US Army Corps of Engineers ®
Tulsa District

APPENDIX C: Economics

Tulsa and West Tulsa Levees Feasibility Study

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1 INTRODUCTION

Appendix C summarizes results of the National Economic Development (NED) analysis for the Tulsa and West-Tulsa Levees Feasibility Study (TWT Study). Section 2 provides an overview of study area demographics and other characteristics as required by the National Environmental Protection Act (NEPA); Section 3 discusses methodology, data and assumptions used to develop NED analyses, and Sections 4 and 5 summarize results. Other appendices and the main body of the report contain additional information regarding plan formulation, engineering and hydrology and hydraulics (H&H). Life loss methods and estimates developed for the Tulsa West-Tulsa Levees Semi-Quantitative Risk Assessment (SQRA) are presented as an addendum to this appendix.

Study team economists evaluated alternatives based on flood-related costs (i.e., damages avoided) consisting of structural damage to homes, businesses and other buildings and vehicles, and losses associated with damage to building contents such as furniture, electronics or industrial equipment. Methodology used meets criteria in Engineering Regulation ER 1105-2-100 (Planning Guidance Notebook). Models applied are USACE certified tools developed by the USACE Hydrologic Engineering Center (HEC) and include HEC-Flood Damage Analysis (HEC-FDA) software, and the recently developed hydrologic and economic data preprocessing module (HEC-GeoFDA). HEC-FDA is similar to HEC-LifeSim, but focuses on monetary damages rather than life loss.

The standard metric used to evaluate plans based on NED is the ratio of benefits (BCRs) to costs where a value of 1.0 or more is a good investment and a value of less than 1.0 is generally not a good investment based solely on economic and financial considerations. The expected annual cost for an alternative in terms of construction and operation is subtracted from expected annual benefits to compute BCRs and net annual benefits. A plan with a BCR equal to or greater than 1.0 is not necessarily the “NED plan.” The NED plan is the alterative with a BCR of at least 1.0 that generates the greatest net economic benefits.

1.1 Overview of Study Area

The study area consists of Levee A and Levee B (referred to as Areas A and B herein) and occupy a portion of the incorporated limits of Sand Springs, Okla., (population 19,727), and a small segment of the City of Tulsa. Most of the study area lies in Sand Springs, which is considered a suburb of the City of Tulsa. Total land area in A is 1.68 square miles and 2.19 square miles in Area B with relatively flat terrain, and most land is developed with both residential and commercial plots along with several schools, churches and parks. There are also large concentrations of industrial facilities in Areas A and B, many of which are suppliers to regional petrochemical refineries.

1.2 Population and Economy

As shown in Table C-1, the study area was home to 6,329 people in year 2000 with most residing in Levee Area B (90 percent). Since then population in both areas has declined (a 17 percent reduction in Area A and a 9 percent decline in Area B). In contrast, population for the City of Tulsa, Tulsa County, Okla. and the U.S. have all increased substantially. At the state and county level, population projections indicate robust growth over the long-term. According to the Oklahoma Department of Commerce, Oklahoma's population will reach 4 million by 2020, and top 5.5 million by 2075.[1] The number of people living in Tulsa County is expected to grow from roughly 640,000 in 2019 to 934,000 in 2075. Population projections for the study area are not available; however, it is unlikely that population levels will increase in the future based on historical trends.

Table C-1: Population Estimates

Geographical Area	2000	2010	2019	Percent Change (2000-2019)
Levee Area A	631	513	522	(-17%)
Levee Area B	5,698	5,134	5,201	(-9%)
Total Study Area	6,329	5,647	5,723	(-10%)
Tulsa (City)	392,752	391,900	411,490	+5%
Tulsa County	563,299	603,403	657,000	+17%
Oklahoma	3,450,654	3,751,351	4,031,901	+17%
United States	281,421,906	308,745,538	332,417,793	+18%
Source: U.S. Census (2000, 2010); ESRI Demographic Data Mapper (2019)				

With a total real gross domestic product of about $55 billion (30 percent of the state total), the Tulsa area has a strong economy and is one of the state's centers for commerce and industry.[2] As shown in Table C-2, the largest sector by both payroll and number of employees in Tulsa County is the health care industry with an annual payroll of $2.5 billion and almost 54,000 paid workers. Manufacturing including a large number of petrochemical refining and supporting businesses is also a key regional industry (38,037 employees paid $2.0 billion annually in wages and benefits).

[1] Oklahoma Department of Commerce, "2012 Demographic State of the State Report: Oklahoma State and County Projections through 2075." December 2012.

[2] Federal Reserve Bank of St. Louis, FRED Economic Data, Total Gross Domestic Product for Tulsa, Oklahoma (MSA) (Dataset NGMP46140). Accessed August 3, 2019. jen

Table C-2: Employment and Payroll by Business Sector in Tulsa County

Industry	Number of businesses	Paid employees	Annual Payroll ($millions)	Percent businesses	Percent employees	Percent payroll
Health care and social assistance	2,120	53,965	$2,548.4	11.2%	16.1%	16.3%
Manufacturing	830	38,037	$2,038.0	4.4%	11.4%	13.1%
Professional, scientific, and technical services	2,369	20,437	$1,428.0	12.5%	6.1%	9.1%
Finance and insurance	1,379	15,470	$1,128.6	7.3%	4.6%	7.2%
Retail trade	2,332	41,617	$1,081.8	12.4%	12.4%	6.9%
Wholesale trade	1,183	16,352	$1,052.6	6.3%	4.9%	6.7%
Management of companies and enterprises	207	10,763	$986.3	1.1%	3.2%	6.3%
Construction	1,443	17,118	$864.3	7.6%	5.1%	5.5%
Administrative support and waste management	1,043	23,603	$768.4	5.5%	7.0%	4.9%
Transportation and warehousing	405	11,333	$659.2	2.1%	3.4%	4.2%
Mining, quarrying, and oil and gas extraction	311	5,412	$620.0	1.6%	1.6%	4.0%
Information	345	10,285	$607.2	1.8%	3.1%	3.9%
Accommodation and food services	1,614	33,042	$520.6	8.5%	9.9%	3.3%
Other services (except public administration)	1,780	15,737	$453.4	9.4%	4.7%	2.9%
Real estate and rental and leasing	980	7,226	$296.5	5.2%	2.2%	1.9%
Educational services	214	7,929	$256.2	1.1%	2.4%	1.6%
Utilities	45	1,904	$174.9	0.2%	0.6%	1.1%
Arts, entertainment, and recreation	247	4,807	$123.0	1.3%	1.4%	0.8%
Agriculture, forestry, fishing and hunting	8	26	$1.0	0.04%	0.01%	0.01%
Industries not elsewhere classified	24	19	$0.6	0.1%	0.01%	0.00%
Total	18,879	335,082	$15,608.8	100.0%	100.0%	100.0%
Source: U.S. Census Bureau County 2017 Business Patterns						

Table C- 3 compares employment reported by Census respondents according to major industry groups for Areas A and B, and regional, state and national figures. Overall, the distribution of occupational patterns in the study area parallels regional and national levels; although, percentages of manufacturing occupations are slightly higher given the local presence of several large industrial facilities in areas A and B.

Table C- 3: Employment by Sector for Study Area and Region, State and Nation

Industry	Levee Area A		Levee Area B		Tulsa (city)	
	Number	Percent	Number	Percent	Number	Percent
Agriculture and mining	1	0.6%	18	0.9%	4,448	2.2%
Construction	12	6.8%	156	8.0%	14,153	7.0%
Manufacturing	22	12.4%	242	12.4%	20,016	9.9%
Wholesale trade	4	2.3%	90	4.6%	5,459	2.7%
Retail trade	32	18.1%	309	15.8%	21,432	10.6%
Transportation and utilities	5	2.8%	111	5.7%	11,322	5.6%
Information	5	2.8%	41	2.1%	5,661	2.8%
Finance, insurance, real estate	10	5.6%	121	6.2%	13,546	6.7%
Services	78	44.1%	791	40.5%	100,486	49.7%
Public administration	9	5.1%	72	3.7%	5,661	2.8%
Total	177	100.0%	1,954	100.0%	202,185	100.0%
	Tulsa (county)		Oklahoma		U.S.	
Agriculture and mining	8,235	2.5%	93,007	5.1%	2,729,332	1.7%
Construction	21,412	6.5%	131,304	7.2%	11,238,427	7.0%
Manufacturing	33,600	10.2%	158,659	8.7%	16,054,895	10.0%
Wholesale trade	9,882	3.0%	47,415	2.6%	4,174,273	2.6%
Retail trade	35,906	10.9%	198,780	10.9%	17,178,738	10.7%
Transportation and utilities	19,435	5.9%	102,126	5.6%	9,151,290	5.7%
Information	9,553	2.9%	32,826	1.8%	3,210,979	2.0%
Finance, insurance, real estate	22,729	6.9%	107,597	5.9%	10,596,231	6.6%
Services	158,448	48.1%	837,065	45.9%	78,508,437	48.9%
Public administration	10,212	3.1%	114,891	6.3%	7,866,899	4.9%
Total	329,413	100.0%	1,823,670	100.0%	160,548,951	100.0%
Source: U.S. Census and ESRI Demographic Data Mapper						

Reported household incomes, both per capita and median, for the study area are substantially lower than regional and national values (Figure C-1). Per capita and median household income in Area A are $25,273and $12,336, and for Area B $30,499 and $15,342 respectively. The percent of households living below the federal poverty level is about 19 percent in Area B and 21 percent in Area A. In contrast, nearly 11 percent of U.S. and 12 percent of Oklahoma and Tulsa County households live below the poverty line (Table C-4).

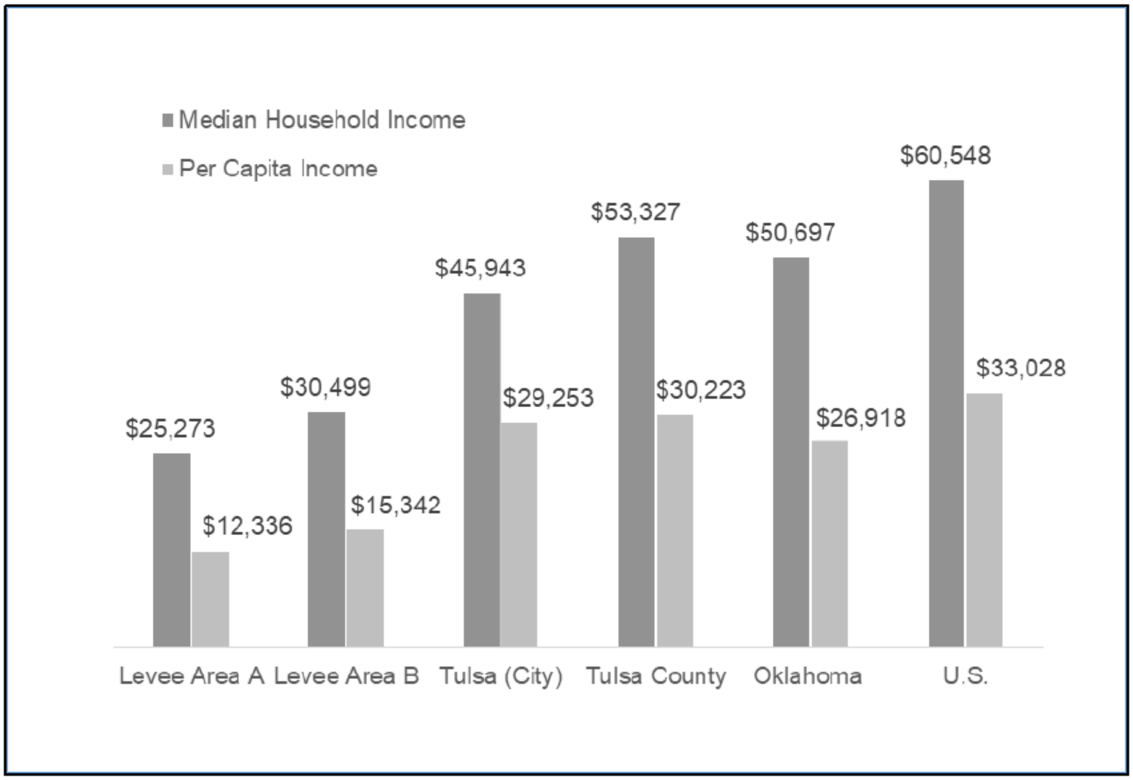

Figure C-1: Median Household and Per Capita Income in the Study Area, Region and U.S. (Source: U.S. Census Bureau)

Table C-4: Employment by Sector for Study Area and Region, State and Nation

Region	Percent of households below federal poverty line	Unemployment rate
Levee Area A	21.7%	15.3%
Levee Area B	19.3%	11.1%
Tulsa (county)	11.8%	5.0%
Oklahoma	11.8%	4.8%
U.S.	10.5%	4.6%
Source: Bureau of Labor Statistics (2017 values) and U.S. Census Bureau American Community Survey 2017		

1.3 Educational Attainment

Table C-5 shows educational attainment for people 25 years and older. In percentage terms, the TWT Study area has lower levels of educational attainment when compared to regional and national values. In both Area A and B, approximately 63 percent of residents reported educational attainment as high school diploma or less versus regional and national levels of 35 to 43 percent for the same category. Only about 5 percent had a college degree versus roughly 20 percent at the regional and national levels, and only 2 to 3 percent had graduate or professional degrees.

Table C-5: Educational Attainment by Sector for Study Area and Region, State and Nation

Area	Less than 9th grade	9th to 12th grade, no diploma	High school graduate	Some college	Associate degree	Bachelor degree	Graduate or professional degree
Levee A	3%	16%	44%	25%	7%	4%	3%
Levee B	6%	17%	43%	20%	7%	5%	2%
Tulsa (city)	5%	7%	25%	23%	9%	21%	11%
Tulsa (county)	4%	6%	25%	23%	9%	22%	11%
Oklahoma	4%	8%	31%	23%	8%	17%	9%
U.S.	5%	7%	27%	20%	9%	20%	13%
Source: U.S. Census and ESRI Demographic Data Mapper							

1.4 Environmental Justice Indicators

Executive Order 12898, entitled "Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations (1994)," addresses disproportionate human health and environmental impacts that a project or plan may have on minority or low-income communities. Thus, the environmental effects of a plan on such communities including Native American populations must be disclosed, and agencies must evaluate projects to ensure that proposed actions do not disproportionally impact minority or low income communities. If such impacts are identified, appropriate mitigation measures must be implemented.

To determine whether a project has a disproportionate effect on potential environmental justice communities (i.e., minority or low income population), the demographics of an affected population within the vicinity of a project must be considered in the context of the overall region. Guidance from the Council on Environmental Quality (CEQ) states that "minority populations should be identified where either: (1) the minority population of the affected areas exceeds 50 percent, or (b) the minority population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis (CEQ 1997)."

Table C-6 displays Census data summarizing racial characteristics of areas adjacent to plan construction sites. The purpose is to analyze whether the demographics of the affected area differ in the context of the broader region; and if so, do differences meet CEQ criteria for an Environmental Justice community. Based on the analysis, it does not appear that minorities in the TWT Study area are disproportionately affected; however, it is possible that the TWT Study area may qualify as a low income population.

Table C-6: Racial Composition for TWT Study Area and Region, State and Nation

	Levee Area A		Levee Area B		Tulsa (city)	
	Number	Percent	Number	Percent	Number	Percent
White	313	60.0%	3,401	65.4%	1,010	43.2%
Black	59	11.3%	343	6.6%	699	29.9%
American Indian and Alaskan Native	72	13.8%	713	13.7%	220	9.4%
Asian	4	0.8%	26	0.5%	56	2.4%
Native Hawaiian or Pacific Islander	0	0.0%	5	0.1%	2	0.1%
Some other race alone	18	3.4%	255	4.9%	122	5.2%
Two or More Races	56	10.7%	468	9.0%	227	9.7%
Total	522	100%	5,201	100%	2,339	100%
Hispanic Origin	41	7.9%	520	10.0%	330	14.1%
	Tulsa (county)		Oklahoma		U.S.	
White	431,649	65.7%	2,786,044	69.1%	231,362,784	69.6%
Black	68,985	10.5%	306,424	7.6%	42,881,895	12.9%
American Indian and Alaskan Native	41,391	6.3%	350,775	8.7%	3,324,178	1.0%
Asian	24,309	3.7%	96,766	2.4%	19,280,232	5.8%
Native Hawaiian or Pacific Islander	657	0.1%	8,064	0.2%	664,836	0.2%
Some other race alone	46,647	7.1%	209,659	5.2%	23,269,246	7.0%
Two or More Races	43,362	6.6%	274,169	6.8%	11,634,623	3.5%
Total	657,000	100%	4,031,901	100%	332,417,793	100%
Hispanic Origin	88,038	13.4%	455,605	11.3%	61,829,709	18.6%
Source: U.S. Census and ESRI Demographic Data Mapper						

1.5 Data, Models and Methods

Plan formulation in the context of National Economic Development (NED) analysis involves comparing monetary damages caused by flooding assuming: 1) no plan is implemented (i.e., the no-action alternative) and 2) different permutations of potential plans. Section 3 outlines the process, data and models applied in the NED analysis.

1.6 Overview of Methodology

At a fundamental level, computation of flood damages using HEC-FDA is straightforward, and is based on the depth of flooding for various flood events characterized by their probability or frequency of occurring. Relationships between the depth of flooding and monetary damages is based on a percentage of a building's value and the value of its contents that increases with flood depth. Damages to cars parked structures are often included as well. Damages to the various structures, accumulated by frequency of events, produce a frequency-damage function.

While the fundamental computation framework is simple, the algorithms are more complex. Using frequency-damage data, an integration process then calculates estimates of expected annual damage. This involves aggregating the multiplication of the mean damage between each pair of flood events by the difference in exceedance probabilities. This is then repeated for a range of flood events in each damage category (e.g., residential, commercial and industrial). Note that nomenclature used in this appendix to describe relative flood risk is the actual probability, rather than the average recurrence interval of flood events. For example, the commonly used term “100-year flood,” refers to a flood that has a 1 percent chance of being equaled or exceeded in any given one-year period and is referred to herein as the 1-percent annual exceedance probability (AEP) flood.

HEC-FDA computes flood damages for without and with project scenarios. The program integrates hydrologic, hydraulic, and floodplain characteristics through application of a Monte Carlo simulation method, and computes single event damages and expected annual damages (EAD), while accounting for uncertainty in the values of structures and contents. Damage susceptibility factors used by the program to estimate flood damages include: number and type of structures, structure and content values, elevation where the structure begins to sustain measurable damages, and flood depth-to-percent damage relationship.

1.7 Economic Inputs to the HEC-Flood Damage Analysis Model

While computation of flood damages (or flood damage reduction benefits of alternative plans) using HEC-FDA is automated and relatively quick once the model is set up, collecting and process inputs can be time consuming with the inventory of flood plain structures often requiring the most effort on the part of economists. Fortunately, recent geo-process tools including ESRI ArcMap and HEC-GeoFDA along with updated datasets from the Flood Risk Management Planning Center of Expertise (FRM-PXC) such as the National Structure Inventory (NSI) have greatly facilitated development of accurate floodplain inventories.

For this TWT Study, the study team inventoried properties within the 0.2 percent (500-year) floodplain, which has the maximum flood inundation depths and extent (see Figures A-2 and A-3). Information was gathered regarding the:

- Type of structure or damage category (i.e., residential, commercial, industrial or public),
- Replacement cost of structures,
- Type and height of building foundations (used to determine first floor finished elevations or the stage at which water would enter a building),
- Square footage, number of stories, and building construction materials; and,
- Value and number of cars per structure susceptible to flooding.

Inventories were cataloged using geospatial files from the National Structure Inventory (NSI). Spatial location of NSI data were verified using aerial imagery from Google Earth and GIS data from the Tulsa County Assessor's Office. Team economists then conducted an onsite 3-day field survey in March of 2019 to verify data with a focus on first floor foundation heights. Additional specifics regarding the inventory are discussed below.

1.7.1 Structure Values

Structure values were obtained from the Appraisers office and reviewed using construction cost per square foot for different types of buildings and depreciation schedules published by RSMeans (2018 Building Costs Book). In general, appraised market value less land were consistent (within plus or minus 5 to 10 percent) with estimates using RSMeans for commercial and public structures based on sample size of 10 percent. Foundations heights for commercial and public structures range from 0 (slab on grade) to 1.0 foot with an average of about 0.5 feet (Figure C-2 and Figure C- 3).

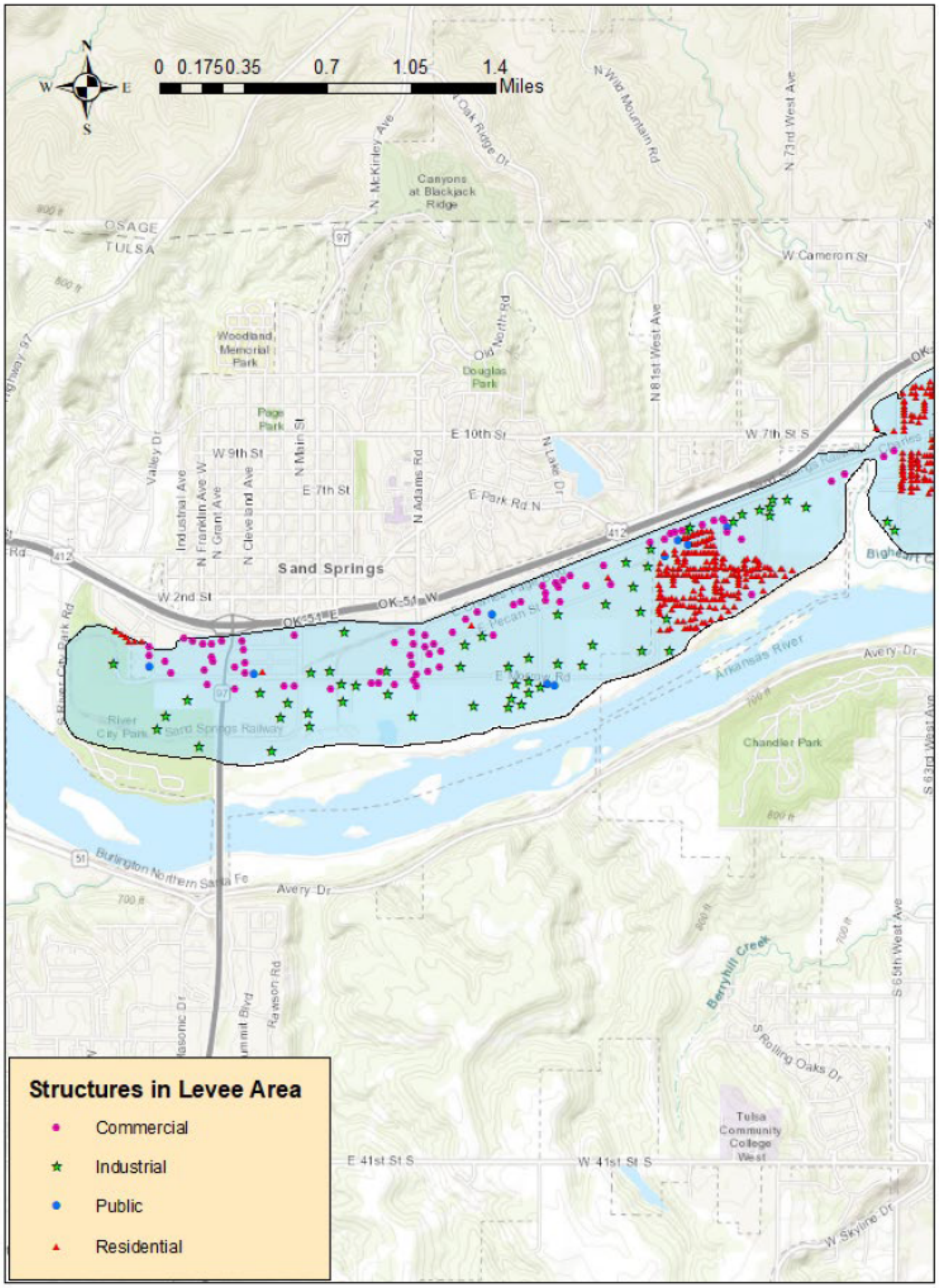

Figure C-2: Spatial Distribution of Structures behind Levee A in the 0.2 Percent Floodplain (500-year)

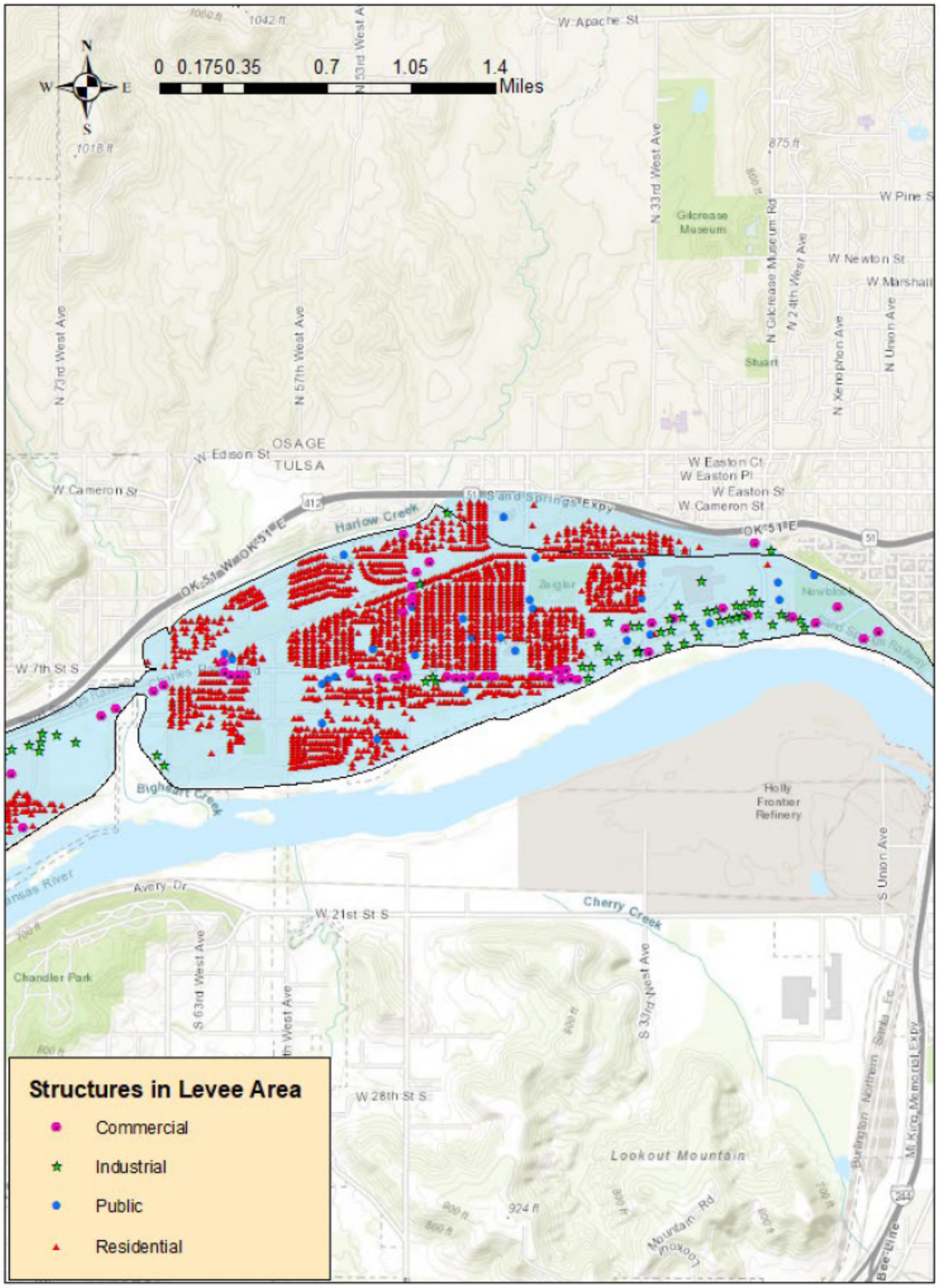

Figure C- 3: Spatial Distribution of Structures behind Levee B in 0.2 Percent Floodplain (500-year)

Using the same sample size, residential value estimates using RS means were slightly higher; however, given the age and condition of many residential structures, the PDT opted to use appraised market value less land value as a proxy for replacement cost less depreciation. The TWT Study area is unique in that local household income is well below state and national averages, and depending upon the neighborhood many homes are older (average year built is 1938), smaller (average of 1,100 square feet) and some are fairly dilapidated and in very poor condition (i.e., depreciation nearing 100 percent). In general, residential home values and condition drops as homes get closer to the Arkansas River. Most homes are wood frame cottages or ranch style single story structures, some with brick veneer and foundations are typically pier and beam, or slabs. Foundation heights range from 0 (slab on grade) to 6 feet with an average of 1.8 feet. Figure C-4 through Figure C-8 illustrate the range of home conditions in the area.

Figure C-4: Typical Residential Neighborhood in TWT Study Area

Figure C-5: Dilapidated and Vacant Residential Structure in Levee Area A

Figure C-6: Typical Lower Value Residential Structure in Levee Area B

Figure C-7: Typical Average Value Home in TWT Study Area

Figure C-8: Typical Higher Value Home in TWT Study Area (Levee Area B)

As noted earlier, there is a significant number of industrial facilities in both Areas A and B including heavy and light manufacturing along with numerous types of warehousing facilities. Assessor's parcel data for manufacturing sites is not suited for estimating replacement costs for industrial structures. In Oklahoma, property used in the manufacture of goods is often exempt from ad valorem (property taxes), and thus appraised market or taxable value of an industrial facility may not include all structures. For industrial facilities, the team used RSMeans to estimate replacement value of industrial buildings. There are also several medium sized full-stream petrochemical refineries in the TWT Study area, each hosting numerous complexes of above ground petrochemical storage tanks (ASTs). Depreciated replacement costs for ASTs are based on values reported in the 2014 State of Michigan Assessors Manual Vol. II Unit in Place Costs for ASTs. Tank costs were indexed to current 2019 price levels using the composite index from the USACE's Civil Works Construction Cost Indices System (CWCCIS).

Table C-7 summarizes the number and value of structures catalogued. Most residences are in Area B (2,015 versus 215 in Area A), and the average structural value in both areas ranges from about $31,000 to $34,000. In total, homes comprise only about 20 percent of structural value in the TWT Study area. Industrial and commercial buildings comprise nearly 70 percent. Total structural value in the TWT Study area based on 2019 price levels is $390 million.

Table C-7: Inventory of Structures in TWT Study Area Flood Plain

Levee Area A		**Aggregate Value by Structure Type**				
Structure type	**Number of residences or facilities**	**Sum**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Single Family Residential	215	$6,715,795	$100	$80,500	$31,236	$16,788
Multi-family Residential	4	$5,059,500	$180,900	$2,494,200	$1,264,875	$1,146,368
Commercial	72	$47,937,109	$11,200	$8,182,000	$665,793	$1,030,131
Industrial	57	$124,373,987	$0	$17,745,054	$2,182,000	$3,716,279
Public	9	$8,279,552	$39,800	$6,142,406	$919,950	$1,970,782
Total Levee Area A	357	$192,365,942	$0	$17,745,054	$538,840	$1,755,961
Levee Area B		**Aggregate Value**				
Single Family Residential	2,051	$70,035,746	$100	$154,643	$34,147	$16,788
Multi-family Residential	2	$8,663,600	$245,100	$8,418,500	$4,331,800	$1,146,368
Commercial	55	$13,883,811	$12,800	$5,410,589	$252,433	$1,030,131
Industrial	47	$80,770,220	$15,500	$34,217,391	$1,718,515	$3,716,279
Public	28	$24,710,248	$23,500	$7,726,501	$882,509	$1,970,782
Total Levee Area B	2,183	198,063,625	297,000	55,927,624	7,219,404	7,880,348
Total Levee Area A and B		**Aggregate Value**				
Single Family Residential	2,266	$76,751,541	$100	$154,643	$55,599	$29,042
Multi-family Residential	6	$13,723,100	$180,900	$8,418,500	$3,914,889	$4,803,197
Commercial	127	$61,820,920	$11,200	$8,182,000	$838,280	$1,829,717
Industrial	104	$205,144,207	$0	$34,217,391	$4,534,994	$11,668,585
Public	37	$32,989,800	$23,500	$7,726,501	$1,337,424	$2,595,169
Grand Total	2,540	$390,429,568	$0	$34,217,391	$305,930	$2,584,116

Source: Based on data from the National Structure Inventory, Tulsa County Tax Assessors Office, USACE field surveys and USACE aerial imagery analysis.

1.7.2 Structural Content Values

Given an expedited TWT Study schedule, estimates for content values for structures are not based on field or mail survey data, and the team relied on default values commonly used in HEC-FDA models referred to as content to value ratios (CVRs). Residential CVRs are embedded in depth damage functions in FDA and assume a value of 1.0. So for example, if a structure's value is $50,000 then the contents inside the house such as furniture, electronics and appliances and other items is $50,000. Default CVRs for commercial and public structures is also 1.0. For industrial facilities, a value of 1.5 was used. Total content value for the TWT Study area based on the above assumptions is approximately $474 million dollars, and this includes the estimated number of vehicles assumed to be inundated by flood waters (see below). Thus, total property affected by flooding is roughly $860 million.

1.7.3 Automobile Values

In addition to buildings, cars are susceptible to flood damage, and thus an estimate of the number of vehicles present during a flood event, and their value is needed to estimate project benefits. Note that car damages are assumed to accrue for residential properties only. Given substantial warning times in the event of a levee breach, the PDT agreed that any cars present at commercial, public or industrial properties (customers or employees) would likely have ample times to evacuate before their cars suffered damage. Another factor are the relatively short evacuation distances. Note that this does include several car dealerships that have large on site inventories of new and used vehicles (discussed below).

As is the case with employers and customers of local businesses, the analysis assumes some residents would have time to evacuate in cars. To estimate the average value of vehicles per residence present when flood waters arrived, economists collected data during the field survey of neighborhoods to get a sample to serve as a reasonable proxy of car values (Table C-8). Based on the estimated age of cars, bluebook values for each make and model of vehicles were obtained from the 2019 National Automobile Dealers Association New and Used Car Price Guide. The number of vehicles present derives from Census data, and a number of assumptions based on previous feasibility studies and professional judgment. Census data from the American Community Survey 2017 shows that there is an average of 1.74 vehicles available for use per household in the TWT Study area. This figure is adjusted using the formula:

$$NPV = [(a*NVH*(b/c) + d*NVH\ (e/c)] * f$$

where:

NPV = number of vehicles present during flood event
NVH = average number of vehicles per household (1.74)
a = percent of vehicles present during non-work hours (75 percent)
b = number of work hours per week (128 hours)
c = total hours per week (168 hours)
d = working hours per week (40 hours)
e = percent of vehicles present during work hours (25 percent)
f = percent of vehicles evacuated during flood (50 percent)

Based on the above equation, the average number of vehicles per household present during flooding is 1.10 prior to evacuation, and it is assumed that 50 percent of vehicles present would have ample time to evacuate. Thus, the final number of car present per residence is 0.55. This value is multiplied by the average value of automobiles in the TWT Study area ($8,895) for a final value applied in FDA of ($8,895 x 0.55 = $4,872).

Table C-8: Estimated Average Value of Residential Cars in TWT Study Area

Make	Type	Model	Year	Bluebook Value
Chevy	Sedan (coupe)	SS	2009	$8,938
Chevy	SUV	Equinox	2009	$8,600
Chevy	Truck	Silverado	2012	$14,229
Dodge	Truck	Dakota	2009	$7,373
Dodge	Truck (4x4)	Ram	2013	$15,515
Ford	Sedan	Taurus	2009	$7,425
Ford	Truck	Ranger	2009	$8,427
Ford	Truck	F150	2009	$9,486
Ford	Truck	Ranger	2009	$8,427
Ford	Truck	Ranger	2009	$8,427
Honda	Sedan	Accord	2014	$13,450
Honda	Sedan	Civic	2009	$5,600
Honda	Sedan	Civic	2009	$5,600
Honda	Sedan	Accord	2009	$7,700
Honda	Sedan	Civic	2016	$17,555
Nissan	Sedan	Sentra	2009	$8,050
Toyota	Sedan	Corolla	2009	$12,025
Toyota	Sedan	Corolla	2015	$5,417
Toyota	Sedan (small)	Camry	2009	$6,036
Toyota	SUV	RAV	2009	$8,068
Toyota	SUV	Highlander	2009	$10,690
Ford	Truck	F150	2009	$6,457
Ford	Compact	Focus	2012	$5,629
Chevy	Compact	Cruse	2013	$6,328
Hyundai	Sedan	Accent	2013	$6,595
Ford	Compact	Fiesta	2015	$8,516
Chevy	Sedan	Impala	2009	$4,954
Chevy	Sedan	Malibu	2009	$5,609
Chevy	Truck	Silverado	2012	$14,229
Dodge	Sedan (coupe)	SS	2009	$4,325
Dodge	Truck	Dakota	2009	$7,373
Dodge	SUV	Journey	2009	$7,100
Dodge	Truck (xcab)	Ram	2013	$15,515
Dodge	Truck (4x4)	Ram	2009	$12,234
Ford	Sedan	Taurus	2009	$7,425

Make	Type	Model	Year	Bluebook Value
Ford	Sedan	Crown Victoria	2009	$6,925
Ford	SUV	Explorer	2009	$7,400
Ford	SUV	Explorer	2009	$7,400
Ford	Truck	F150	2009	$9,486
Ford	Truck	F150	2012	$13,375
Honda	Sedan	Civic	2009	$5,600
Honda	Sedan	Accord	2009	$7,700
Nissan	SUV	Pathfinder	2009	$6,700
KIA	Van	Sedona	2009	$4,463
Chrysler	Van	Pacifica	2017	$19,080
Ford	Compact	Focus	2012	$5,629
Hyundai	Sedan	Elantra	2010	$4,627
Chevy	Compact	Sonic	2013	$5,554
Ford	Compact	Fiesta	2009	$4,722
Jeep	SUV	Wrangler	2013	$20,463
Jeep	SUV	Cherokee	2015	$15,198
			`Average for Sample	**$8,895**

In addition to vehicles damaged at homes during flooding, there are several automotive dealerships and automotive parts dealers in the area, two of which, keep large inventories of new, used and salvaged cars. Using current and historic aerial imagery, the largest dealership carries an onsite inventory of about 560 new and used cars, and the salvage yard, which strips vehicles and sells aftermarket parts maintains an inventory averaging 700 vehicles. Inventory value for dealerships is based on the current average cost of new and used cars as reported in Edmunds and Kelly Blue Book ($35,742 and $19,647). Assuming a 50 percent split between new and used vehicles, total inventory value for the largest dealer is $10.5 million. A sample of realized auction prices in Tulsa from Salvage World Online indicate that the value of salvaged vehicles in Tulsa typically ranges anywhere from $375 to $7,500 with average of $3,751. Based on this average, the value of the salvage yard stock is $2.6 million. Three distinct FDA models (i.e., for each Level Control Location) were created to estimate damages to vehicles based on the above data. In other words, the inventory of cars is a separate import files into FDA that are distinct from models using the structure inventory; however, hydrologic and geotechnical inputs are the same.

1.7.4 Depth Damage Functions

Depth damage functions map relationships between flood depths to the amount damage suffered at different depths. For example, based on an index elevation (typically the first floor of a building or ground elevation), 3 feet of water inside a structure results damages totaling 40 percent of the structure’s value. As the water gets deeper, percent damages increase. For residential structures, damage functions for both structures and contents were compiled by the

USACE Institute of Water Resources (IWR), based on data collected from flooding events throughout the United States between 1996 and 2001.[3] These functions vary depending upon “structure occupancy types” that reflect differences in homes such as the number of stories, and whether or not a home has basement, or slab foundation versus a pier and beam foundation with a crawl space.

Damage relationships for commercial, industrial and public structures are based on analyses of historical data collected from major flood events across the U.S. and are supplemented with findings from subsequent economic field surveys of floodplain properties in the Fort Worth District, considering such factors as the design of the structure and nature of structure contents. These are vary depending on the type of business or public facility (restaurants, retail shops, grocery stores, schools, government buildings, heavy versus light manufacturing etc.). USACE Economic Guidance Memorandum (EGM) 09-04 is the source of automobile depth-damage curves. For automobiles the first floor elevation applied was zero in all cases.

1.7.5 First Floor Elevations and Creation of HEC-GeoFDA Import Files

As alluded to above, a key parameter for any FDA model is the ground elevation measured based on common geographic datum where socioeconomic damages begin to accrue during a flood. Generally, this is the first finished floor above structural foundations, which can vary in height by many feet. Historically, identifying and incorporating first floor elevations in FDA has been one of the more time consuming tasks; however, the HEC recently released HEC-GeoFDA that greatly facilitates this and many other geospatial tasks. Among other things these tasks include creating, editing and loading of geospatially referenced terrain data, one and two dimensional hydraulic data grids, impact area polygons, structure inventories and more. GeoFDA processes data into HEC-FDA compatible import files. It also easily assigns first floor elevations based on hydraulic terrain grids and structure inventory shapefiles. Software users supply foundation height that can verified in the field or via desktop by using street level satellite imagery such as Google Maps by counting the number of steps on a front porch or building portico. Each FDA model scenario used in this TWT Study relied on GeoFDA to prepare a global FDA import file that populates many data vectors needed to run FDA.

1.7.6 Risk and Uncertainty in Economic Inputs

As described in Engineering Manual (EM) 1110-2-1619 “Risk-Based Analysis for Flood Damage Reduction Studies,” as is the case with any model, there are risks and uncertainties associated with parameters often arise as a result of things such as analytical or measurement errors, data limitations or just natural randomness in data. To address uncertainties, FDA incorporates standard deviations as a measure of data variance into Monte Carlo simulations, where higher values of variance apply where uncertainties are greatest. Ambiguity associated with residential

[3] USACE Economic Guidance Memorandum (EGM) 04-01 “Generic Depth-Damage Relationships for Residential Structures.” April, 2001.

structures and contents is modeled using a normal distribution with a standard deviation of 5 percent. Commercial, industrial and public structures also use the normal distribution with a standard deviation of 10 percent. These values are default in HEC-FDA. Uncertainty distribution, and uncertainty parameters. Uncertainty regarding first floor stages use a normal distribution with a standard deviation of 0.5 feet.

1.8 Hydrologic and Geotechnical Inputs into the HEC-Flood Damage Analysis Model

Flood scenarios modeled are based on HEC-RAS inundation depth grids and one of two loading conditions at 3 levee control locations[4] (LCLs) throughout the TWT Study area: 1) Levee overtopping and subsequent levee failure, or 2) levee failure with surface water elevations at the top of levee. For the NED analysis, there are 3 Levee Control Locations: [redacted] and two levees, A and B [redacted]

Geotechnical and hydrologic analyses are discussed in detail in Appendices X and X; however, several sets of data are important for NED assessment and HEC-FDA modeling including, stage frequency parameters and stand deviations, levee fragility curves, and levee crest elevations. These are incorporated into HEC-GeoFDA to create an FDA import file with water surface profiles at all structure points, FDA exceedance probability functions, and FDA stage discharge functions. Levee fragility curves and other features are entered directly into FDA.

1.8.1 Stage Flow Frequency Relationships

Table C-9 displays stage flow frequency relationships for [redacted] on tributaries of the Arkansas). [redacted] water surface profiles were developed based the 0.50, 0.20, 0.10, 0.05, 0.02, 0.014, 0.012, and 0.010 AEP flood events (i.e., 2, 5, 10, 25, 50, 70, 85 and 100-year floods), and their associated flows and stages. Water surface profiles were used to delineate depth and extent of flooding, and thus estimate the extent of damage based on elevation and frequency of flood events. As mentioned earlier, the computation of flood damages is based on the depth of flooding for various flood events and a relationship between the depth of flooding and the estimated damages based on a percentage of the structure and contents value or vehicle value. Table C-10 shows stage flow frequency relationships for [redacted] (flooding on the main-stem of the Arkansas River). For both locations, water surface profiles were developed based the 0.50, 0.20, 0.10, 0.05, 0.02, 0.014, 0.012, and 0.010 AEP flood events (i.e., 2, 5, 10, 25, 50, 100, 200 and 500-year floods), and associated flows and stages.

[4] The TWT SQRA risk analysis team identified LCLs, which correspond to historical breach and overtopping locations, large concentrations of infrastructure and population, large levee heights and incipient overtopping locations.

Table C-9: Stage Flow Frequency Relationship for Level Control Location 1

Recurrence interval	Annual exceedance probability	Flows (cubic feet per second)	Stage (feet)
2-year	0.500	85,000	629.9
5-year	0.200	100,000	631.0
10-year	0.100	105,000	631.3
20-year	0.050	125,000	632.6
50-year	0.020	155,000	634.4
70-year	0.014	205,000	637.1
85-year	0.012	310,000	645.5
100-year	0.010	490,000	654.5

Table C-10: Stage Flow Relationship for Level Control Locations 2 and 4

Recurrence interval	Annual exceedance probability	Flows (cubic feet per second)	Stage (feet)
2-year	0.500	85,000	629.9
5-year	0.200	100,000	631.0
10-year	0.100	105,000	631.3
20-year	0.050	125,000	632.6
50-year	0.020	155,000	634.4
100-year	0.010	205,000	637.1
200-year	0.005	310,000	645.5
500-year	0.002	490,000	654.5

1.8.2 Levee Characteristics

It is important to note that all model inputs (economic and hydrologic) discussed so far are constant among each LCL for both the without project condition and for each plan or alternative evaluated. The critical exceptions are the levee fragility curves for the existing levee, and the two proposed modifications to the existing levee (Table C-11 and Table C-12). Existing levees are the without-project alternative, and Alternative 1 and 2 are proposed plans. Proposed plans reduce the probability of levee failure, which translates into a lower likelihood of flood damages to communities behind the levees.

Fragility curves capture the probability that either levee will fail at different flood frequency and stages. Floods will low frequencies, but higher stages and flows put more water against the levee (i.e., loading) and thus more physical force. As loading increases, the likelihood of the levee breaching increases. For tributaries, the probabilities are fairly low but not insignificant particularly for the 100-year flood. For the main-stem See Table of probabilities are much higher at the low frequency flood events. At stages generate by the 500 year flood or AEP 0.002 flood, there is a 100 percent chance of failure for the without project condition and Alternative 1, and a 50 percent chance for Alternative 2.

Table C-11 and Table C-12 also show levee crest elevations for LCL, or the point at which flood waters would overtop levees and causes them to breach. For See Table of overtopping occurs at the 0.01 AEP (100 year) event for all three alternatives, and See Table of Contents happens at the 500 year event for all three plans. See Table not overtop. Over-topping in this case is important from the perspective of NED analysis because most flood damage occurs at the low frequency events (see Section 5), and since overtopping and breaching occurring at the same flood stage, damages are not included in the NED analysis for two reasons. First, breaching and overtopping cannot be comingled in a FDA model; and second, neither plan addresses overtopping so even though the two proposed action alternatives reduce breach probabilities, they would still overtop and there would be flood damages. As a result, reduced damages for the 100 year event See Table of the 500 year See are not included in the NED analysis.

Table C-11: Levee Fragility Curves See Table of Contents for With-project and Without-project Conditions (applies to both levees A and B)

			Fragility curves (probability of failure)		
Recurrence interval	**Annual exceedance probability**	**Stage (feet)**	**Without Project**	**Alternative 1 (Risk informed plan)**	**Alternative 2 (Locally preferred plan)**
	0.500	651.5	0.000001%	0%	0%
5-year	0.200	653.1	0.000014%	0.000001%	0%
10-year	0.100	654.2	0.00028%	0.000004%	0%
20-year	0.050	655.5	0.0056%	0.00002%	0.000002%
50-year	0.020	656.7	0.113%	0.00015%	0.000011%
70-year	0.014	657.1	2.25%	0.0005%	0.00005%
85-year	0.012	657.2	2.63%	0.003%	0.0003%
100-year	0.010	657.7	4.16%	0.319%	0.317%
**Levee crest elevation = 657.6 feet*					

Table C-12: Levee Fragility Curves See Table of Contents NOTE 1 - for With-project and Without-project Conditions (applies to both levees A and B)

			Fragility curves (probability of failure)		
Recurrence interval	**Annual exceedance probability**	**Stage (feet)**	**Without Project**	**Alternative 1 (Risk informed plan)**	**Alternative 2 (Locally preferred plan)**
		629.9	0%	0%	0%
5-year	0.200	631.0	0%	0%	0%
10-year	0.100	631.3	0%	0%	0%
20-year	0.050	632.6	0%	0%	0%
50-year	0.020	634.4	0.472%	0.0123%	0.0102%
100-year	0.010	637.1	4.72%	0.0246%	0.0204%
200-year	0.005	645.5	75.5%	0.0493%	0.0409%
500-year	0.002	654.5	100%	100%	50%
**Levee crest elevation for LCL 2 = 660.4 feet* **Levee crest elevation for LCL 4 = 652.0 feet*					

1.9 Other Assumptions Regarding NED Modeling

Several other assumptions are notable:

1) The future without projection condition is the same as existing conditions. In other words, socio economic characteristics in the TWT Study are assumed not to change over the period of analysis. For example, population remains constant as do monetary measures other than monetary inflation.
2) No buildings were added or removed from the floodplain during the period of analysis.
3) Structure value, content value and type of use remains constant.
4) Each building's condition remains constant over the period of analysis. Historically, some homeowners in the floodplain have remodeled and renovated units over time, and any deterioration of condition to some buildings is assumed to be offset by renovation of other buildings, such that the overall condition and structure valuation remains constant.
5) In consultation with team engineers, geologist and hydrologists, all hydrologic and geotechnical inputs are assumed to remain constant over the period of analysis.

2 RESULTS

Section 4.0 presents two types or formulations of model outputs: 1) single event damages, and 2) expected annual damage (EAD), and there are critical analytical differences between the two. Single event damages assume each flood as defined by it frequency or annual exceedance probability occurs regardless of the statistical probability of the event occurring in any given year. Damages are not adjusted to reflect the probability that could occur. Damages are tabulated for the 2 year (0.50), 10 year (0.10), 50 year (0.02) events and so on. In addition, single event damages do not factor in the effects of alternative plans or any existing measures in place that mitigate flooding. Therefore, the only thing that varies is the stage flow frequency relationship and corresponding surface water profiles associated with each event (i.e., the depth and extent of flooding in a given floodplain).

In contrast, EAD factors in the statistical probability that *any* of the events happen in a given year, and EAD considers the effect of existing flood risk management measures and any proposed flood management measures in the TWT Study. In this case of this TWT Study, EAD also considers the presence and probability that levees A or B would fail during a given flood event. EAD values are the proper figures to use when comparing alternative plans during NED evaluation, and since they factor in frequencies or probabilities (in this case joint probabilities) they are much smaller than single event damages.

2.1 Single Event Damages

Table C-13 through Table C-15 summarize FDA model outputs for single event damages by AEP and interval frequency for both damages reaches and See Table of As noted earlier, the highest damages occur in the lowest frequency events along the main-stem of the river, and Levee Area B suffers more damage than Levee Area A. Damages for both See Table of Contents from $6.4 million at the 2-year event to $13.4 million at the 100-year event. See Table of are only expected to occur in the 500-year event and are nearly $311.7 million. See Table of suffer the greatest single event damages - $208.7 million during the 200-year event and $311.7 during the 500-year event.

Table C-13: Number of Structures and Damages for Single Flood Events Damages in Levee Area A

See	AEP	0.5	0.2	0.1	0.05	0.02	0.014	0.012	0.01
	Interval	2-year	5-year	10-year	20-year	50-year	70-year	85-year	100-year
Structures	-	1	1	1	1	9	10	10	14
Damages	-	$23	$39	$55	$71	$176,464	$179,052	$181,646	$230,205
See	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	0	85	316
Damages	-	$0	$0	$0	$0	$0	$0	$13,445,891	$168,268,900
	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
See	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	0	17	525
Damages	-	$0	$0	$0	$0	$0	$0	$1,143,146	$168,313,711
Damages includes flooded automobiles parked adjacent to structures									

Table C-14: Number of Structures and Damages for Single Flood Events Damages in Levee Area B

See	AEP	0.5	0.2	0.1	0.05	0.02	0.014	0.012	0.01
	Interval	2-year	5-year	10-year	20-year	50-year	70-year	85-year	100-year
Structures	-	676	676	676	676	734	769	779	789
Damages	-	$6,438,300	$6,539,899	$6,642,039	$6,743,454	$9,754,791	$11,684,884	$12,431,923	$13,363,614
See	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	0	0	2,157
Damages	-	$0	$0	$0	$0	$0	$0	$0	$311,718,739
	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
See	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	122	1,902	2,157
Damages	-	$0	$0	$0	$0	$0	$1,075,717	$208,675,909	$311,719,756
Damages includes flooded automobiles parked adjacent to structures									

Table C-15: Number of Structures and Damages for Single Flood Events Damages in Levee Areas A and B

[redacted]	AEP	0.5	0.2	0.1	0.05	0.02	0.014	0.012	0.01
	Interval	2-year	5-year	10-year	20-year	50-year	70-year	85-year	100-year
Structures	-	677	677	677	677	743	779	789	803
Damages	-	$6,438,322	$6,539,938	$6,642,094	$6,743,525	$9,931,256	$11,863,936	$12,613,569	$13,593,819
[redacted]	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	85	316	2,157
Damages	-	$0	$0	$0	$0	$0	$0	$13,445,891	$479,987,640
	AEP	0.5	0.2	0.1	0.05	0.02	0.01	0.002	0.005
[redacted]	Interval	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year
Structures	-	0	0	0	0	0	122	1,919	2,682
Damages	-	$0	$0	$0	$0	$0	$1,075,717	$209,819,055	$480,033,466
**Damages includes flooded automobiles parked adjacent to structures*									

2.2 Expected Annual Damages

Table C-16 through Table C-18 summarize model outputs for the without project condition, and the two final alternative plans: Alternative 1 and the Alternative 2 expressed as EAD as opposed to single event damages. EADs follows the same general pattern as single event figures where [redacted] and damages are significantly higher in Levee Area B. However, as noted when discussing nuances associated with levee characteristics (i.e., relationships between overtopping and breaching) in Section 3.3.2, damages associated with the 500-year event [redacted] the 100-year event [redacted] are not included in the calculations.

Table C-16: Number of Structures and Expected Annual Damages for Final Array of Plans for Levee Area A

				Exceedance probabilities for damages reduced		
See Table	Without-project	With-project	Damages reduced	75%	50%	25%
No-Action	$181,198	$181,198	$0	$0	$0	$0
Alternative 1	$181,198	$181,064	$134	$7	$14	$99
Alternative 2	$181,198	$181,059	$139	$7	$13	$98
See						
No-Action	$735,897	$735,897	$0	$0	$0	$0
Alternative 1	$735,897	$651,320	$84,577	$40,844	$92,089	$98,458
Alternative 2	$735,897	$447,548	$288,349	$97,710	$262,795	$472,822
See						
No-Action	$639,395	$639,395	$0	$0	$0	$0
Alternative 1	$639,395	$637,421	$1,973	$786	$1,432	$2,359
Alternative 2	$639,395	$637,421	$1,974	$786	$1,432	$2,359
Total						
No-Action	$1,556,490	$1,556,490	$0	$0	$0	$0
Alternative 1	$1,556,490	$1,469,805	$86,684	$41,637	$93,534	$100,916
Alternative 2	$1,556,490	$1,266,027	$290,462	$98,503	$264,240	$475,280
*Damages includes flooded automobiles parked adjacent to structures						

Table C-17: Number of Structures and Expected Annual Damages for Final Array of Plans for Levee Area B

				Exceedance probabilities for damages reduced		
See Table of	Without-project	With-project	Damages reduced	75%	50%	25%
No-Action	$758,539	$758,539	$0	$0	$0	$0
Alternative 1	$758,539	$756,713	$1,826	$123	$937	$2,446
Alternative 2	$758,539	$756,691	$1,848	$124	$937	$2,464
See						
No-Action	$1,376,599	$1,376,599	$0	$0	$0	$0
Alternative 1	$1,376,599	$1,232,440	$144,158	$61,692	$165,557	$167,579
Alternative 2	$1,376,599	$832,291	$544,308	$175,143	$500,463	$868,310
See						
No-Action	$1,992,896	$1,992,896	$0	$0	$0	$0
Alternative 1	$1,992,896	$1,739,103	$253,793	$145,524	$210,778	$392,951
Alternative 2	$1,992,896	$1,738,803	$254,093	$145,542	$212,122	$392,661
Total						
No-Action	$4,128,034	$4,128,034	$0	$0	$0	$0
Alternative 1	$4,128,034	$3,728,256	$399,778	$207,340	$377,272	$562,976
Alternative 2	$4,128,034	$3,327,786	$800,249	$320,809	$713,523	$1,263,435
*Damages includes flooded automobiles parked adjacent to structures						

Table C-18: Number of Structures and Expected Annual Damages for and Final Array of Plans for Levee Areas A and B

				Exceedance probabilities for damages reduced		
LCL and Plans	Without-project	With-project	Damages reduced	75%	50%	25%
No-Action	$939,738	$939,738	$0	$0	$0	$0
Alternative 1	$939,738	$937,777	$1,961	$130	$951	$2,545
Alternative 2	$939,738	$937,750	$1,987	$130	$951	$2,563
See						
No-Action	$2,112,496	$2,112,496	$0	$0	$0	$0
Alternative 1	$2,112,496	$1,883,760	$228,735	$102,537	$257,646	$266,037
Alternative 2	$2,112,496	$1,279,839	$832,657	$272,853	$763,258	$1,341,133
See						
No-Action	$2,632,291	$2,632,291	$0	$0	$0	$0
Alternative 1	$2,632,291	$2,376,524	$255,767	$146,310	$212,210	$395,310
Alternative 2	$2,632,291	$2,376,224	$256,067	$146,328	$213,554	$395,020
Total						
No-Action	$5,684,524	$5,684,524	$0	$0	$0	$0
Alternative 1	$5,684,524	$5,198,062	$486,462	$248,977	$470,806	$663,892
Alternative 2	$5,684,524	$4,593,813	$1,090,711	$419,311	$977,763	$1,738,715

**Damages includes flooded automobiles parked adjacent to structures*

3 NED PLAN COMPARISON

Table C-19 and Table C-20 present the proverbial bottom line and compare annualized costs and benefits for the two final alternative: Alternative 1 (filtered berm with toe drains) is the tentatively selected plan, and Alternative 2 (full cutoff wall) is the locally preferred plan. Costs consist of construction costs (project first costs), mitigation, real estate, and interest during construction. Annual benefits are expected annual damages for Levee Areas A and B summed by LCL. Costs and benefits for each alternative are based on 2019 price levels, and if applicable include construction, maintenance and repair costs, and interest costs during construction. The period of analysis is 50 years, and cost and benefits were annualized to annual equivalent values using the FY 2019 Federal Discount Rate of 2.875 percent. As shown, both alternatives have BCRs less than one, and do not generate positive net economic benefits.

Table C-19: Cost and Benefits for Alternative 1

Period of Analysis (Years)	50
Construction Period (Years)	2.0
Interest Rate (Percent)	2.875%
Construction Costs	$148,808,000
Mitigation Costs	$0
Real Estate Costs	$3,400,000
Interest During Construction	$8,679,459
Total Investment Cost	$160,887,459
Annual Costs:	
Interest	$4,625,500
Amortization	$1,479,900
Operation & Maintenance	$402,219
Total Annual Costs	$6,507,619
Annual Benefits:	
Damages Avoided	$486,462
Benefit-to-Cost Ratio	0.07
Net Benefits	($6,021,156)

Table C-20: Cost and Benefits for Alternative 2

Period of Analysis (Years)	50
Construction Period (Years)	2.5
Interest Rate (Percent)	2.875%
Construction Costs	$389,786,000
Mitigation Costs	$0
Real Estate Costs	$10,920,000
Interest During Construction	$28,622,845
Total Investment Cost	$429,328,845
Annual Costs:	
Interest	$12,343,200
Amortization	$3,949,000
Operation & Maintenance	$974,465
Total Annual Costs	$17,266,665
Annual Benefits:	
Damages Avoided	$1,090,711
Benefit-to-Cost Ratio	0.06
Net Benefits	($16,175,954)
*Includes construction costs (project first costs), interest during construction, and operation, maintenance, repair, rehabilitation, and replacement costs (OMRR&R). Assumes FY2019 price levels and interest rate of 2.875 percent.	

ADDENDUM 1

LIFE LOSS CONSEQUENCE MODELING

4 CONSEQUENCE MODELING APPROACH

The life loss methodology in HEC-LifeSim 1.0.1 (LifeSim) is based on the LIFESim methodology developed by Utah State University's Institute for Dam Safety Risk Management (Aboelata and Bowles 2005). A version of LIFESim has been integrated into HEC-LifeSim 1.0.1 and performs the steps listed below to estimate life loss for a selected hazard event-exposure scenario, given structure inventory (initial population distributed to each structure) and given road network (used when simulating evacuation estimate life safety risk on roads). LifeSim utilizes Monte Carlo analysis and computes many iterations in order to obtain a range of possible life loss outcomes. LifeSim software was used as the consequence modeling tool for the SQRA. LifeSim was used to estimate life loss in structures and while evacuating, structure and content damages. A road network was developed to model evacuation on the road network.

The LifeSim modeling effort is documented by describing the inputs to the model such as the structure inventory and emergency planning zones (impact areas), the parameters set for the model such as warning times, warning diffusion curves, and mobilization curves, the uncertainty results, and the sensitivity analysis for the mobilization and the hazard identified relative time parameters. Table C-9 through Table C-12 display inundation extents for depths for different scenarios.

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

Multiple levee breach/failure scenarios were simulated. The locations of these breaches were agreed upon by the entire risk analysis team and designated as “levee control” locations (LCLs). Locations that were chosen corresponded to historical breach and/or overtopping locations, large concentrations of infrastructure, large population concentrations, large levee section heights, and/or incipient overtopping locations, amongst others. Locations were chosen to be representative of various portions of the system so the results could be directly applied and or interpolated to the desired location. The risk team determined that only the top of levee and two-foot overtopping scenarios would breach the levee.

Only one failure/breach was simulated at a time; however, if the input hydrograph required to reach a desired WSEL resulted in overtopping anywhere within the TWT system, that overtopping was allowed to proceed. The assumption of a single failure during a single simulation should be investigated more thoroughly during future studies through the use of levee fragility relationships and Monte Carlo simulations.

Due to the non-linear relationship between depth and incremental risk, the events for each control location. For instance, the 1/230 ACE Arkansas River event results in a WSEL of 655.5 feet NAVD88 [redacted] corresponds to an approximate 75% loading (i.e. 75 percent of the levee height is loaded). To achieve a loading equivalent to the top of the levee at this location (659.5 feet NAVD88) requires an approximate 1/500 ACE Arkansas River event, which would significantly overtop other portions of the TWT system and likely result in considerable consequences. As such, the incremental, system-wide risk associated with a breach/failure at [redacted] a 1/500 ACE Arkansas River event would be much smaller than a breach/failure during the 1/230 ACE Arkansas River event.

At each control location within the Levee A and B segment that was loaded by an Arkansas River event, three loadings were simulated: 50 percent loading, 1/230 ACE, and 1/260 ACE. The event needed to achieve a 50 percent loading varied for each control location. The 1/230 ACE event corresponded to a top of levee loading at Pump Station #5 [redacted] Similarly, the 1/260 ACE event corresponded to a 2 foot overtopping loading [redacted] reasoning behind these levee loadings relates back to the stage-frequency curves which were previously shown and explained.

A similar approach was used to analyze [redacted] Levee A and B Tiebacks associated with a tributary stream event. However, the simulated events corresponded to a 50 percent levee loading, 1/85 ACE event, and 1/1000 ACE event. The 1/85 ACE and 1/1000 ACE events corresponded to a top of levee loading and a 2 foot overtopping loading [redacted] Each ordinate of the 1/1000 ACE event tributary event hydrographs (as computed within the HEC-HMS model) were adjusted up or down to achieve the desired WSEL/levee loading. The ACE associated with the resulting peak flow rate was then compared with the peak flow-frequency relationship.

Finally, at each control location within the Levee C segment that was loaded by an Arkansas River event, three loadings were simulated: 50 percent loading, 1/240 ACE, and 1/270 ACE. The 1/240 ACE event corresponded to a top of levee loading See Table of Contents NOTE 1 - [redacted] Similarly, the 1/270 ACE event corresponded to a 2 foot overtopping See Table of [redacted]

Figure C-13 displays Levee A and B See Table of Contents NOTE 1 for different ACE events, Figure C-14 displays the Tieback Levee B ACE , and Figure C-15 displays the See Table of [redacted] for different ACE events. Additional information on the H&H modeling can be found in the H&H appendix.

Control Location	Approximate Levee Elev (ft NAVD88)		50% Levee Loading		1/230 ACE WSEL*	1/260 ACE WSEL*
	Toe	Crest	Elev (ft NAVD88)	ACE		
See Table of Contents NOTE 1 - Pursuant	642.5	659.5	650.5	1/120	655.5	657
	637.5	650.6	643.5	1/145	647.6	649.4
	636	651.5	643.5	1/145	648	649.85
	632	648	640	1/120	648	650
	645	656.87	651	1/240	650.35	652
	644	657	650.5	1/220	650.75	652.35
	638	653	645.5	1/155	648.8	650.6

*See Table of Contents NOTE 1 - Pursuant to

Figure C-13: Levee A and B Control Location Information

Control Location	Approximate Levee Elev (ft NAVD88)		50% Levee Loading		1/85 ACE WSEL	1/1000 ACE WSEL
	Toe	Crest	Elev (ft NAVD88)	ACE		
See	651.5	657.5	654.25	1/17.5	657.5	659.5

Figure C-14: Levee A and B Control Location Information

Control Location	Approximate Levee Elev (ft NAVD88)		50% Levee Loading		1/230 ACE WSEL*	1/260 ACE WSEL*
	Toe	Crest	Elev (ft NAVD88)	ACE		
See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074	639	645	642	1/500	640.4	640.9
	646	654	649.75	1/235	650	651.63
	640	647.25	643.625	1/150	647.25	649.25
	637	654.8	645.9	1/160	650.25	651.82
	632.7	641.7	637.2	1/205	638.25	638.7
	632.5	639.4	635.95	1/500	633.15	633.6
	640	648.5	644	1/165	647.6	649.5
	640	648.5	644	1/165	647.6	649.5
	645	652.75	648.88	1/235	649.4	651.25
	647	650	648.50	1/240	648.5	650.3
	623.5	638	630.75	1/250	630.65	631.2

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

Figure C-15: Levee A and B Control Location Information

4.1 Structure Inventory

The structure inventory was developed using 2018 Tulsa County Assessor's Data obtained from the Assessor's Office which included updated replacement minus depreciation structure values for the structures located in the TWT Levee System. The County Assessor's data was provided in parcel outline shapefiles and the centroid was created for each parcel. Structure location checks were performed using aerial imagery. HAZUS-based population data in the form of a point shapefile was used to spatially join population data to the County Assessor's data. Structure values are reported at October 2018 price levels while the population values are reported at 2017 values. The team compared historical population values and aerial imagery and look at future population projections and determined that the leveed protected area would not see a significant increase in population over the period of analysis.

4.2 Emergency Planning Zones

Three Emergency Planning Zones (EPZ) were defined for the TWT Study. The Arkansas River Channel and Levee A, B, and C were created as EPZ. The LifeSim parameter Hazard Identified Relative Time is set according to the EPZ polygons. EPZ are based on the TWT Study area boundary and include polygons which delineate the in-river, non-fail, and levee protected areas. This is accomplished by combining the TWT Study area with the river and non-fail inundation boundary. The non-fail inundation boundary and the river boundaries receive at least 72 hours of warning prior to the start of the simulation.

For TWT, only the three overtopping scenarios had double warning. During a double warning simulation, structures within the non-fail inundation and pool area receive the non-fail hazard identification time and the structures that become inundated only after a failure occurs will receive the fail hazard identification time. Separating these areas based on when they experience flow serves to capture the double warning effect, which recognizes that areas flooded prior to a breach or overtopping would be warned and evacuated beforehand.

4.3 Emergency Preparedness

The chief of the Tulsa County Emergency Management Agency (EMA) was interviewed using the Mileti-Sorensen methodology. Tulsa County EMA uses the National Incident Management System (NIMS) to respond, manage, and coordinate during expected flood events. The USACE releases water from Keystone Lake into the Arkansas River. Coordination occurs between the USACE, NWS, and Tulsa County EMA. If flooding is eminent, the NWS will issue a flood warning for the Arkansas River. Tulsa County EMA in coordination with the City of Tulsa Engineering Service will activate the Sirens near the river to alert the public. During a flood event, Tulsa County EMA coordinates with Tulsa County Sheriff's office, Tulsa Fire, Tulsa Police, USACE, NWS, and other state agencies.

Below are the responses to different flow rates on the Arkansas River:

- 50K Response Community preplanning looking at what if scenarios
- 100K Resources activated, Emergency Declared and Incident Command Service setup
- 150K Levee is walked looking for signs of distress
- 200K When Forecasted, residents behind the levee are warned and told to leave
- 334K Top of Levee A and B
- 347K Top of Levee C

A consequence elicitation was held with Tulsa County EMA. The TWT Study area would be impacted by dam breach, controlled dam releases, levee breaching and flash flooding scenarios. The County has the inundation areas identified for the full range of events ranging from levee breach/non-breach scenarios to FEMA modeling. The county has a general emergency plan along with a hazard-specific warning plan for flooding scenario including levee breaches. Their process of issuing the warning is written down with the positions written down along with backups. The facility is staffed 24 hours a day seven days a week.

Warning messages would initially be delivered to PAR by multi-faceted audio sirens. The sirens have specific tones for types of hazards and can also be activated in individual locations to notify specific areas of an impending hazard. The emergency sirens are used in concert with the Emergency Alert System (EAS), NOAA Weather Radios, social/local media outlets, aircraft (police helicopter) and door-to-door evacuation route alerting if necessary. Subsequent warnings will be issued through local media so that people can monitor a developing hazard. Emergency responders will initially be responsible for full-time day and night monitoring, but then Levee District 12 would disperse people to monitor the levees during a high hazard event. City and county officials along with the USACE representatives meet with local residents yearly to inform and discuss the potential impacts.

The sirens would alert people that there was an emergency situation, but the nature of the situation would come from media outlets. The voice broadcasting capability of the sirens would allow for some information to be disseminated if need be. People without access to local media would be warned through social service agencies like John 316, the Salvation Army and Tulsa County Social Services. No systems are currently in place for those who are hearing impaired or have vision impairment.

4.4 Life Loss Parameters

To estimate life loss due to flooding, parameters must be set to estimate how likely it will be that the population at risk will be able to evacuate to safety. In order for an evacuation to occur, multiple actions must take place. First, a potential danger must be identified. Next, information regarding the danger (i.e., a warning) must be communicated to the population at risk. And finally, that population at risk must decide to take a protective action (also referred to as mobilization), which often results in evacuation depending on the nature of the danger. Figure C-16 displays the flood warning and evacuation timeline. There are other parameters within

HEC-LifeSim that are standardized and do not change, such as the structure depth-damage curves based on occupancy types and the fatality zones and their associated fatality rates, which are determined based on structure heights and type.

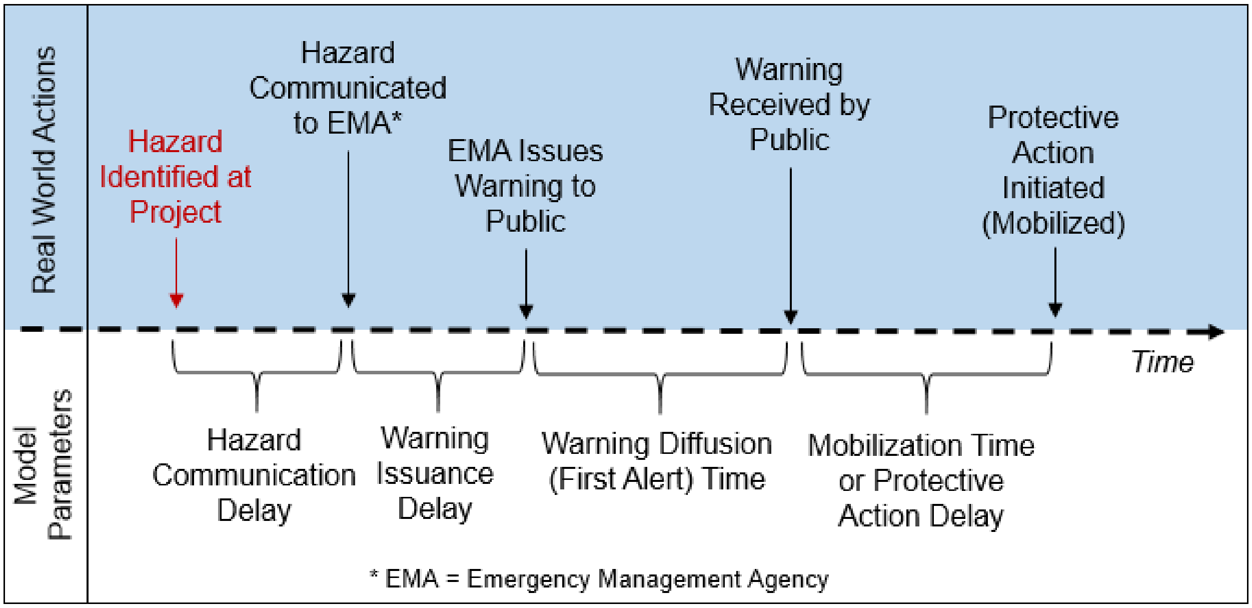

Figure C-16: Flood Warning and Evacuation Timeline

4.4.1 Hazard Identification and Warning Time

In HEC-LifeSim, warning time incorporates several different time steps as defined below.

- Hazard Identified Relative Time: The time at which a dam owner determines a hazard is about to occur or is actively occurring and local emergency officials should be alerted so they can begin the warning and evacuation process.
- Communication Delay: The time it takes for the dam owner to contact local emergency officials to alert them of the hazard
- Warning Issuance Delay: The time it takes the local emergency officials to issue a warning; could include getting approvals or time to craft messages among other factors.
- Imminent Hazard Time: The time at which a hazard actually begins to occur (such as initiation of a breach or overtopping).

The process began with setting the Imminent Hazard Time for each hydraulic event. This was selected based on the failure mode for the scenario and was uploaded to the model as a Hierarchical Data Format file which was provided by the H&H modeler. The imminent hazard time is set at the initiation of the breach.

4.4.2 Hazard Identified Relative Time

Next, a Hazard Identified Relative Time was set for each EPZ polygon that reflects when the warning process for each impact area would begin relative to the Imminent Hazard (breach or overtopping). For this analysis, this time is different depending on whether the area would receive flooding prior to the Imminent Hazard or not. Discussions occurred with Tulsa County and the warning behind the levees would occur when the Arkansas River is forecasted to reach 200K cfs. For TOL failure scenarios on the Arkansas River it was assumed that 24 hours prior to breach initiation (+/- 6 hours) warning would occur. For the tieback levees, little warning would occur and is flashy in nature. For these locations it was assumed two hours prior to breach (+/- 2 hours).

4.4.3 Hazard Communication Delay

Once the hazard is identified the issuance of a warning is not instantaneous; there will be some delays caused by communication lag, gathering additional information, making decisions, and crafting messages. HEC-LifeSim allows the user to input both a Hazard Communication Delay and a Warning Issuance Delay. The hazard communication delay for all scenarios was set as a uniform uncertainty distribution between 0.01 hours and 0.5 hours.

4.4.4 Warning Issuance Delay

Warning Issuance Delay (Figure C-17) is the time it takes from when the emergency managers receive the notification of the imminent hazard to when an evacuation order is issued to the public. The issuance of a warning is not instantaneous, there will be some delays caused by communication lag, gathering additional information, making decisions, and creating messages. Results from the consequence elicitation with Tulsa County EMA were used to develop the warning issuance delay for the TWT Study.

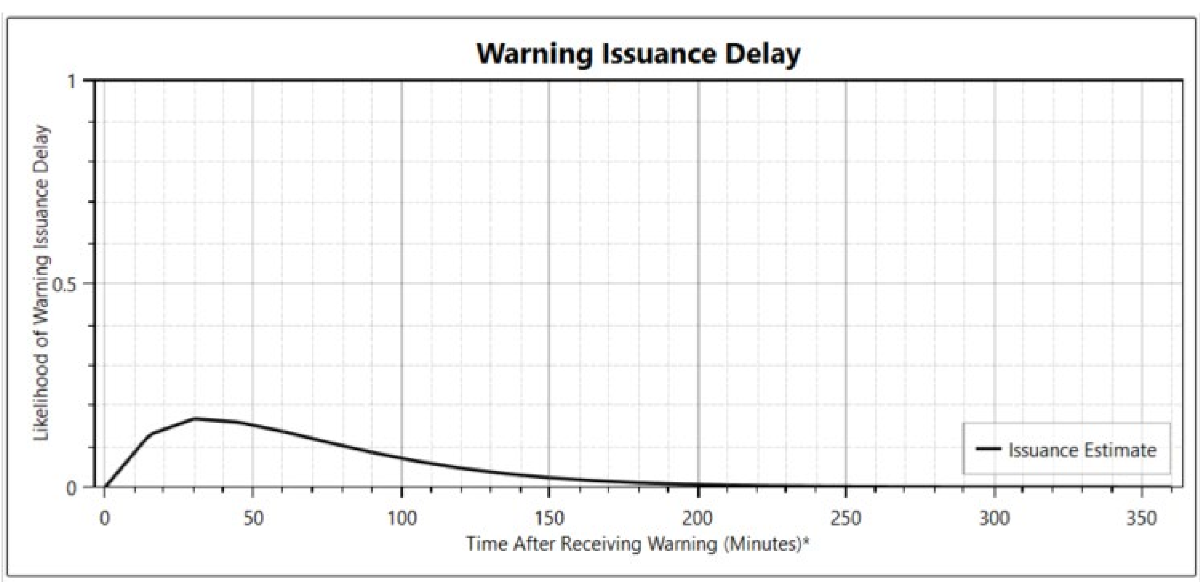

Figure C-17: Warning Issuance Delay

4.4.5 Warning Diffusion

Warning diffusion time is the time period after a first alert or warning is issued and the time that people receive that warning. It is primarily dependent on what type of warning systems and procedures are in place and the ability of the population to receive the warning via those systems. The warning diffusion curve represents the efficiency of a warning after it is issued. Results from the consequence elicitation with Tulsa County EMA were used to develop the warning diffusion rates for the TWT Study. The day warning diffusion curve is shown in Figure C-18 while the night warning diffusion curve is shown in Figure C-19.

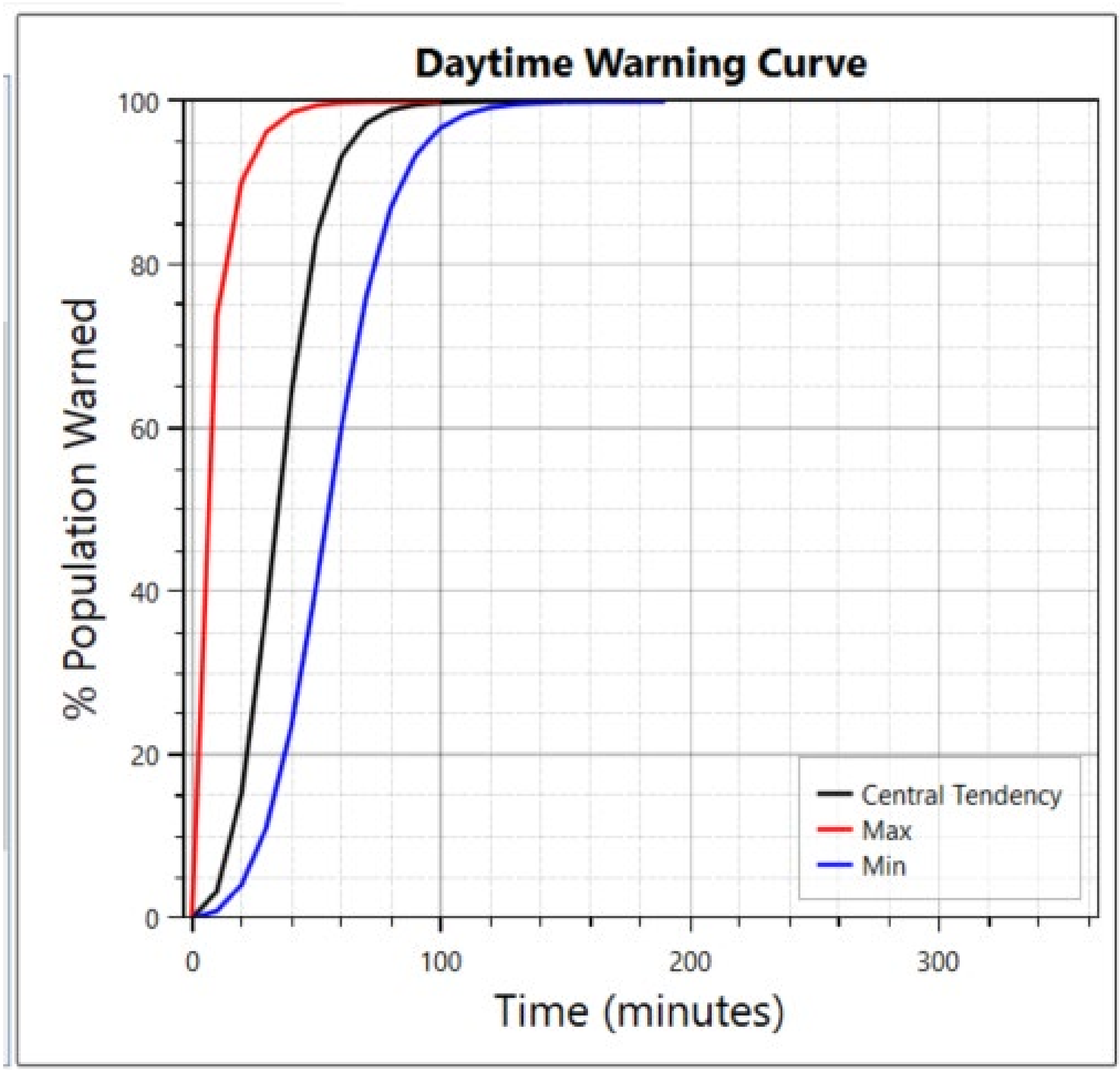

Figure C-18: Daytime Warning Diffusion Curve

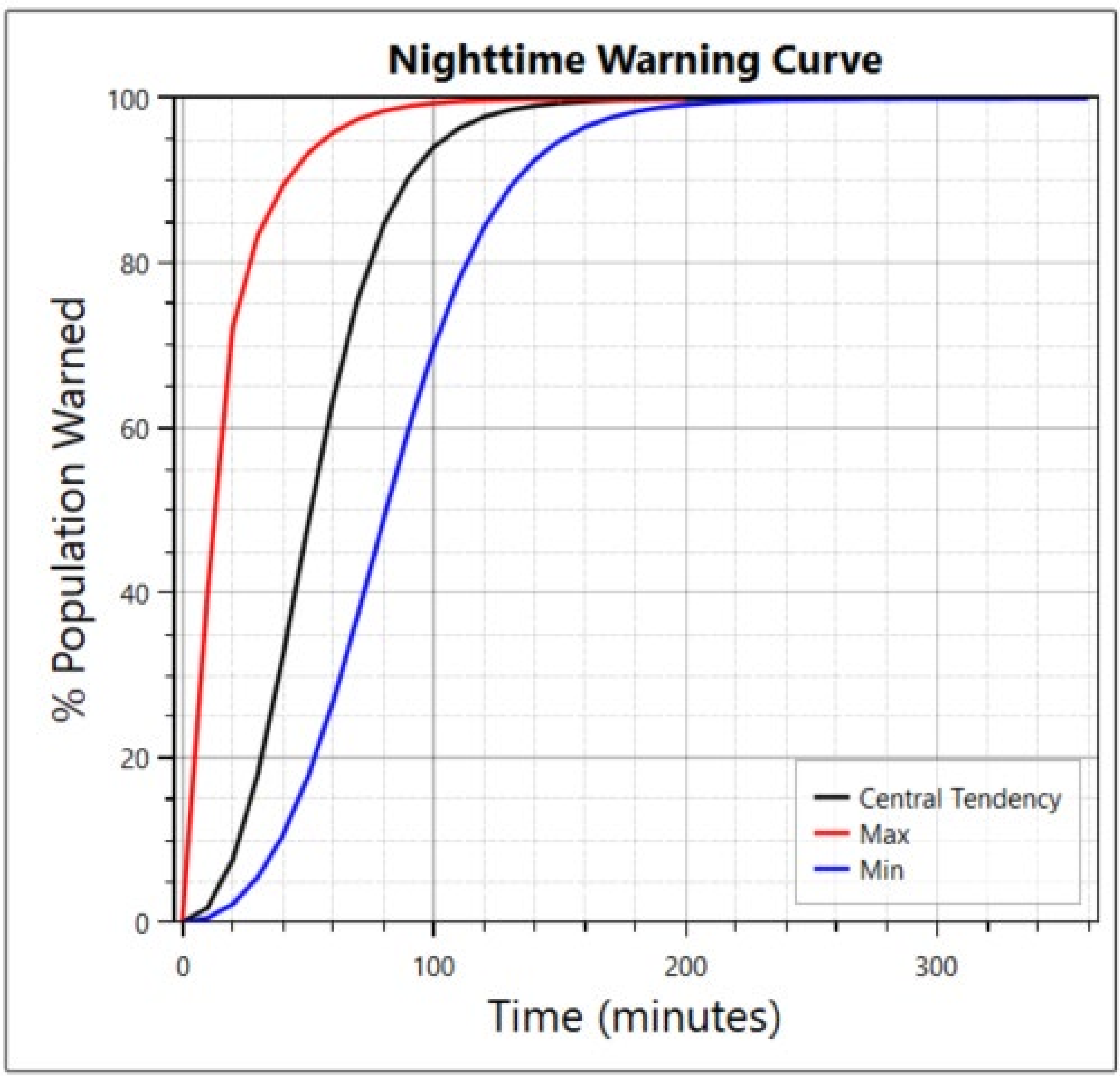

Figure C-19: Nighttime Warning Diffusion Curve

4.4.6 Protective Action Initiation

After receiving a warning, people engage in various activities prior to taking a recommended protective action. This time period is represented by the mobilization curve. These activities can include gathering more information and deliberating about making the decision to take an action, gathering family members and belongings together, and preparing to take action once a decision has been reached. For this reason, the mobilization is typically seen as an “S” curve because most people will have at least some delay between when they receive a warning and when they take action. The curve flattens out at the top, representing those who may not be able to take an action due to various reasons, such as having no transportation, physical limitations, a misunderstanding of the warning and severity, or simply refusing to take action.

The content and delivery of warning messages can have a significant impact on the effectiveness of mobilization, which makes the prediction of mobilization due to hypothetical events highly uncertain. To account for this, a relatively wide band of uncertainty is included around the estimated mobilization curve.

The mobilization curve contains two important pieces of information when it comes to determining the number of people that have evacuated their structures when the flood arrives: (1) the percentage of warned people that mobilize over time; and (2) the maximum mobilization percentage. The maximum mobilization percentage defines the highest percentage of people that are thought to mobilize given the characteristics of a warning. One hundred percent minus the maximum mobilization percentage yields the percentage of people that are either unable or choose not to mobilize after receiving the warning. The consequence elicitation with Tulsa County EM was used to estimate the PAI curve (Figure C-20). A triangular distribution was applied to the PAI curve. A most likely value of 96.4 percent of the PAR was estimated they would take the recommended action after 72 hours. The lower bound was estimated at 91.6 percent with the upper bound at 98 percent.

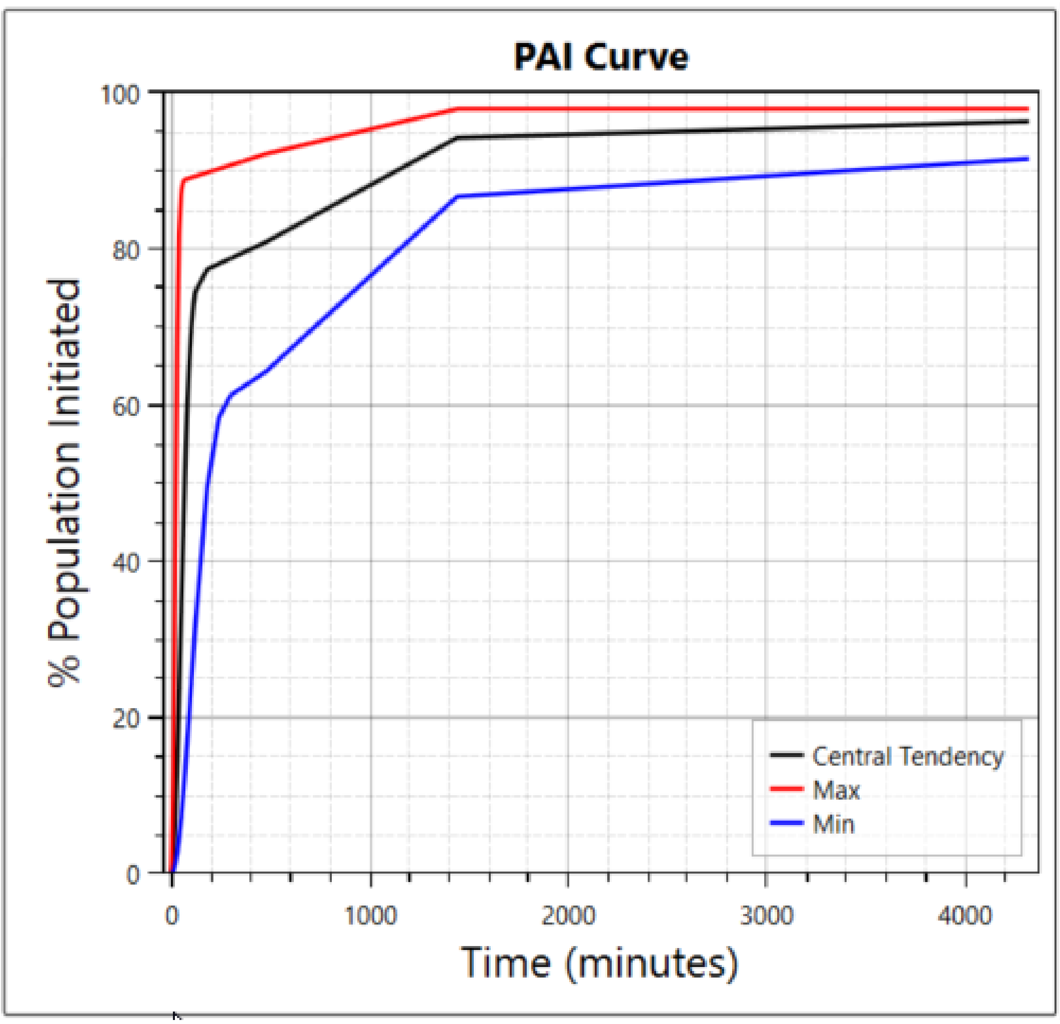

Figure C-20: Protection Action Initiation for Tulsa County

4.4.7 Evacuation Destinations and Streets

The road network was developed using data from OpenStreetMaps. The data contains information about road type, bridges and directional attributes (one way). The road network was modified in order to properly account for all overpasses and bridges in order for each road segment to have the appropriate vertical offset relative to the ground elevation. Destination points were created which represent the possible evacuation locations during flooding events. These points were set to main intersections outside the inundation area with input from Tulsa County EM. Top of Levee failure scenarios on the Arkansas River had very little (if any) life loss while evacuation. Figure C-21 display the road network used to simulate evacuation. The yellow starts represent the destination points.

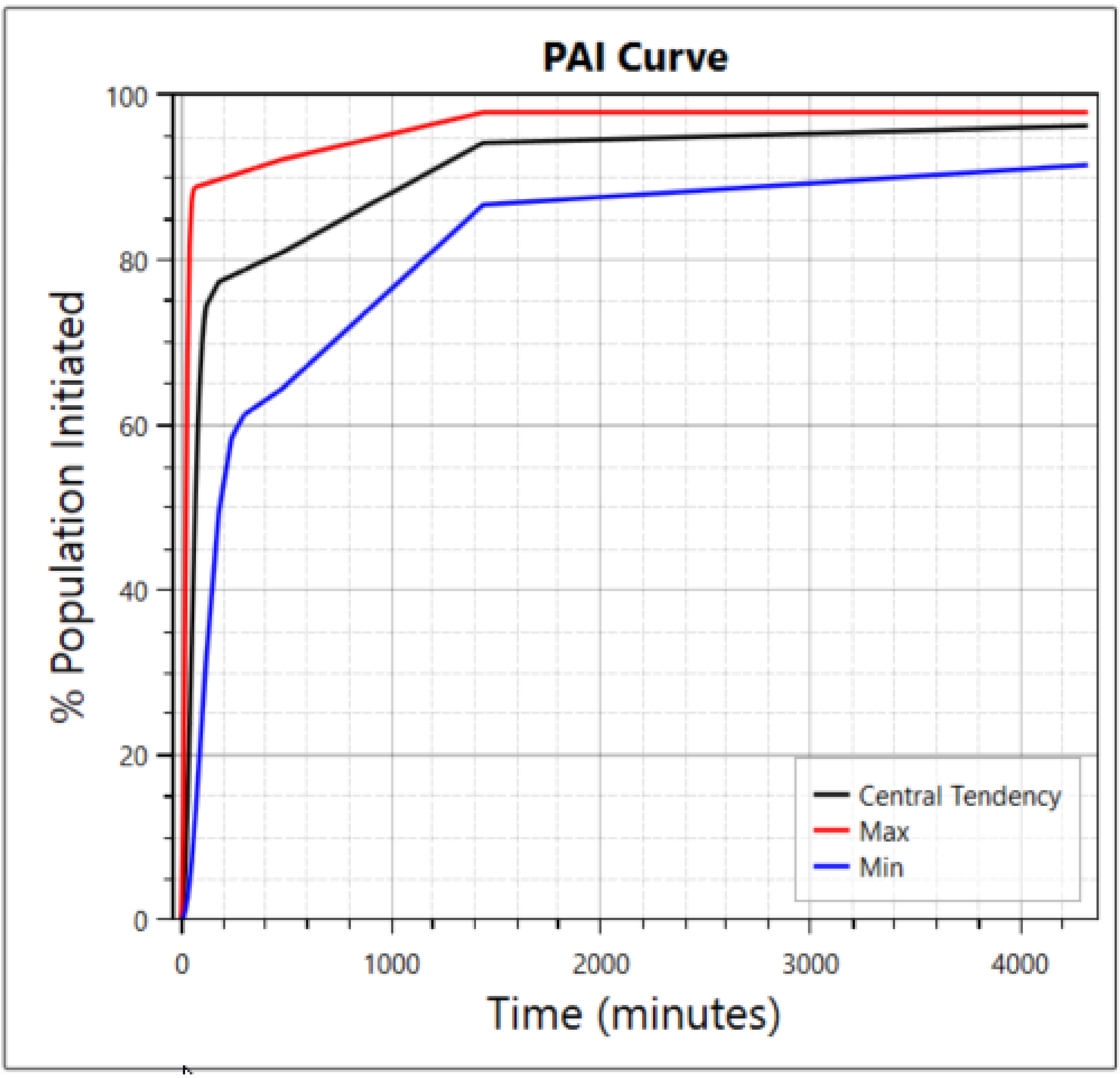

Figure C-21: Levee B Road Network

4.5 HEC-LifeSim Results

For each scenario analyzed, a Monte Carlo uncertainty analysis was preformed, with the uncertain variable inputs (warning issuance delay, warning diffusion, protective action initiation, warning time, and hazard communication delay) sampled from the distributions. For each scenario 1,000 iterations were run. Table C-1 displays the population at risk, impacted structures, and property damages for TOL (Top of Levee) fail scenarios while Table C-22 represents the two foot overtopping scenarios. TOL represents an approximate 1/230 year event along the Arkansas River and the 2-foot Overtopping scenario represents an approximate 1/270 year event along the Arkansas River. Estimated life loss for the TOL failure scenarios are shown in Table C-23 while the two foot overtopping scenarios are shown in Table C-24.

Development in Levee A is mixed between commercial/industrial structures with residential structures intermixed. Development in Levee B is primarily residential with commercial development scattered. Development in levee C is primarily commercial with a refinery. Residential development is isolated in the middle part of Levee C by LCL 8.

For TOL failure scenarios evacuation distances can be up to one-mile in Levee A and B. Levee C evacuation distances are generally less than a quarter mile with isolated areas up to a third of a mile. Max depth of flooding in structures during a TOL failure at LCL 4 is approximately 15.9 feet. Average depths are approximately 6.6 feet. Max depth of flooding in structures during a 2-foot OT scenario at LCL 4 is approximately 17.8 feet with averages depths of approximately 7.8 feet.

See Table of [redacted]

Table C-21: Human and Property Impacts TOL Fail Scenarios

Hydrologic Loading Condition	Structures Inundated	PAR		Property Damage
		Day	Night	
See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074 [redacted]	844	1,529	1,802	$10,755,045
[redacted]	41	358	347	$2,664,519
[redacted]	1,980	3,898	4,847	$91,479,820
[redacted]	2,135	4,210	5,209	$104,674,331
[redacted]	1,681	3,350	4,186	$68,087,970
[redacted]	18	437	78	$11,672,459
[redacted]	255	2,433	2,441	$40,686,354
[redacted]	925	2,102	2,423	$16,469,346
[redacted]	1,573	4,197	3,942	$51,398,484
[redacted]	2,159	4,246	5,263	$107,329,080
[redacted]	33	723	131	$25,012,536
[redacted]	259	2,168	2,311	$24,501,910
[redacted]	48	368	361	$3,221,696
[redacted]	311	3,649	2,672	$70,574,820
[redacted]	75	543	224	$2,920,987
[redacted]	48	368	361	$3,409,986

Table C-22: Two Foot Overtopping Scenarios

Hydrologic Loading Condition	Structures Inundated	PAR		Property Damage
		Day	Night	
Fail				
See [redacted]	766	1,530	1,920	$8,064,872
See [redacted]	2,258	4,976	4,974	$121,667,600
See [redacted]	345	2,859	2,871	$69,016,590
Non-fail				
See [redacted]	264	413	556	$524,455
See [redacted]	1,446	2,853	3,601	$47,342,020
See [redacted]	117	1,165	1,725	$10,499,833
Incremental				
See [redacted]	502	1,117	1,364	$7,540,417
See [redacted]	812	2,123	1,373	$74,325,580
See [redacted]	228	1,694	1,146	$58,516,757

See Table of Contents NOTE 1 - Pursuant to EC-1105-2-413 and EC 1110-2-6074

[redacted]

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