.4. Disposition and reporting of site crash density results

APPENDIX E. SUMMARY OF NTSB DATA FILTERING

APPENDIX E. SUMMARY OF NTSB DATA FILTERING

Table E.1 – Summary of NTSB Data Filtering

Parameter	**2000-2007**	**2008-2019**
Raw NTSB GA Accident/Incident Event Data Set		
NTSB GA Events	12,555	15,890
Duplicate GA Events	--	1,159
NTSB GA Acc	12,429	15,664
NTSB GA Incidents	126	226
Aircraft Damage Incurred (Accidents only)		
Damage: Not Specified	--	2
Damage: None	77	49
Damage: Minor	68	108
Damage: Substantial	10,130	14,099
Damage: Destroyed	2,154	1,406
GA Accidents by Phase of Flight (PoF) (only for Substantial and Destroyed Aircraft)		
PoF: Approach	1,668	1,830
PoF: Emergency Descent	45	87
PoF: Enroute	2,560	2,486
PoF: Initial Climb	1,462	1,626
PoF: Landing	3,731	5,215
PoF: Maneuvering	1,345	1,720
PoF: Push Back/Towing	1	0
PoF: Post Impact	0	8
PoF: Standing	111	164
PoF: Takeoff	943	1722
PoF: Taxi	304	411
PoF: Uncontrolled Descent	29	42
PoF: Unknown	85	194
Non-Airport GA Accidents by Aircraft Class (only for Substantial and Destroyed Aircraft)		
Non-Airport: Balloon	12	1
Non-Airport: Glider	57	14
Non-Airport: Powered Parachute	2	1
Non-Airport: Powered Aircraft	3,908	4,319
Non-Airport Powered-Aircraft GA Accidents with No Lat/Long Data (only for Substantial and Destroyed Aircraft)		
No Lat/Long Data	179	7

Table E.1 – Summary of NTSB Data Filtering (continued)		
Parameter	**2000-2007**	**2008-2019**
Non-Airport Powered-Aircraft GA Accidents CONUS / Non-CONUS (only for Substantial and Destroyed Aircraft)		
CONUS	3,568	3,568
Non CONUS	161	241
Non-Airport Powered-Aircraft GA Accidents CONUS FW/RW (only for Substantial and Destroyed Aircraft)		
Fixed-Wing CONUS	3,060	3,460
Rotary-Wing CONUS	508	611