King County Levee Breach Analysis, Mapping, and Risk Assessment (LBAMRA)

Lower Raging River - Economic Evaluation of Flood Risk with Equity and Social Justice Assessment Technical Memorandum

September 2023

Photo source: Tetra Tech, Inc (March 23, 2021)

KING COUNTY FLOOD CONTROL DISTRICT

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ABBREVIATIONS AND ACRONYMS

AEP – Annual Exceedance Probability

AIAN – American Indian and Alaskan Native

BLS – United States Bureau of Labor Statistics

CDC – Centers for Disease Control and Prevention

CFS – Cubic Feet per Second

EAD – Expected Annual Damages

ESJ – Equity and Social Justice

FDA – HEC's Flood Damage Reduction Analysis software

FEMA – Federal Emergency Management Agency

FT – Feet/Foot

LBAMRA – King County Leve Breach Analysis, Mapping, and Risk Assessment

MIN – Minutes

NHC – Northwest Hydraulic Consultants, Inc.

NBI – National Bridge Inventory

RED – Regional Economic Development

SF – Square Feet

SFR – Single Family Residential

USACE – United States Army Corps of Engineers

WCC – Washington Conservation Corps

WSDOH – Washington State Department of Health

WSDOT – Washington State Department of Transportation

YR – Year

1. INTRODUCTION

1.1. INTRODUCTION

This technical memorandum (memo) is the deliverable associated with Subtask 8.6, Develop a Technical Memorandum that Summarizes the Methodology and Results of the Economic Evaluation of Flood Risk, in the scope of work for King County Levee Breach Analysis, Mapping, and Risk Assessment (LBAMRA), Contract Number E00670E20. The objective of this memo is to document the results of the economic evaluation completed in Subtask 8.4, Conduct Economic Evaluation for the Lower Raging River levee system.

1.2. PURPOSE

The purpose of this memo is to present the evaluation of impacts and consequences of potential flooding along the containment levee systems on the Raging River based on findings from geotechnical and hydraulic studies. The evaluation of impacts and consequences considers how the levee system is expected to perform under a variety of flood conditions. This flood risk analysis considers and quantifies potential damages to homes, businesses, infrastructure and other categories and considers the economic and other impacts to the community such as business closures and transportation impacts associated with flooding. The evaluation also includes an analysis of Equity and Social Justice (ESJ), considerations including impacts to vulnerable populations and public health and safety.

1.3. PREVIOUS MEMORANDUMS AND DOCUMENTS

The following is a list of primary memorandums and documents developed for use in the impacts and consequences as part of the flood risk analysis with a brief description of the document and how the document is incorporated into this current analysis:

- King County Levee Breach Analysis, Mapping and Risk Assessment: Economic Inventory Status Memo, Tetra Tech, 1 February 2022

    This document presents the potential sources available for use in supplementing the economic analysis' datasets, information sources and references. This document was cited extensively to develop the data required for assessing damages in each of the damage categories discussed in this memo.

- King County Levee Breach Analysis, Mapping and Risk Assessment: Economic Approach Memo, Tetra Tech, 20 June 2022

    This document presents the detailed methodology for assessing the economic impacts of flooding presented in this memo. This document was used as the basis for estimation of all damages presented here within.

- King County Levee Breach Analysis, Mapping, and Risk Assessment Project: Draft Raging River Flood Hazard Analysis, Northwest Hydraulic Consultants Inc. (NHC), 30 September 2022

    This document presents the results of the hydraulic flood hazard analyses performed for use in this project. All flood depth information used in the economic analysis was taken from this report and the resulting depth grids provided by NHC. This report also documented key economic model data inputs such as breach locations, levee heights, and climate change data.

- Stability Analysis Report, Levee Breach Analysis Mapping and Risk Assessment, Lower Raging River, King County, Washington, Shannon & Wilson, 30 September 2022

This document presents the results of the geotechnical stability analyses and associated fragility curves produced for the Lower Raging River. The levee failure information from this report has been used to incorporate levee failure probabilities by geotechnical failure mechanisms into the economic analysis.

1.4. Organization of this Memorandum

The following is a brief discussion of each of the sections contained in this memo.

- Section 2 presents a brief overview of the economic approach and framework used to estimate the damages presented later in this memo.
- Section 3 presents an overview of the study area, including presentation of existing economic inventory information (i.e., structure inventory information) and socio-economic data.
- Section 4 presents a summary of the hydraulic and geotechnical information used in the economic analysis.
- Section 5 presents key assumptions that were developed and incorporated into the economic analysis.
- Section 6 presents the resulting expected annual damages for each of the damage categories presented in the Approach Memo. A discussion of equity and social justice (ESJ) is also included for each damage category.
- Section 7 presents the calculation steps for the weighted estimated annual damages (EAD) value as proposed in the Approach Memo (Tetra Tech, June 2022).
- Section 8 presents the levee performance statistics that are calculated within the HEC-FDA software.
- Section 9 presents an overall discussion of the equity and social justice impacts in the study area.
- Section 10 presents a summary of other key flood risk indicators such as populations, average flood depths, lengths of roads inundated, among others based on inundation for the 1% annual exceedance probability (AEP) event.
- Section 11 presents the change in flood risk due to modelled climate change impacts in the study area.
- Section 12 presents a discussion of other sources of flood risk in the study area that were not included in the EAD results presented in previous sections.
- Section 13 provides an overall summary of the project and discusses relevant conclusions regarding levee risk along the levee containment system of the Lower Raging River.
- Section 14 provides all maps referenced throughout the memo.
- Section 15 provides a list of all reference documents used in development of this memo.

1.5. Scope of Work Crosswalk

This provides the deliverable Technical Memorandum that Summarizes the Methodology and Results of the Economic Evaluation of Flood Risk, addressing Subtask 8.6, as part of the economic evaluation of flood risk for the Lower Raging River Basin (Task 300) of the LBAMRA project.

Table 1 summarizes the relevant scope and notes the sections of this memo which address each primary scope item.

Table 1 – Scope of Work Reference Table

	Scope Item	Document Reference
A:	Develop a technical memorandum that summarizes the methodology and results of the economic evaluation of flood risk.	This technical memorandum is the deliverable that satisfies this scope item.
B:	For each risk category present total expected annual damage and other socio-economic considerations.	Expected annual damage results are presented for each damage category (see Section 6).
C:	Conduct future conditions economic model runs	Future conditions economic models were developed for each economic scenario and the results are discussed in Section 11.

1.6. Economic Price Levels and Other Assumptions

The economic damage calculations presented in the subsequent sections rely on several key assumptions and values. All prices and assumptions are based on the following, unless specifically noted otherwise.

- Price levels: January 2023 prices
- Period of Analysis: 50-year period of analysis
- Discount Rate: Current Federal discount rate of 2.50%

2. ECONOMIC APPROACH SUMMARY

2.1. LBAMRA Conceptual Framework

The purpose of this economic analysis is to characterize the flood risk associated with the existing levee containment system of the Raging River by quantifying the impacts of flooding on people and property, including consideration of the possibility of levee breaches during a flood. For this purpose, risk is defined as the combination of the likelihood of the hazard occurring and the resulting consequences or impacts of that hazard given by the equation below.

Risk = Probability x Consequence

This simple definition encompasses the framework completed for this study area. Using this equation, the probability multiplier primarily consists of geotechnical and hydraulic information, and the consequences multiplier consists of the economic damage assessment and other quantified and qualitative assessment of impacts.

The geotechnical and hydraulic work developed for this study incorporates many variables and statistical uncertainties for those variables to define the relationships between river discharge, stage, levee failure, potential impacts of climate change, and resultant depth of inundation in the floodplain. The economic analysis focuses on the estimate of consequences, or damages, which are the adverse impacts that arise from floodplain inundation. The economic analysis also considers uncertainty in the development of the floodplain inventory inputs used for the economic consequence modelling. The economic modeling analyzes the consequences for eighteen (18) impact categories that relate to direct physical damages, response and restoration costs, implicit costs, public health and safety, and equity and social justice. Equity and Social Justice is a high priority within King County and its partners. The ESJ evaluation builds upon and leverages the results of the consequence analysis.

A simplified flow chart of the conceptual framework for this analyses is presented in Figure 1. A more detailed conceptual framework figure is presented in the Approach Memo (Tetra Tech 2022).

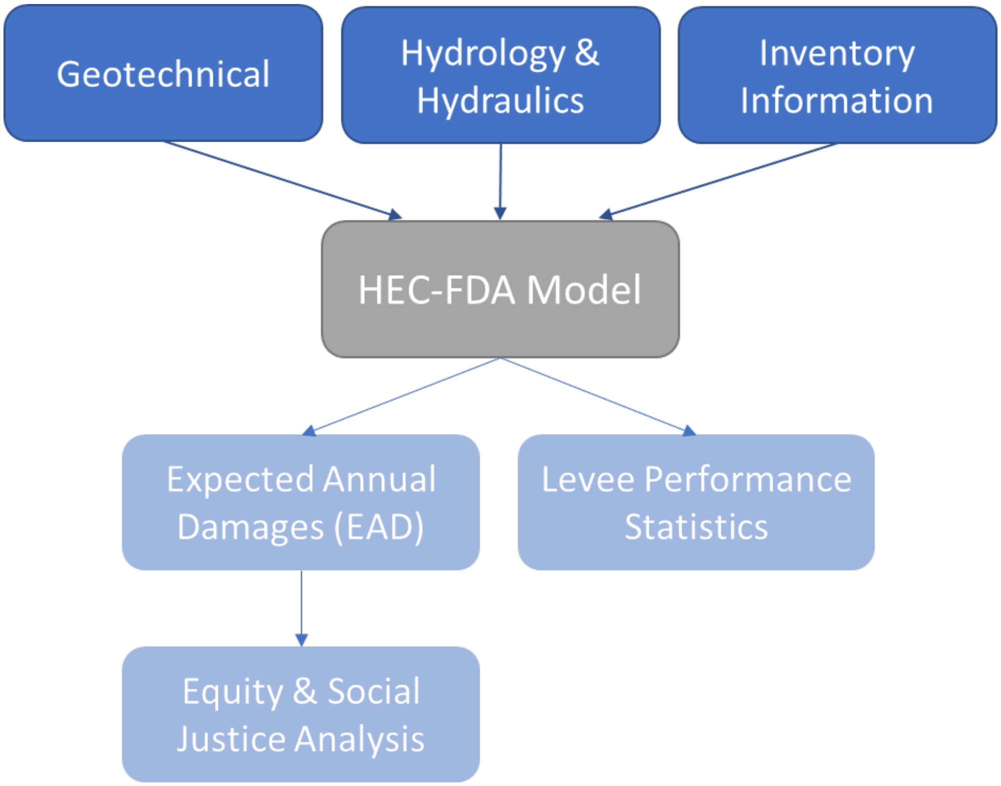


Figure 1 – Simplified LBAMRA Conceptual Framework

2.2. USACE HEC-FDA

The following is a summary of how HEC-FDA is used for estimating flood damages based on the specifics of this project. A detailed description of the computational processes used within FDA, and how the program incorporates uncertainty and other parameters, can be found within the Economic Approach Memo (Tetra Tech 2022).

The flood risk analysis combines the probability and consequence sides of the above equation, through modeling software, HEC-FDA (FDA), to estimate monetized flood risk for this study area. The United States Army Corps of Engineers (USACE) developed the HEC-FDA software to support analysis of flood risk and levee performance. This software allows for input of key hydraulic, geotechnical and economic data as well as parameters of uncertainty for many model inputs. Many iterations of potential flood and levee performance scenarios are estimated through Monte Carlo simulations to reflect uncertainty and included in the computational results of flood risk. The program also allows incorporation of levee geotechnical fragility data for probabilistic assessments of levee failure. The latest certified version of HEC-FDA (version 1.4.3) has been used for this analysis. The general process for using FDA includes importing key hydraulic, geotechnical, and economic data. The following is a list of the primary inputs that were developed through this study and incorporated directly into the FDA model. Where appropriate, these inputs include uncertainty around the parameters and values.

- Structure Inventory – detailed list of structures in the study area for calculating structure and content damages, which are the standard flood damage categories in most studies. The structure inventory is then further utilized to generate the inventory information for many of the other damage categories analyzed in this study.
- Water Surface Profiles – for each structure and pseudo-structure point, flood depth information is extracted from the hydraulic model results for each modeled flood event and imported into FDA. With the depths imported into FDA, the FDA program then develops several key hydraulic datasets required for completing the FDA analysis. These other relationships are based on the water surface profile inputs, but are developed within FDA and include:
  - Exceedance Probability Function – this function relates discharge rates to exceedance probabilities and incorporates an uncertainty distribution around the discharge values.
  - Stage-Discharge Function – this function relates discharge to a water surface stage, with uncertainty range calculated around the stage elevation.
- Levee Features – these are key levee parameters, including levee heights, pseudo-levee heights (to set a trigger point for damages to begin), and levee failure probabilities for breach scenarios.
- Depth-Damage Curves – these relationships define the percentage of damages based on flood depth for the various damage categories. These damage curves were taken primarily from USACE and FEMA sources.

3. STUDY AREA SUMMARY

3.1. Economic Study Area Extent

The section of channel analyzed for this work is the Raging River from the 328th Way SE bridge to the mouth of the Raging River at its confluence with the Snoqualmie River. The economic extent of this study area was further refined with the results of the hydraulic modeling to include analyzing sufficient area to account for potential flooding on both the right and left banks of the Raging River, while attempting to exclude areas where the flood source is entirely attributed to the Snoqualmie River (ex. right bank area at golf course). Figure 2 provides the economic study area extent used for all subsequent analyses in this memo.

The economic study area lies entirely within Fall City, WA, an unincorporated area within King County. This area consists of the downtown section of Fall City and includes the two primary roadways (Redmond-Fall City Road and Preston-Fall City Road) into this section of King County.

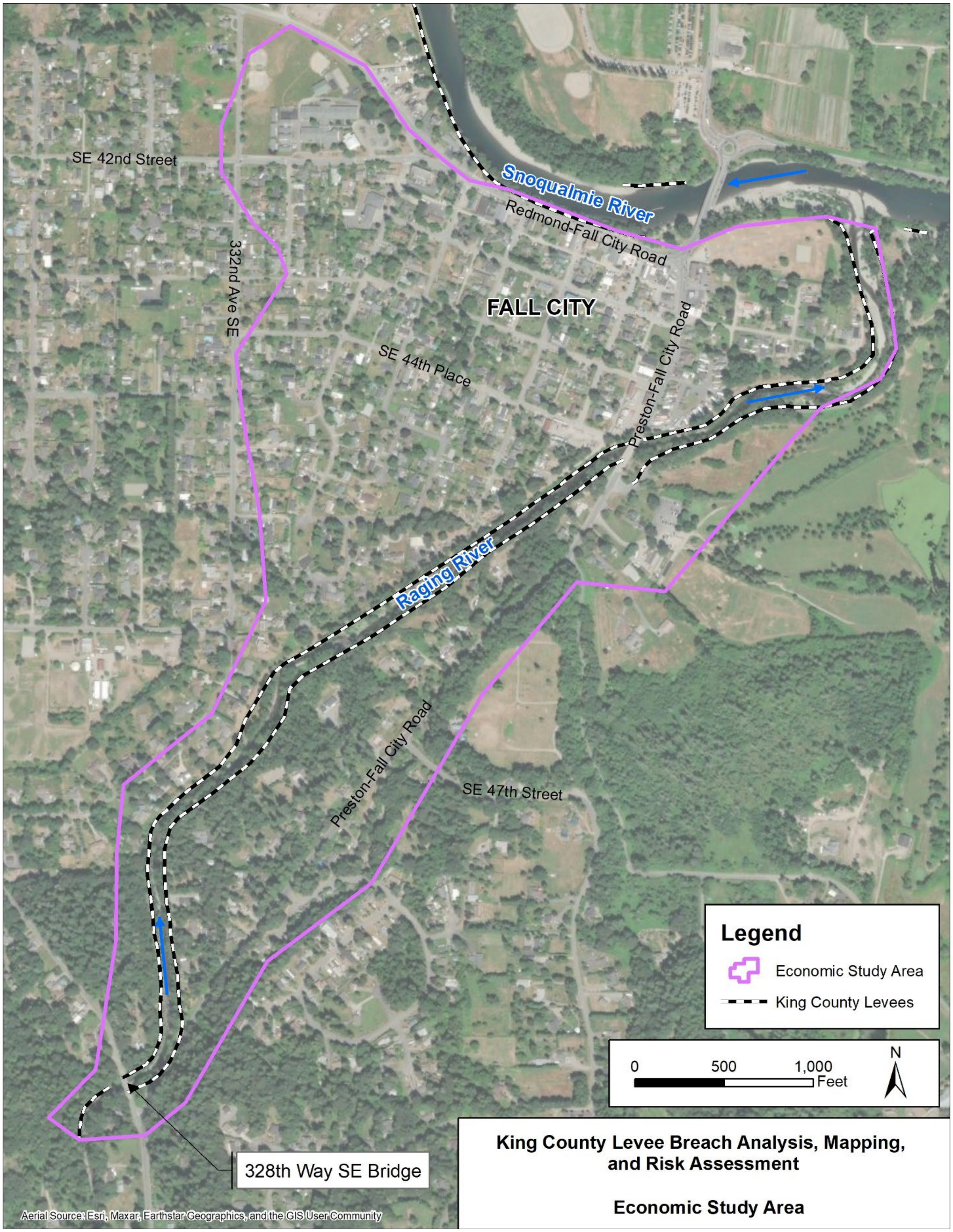


Figure 2 – Economic Study Area Extent

3.2. STRUCTURE INVENTORY

A detailed structure inventory has been developed within the economic extents referenced previously. The primary source of the structure inventory came from parcel data obtained from King County Department of Assessment. The provided parcel data included key building information such as building type/use, size, and replacement value. Other required data has been amended to the parcel data for use in the economic analysis.

The parcel data were further refined to create a dataset wherein one point was placed in each parcel to represent the approximate center of the structure. All parcels were reviewed to account for the potential of multiple structures within one parcel. Each of the final structure points was reviewed to ensure the structure category, occupancy type (see Table 2 for structure categories and occupancy types in study area), replacement values, and structure square footage were applied consistently.

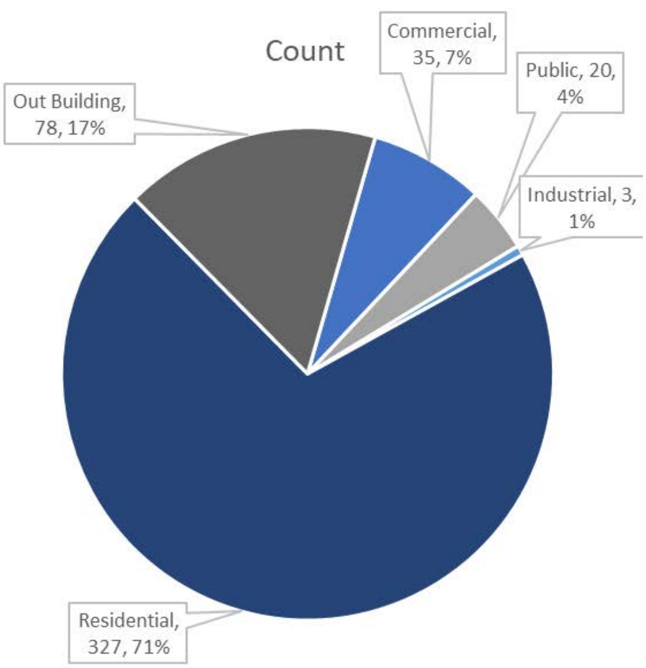
Table 2 – Primary Structure Categories and Occupancy Types in Study Area

Structure Category	***Occupancy Type***	***Occupancy Description***
Commercial	COM1	Retail, grocery, convenience
	COM2	Storage, auto, warehouse
	COM3	Auto service
	COM4	Office
	COM7	Medical, dental
	COM8	Restaurant
Public	EDU1	Elementary school
	GOV1	Government service, library
	GOV2	Fire station
	REL1	Church
Industrial	IND2	Light Industrial
Residential	RES1-1SNB	1-story single family res (sfr)
	RES1-1SWB	1-story sfr w/ basement
	RES1-2SNB	2-story single family res (sfr)
	RES1-2SWB	2-story sfr w/ basement
	RES2	Manufactured homes
	RES3A	Duplex
	RES3B	Multi Family - 3 to 4 units
Out Buildings	OUT1-SB	Out building - shed/office
	OUT2-SH	Out building - tool shed
	OUT3-DG	Out building - detached garage

In total, the economic study area includes 463 structures and over $99 million dollars in depreciated replacement value of structures and contents. Depreciated replacement value is used in this analysis to reflect the actual value of the structures, as opposed to a full replacement cost which would reflect a betterment relative to the structures' actual conditions at this time. A breakdown of the structure inventory by primary structure category is provided in Table 3 and Figure 3. A more detailed breakdown of the inventory by detailed occupancy type is provided in Table 4.

Table 3 – Structure Inventory by Structure Category

Structure Category	***Count***	***Structure Value***	***Content Value***	***Total Value***
Commercial	35	$3,514,100	$3,585,400	$7,099,500
Public	20	$11,515,900	$13,694,000	$25,209,900
Industrial	3	$145,200	$217,800	$363,000
Residential	327	$39,644,700	$19,822,350	$59,467,050
Out Buildings	78	$3,287,300	$4,930,950	$8,218,250
Total	**463**	**$58,107,200**	**$42,250,500**	**$100,357,700**



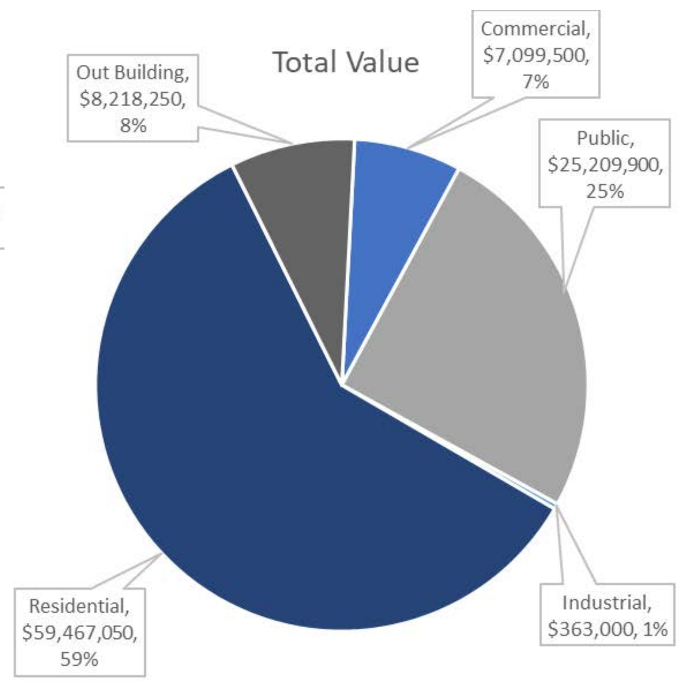


Figure 3 – Structure Inventory Counts and Values

Table 4 – Structure Inventory by Occupancy Type

Occupancy	***Count***	***Structure Value***	***Content Value***	***Total Value***
COM1	8	$486,300	$486,300	$972,600
COM2	2	$16,900	$16,900	$33,800
COM3	8	$778,800	$778,800	$1,557,600
COM4	4	$387,900	$387,900	$775,800
COM7	1	$142,600	$213,900	$356,500
COM8	12	$1,701,600	$1,701,600	$3,403,200
EDU1	10	$5,031,600	$5,031,600	$10,063,200
GOV1	6	$1,718,900	$1,718,900	$3,437,800
GOV2	2	$4,356,200	$6,534,300	$10,890,500
IND2	3	$145,200	$217,800	$363,000
OUT1-SB	6	$149,100	$223,650	$372,750
OUT2-SH	5	$39,300	$58,950	$98,250
OUT3-DG	67	$3,098,900	$4,648,350	$7,747,250
REL1	2	$409,200	$409,200	$818,400
RES1-1SNB	145	$19,684,200	$9,842,100	$29,526,300
RES1-1SWB	31	$4,223,500	$2,111,750	$6,335,250
RES1-2SNB	36	$7,724,400	$3,862,200	$11,586,600
RES1-2SWB	24	$3,839,100	$1,919,550	$5,758,650
RES2	84	$3,115,400	$1,557,700	$4,673,100
RES3A	5	$810,500	$405,250	$1,215,750
RES3B	2	$247,600	$123,800	$371,400
Total	463	$58,107,200	$42,250,500	$100,357,700

Map 1 presents a spatial view of the structure inventory broken out by primary structure category, and Map 2 presents the structure inventory by specific structure occupancy type.

3.3. Study Area Socio-Economic Profile

Fall City is a small unincorporated town in the eastern, more rural section of King County and encompasses the economic study area for the Lower Raging River Breach analysis. The project is located within the aboriginal homeland of the Coast Salish peoples whose contemporary local descendants have organized themselves into the Snoqualmie and Tulalip Tribes.

With a population of 2,970 people, the Fall City census tract accounts for a mere 0.1 percent of King County's entire population. Fall City is not particularly diverse in terms of race and ethnicity. Almost 89 percent of the population is white, just over 6 percent are Hispanic or Latino, 3 percent are multiracial, and 1 percent are Asian (WSDOH 2023). Other minority groups combined account for the remaining one percent of the population. Comparatively, only 57.7 percent of the King County population is white, 19 percent are Asian, 10.3 percent are Hispanic or Latino, 6.8 percent are black, 0.07 percent are American Indian and Alaskan Native (AIAN), and 4.7 percent are multiracial. King County as a whole is much more diverse than Fall City.

The median household income in Fall City is $128,224 in 2021 dollars, which is significantly greater than King County's median household income of $106,326 in 2021 dollars (USCB 2020). Fall City also has a 3.1 percent unemployment rate for residents over the age of 16 (WSDOH 2020) compared to King County's unemployment rate of 4.3 percent (WSDOH 2020a). Fall City has a low percentage of minority populations, has a greater median household income than King County and has a lower unemployment rate, all of which indicate that the city has fewer environmental and social justice (ESJ) populations and experiences fewer environmental health disparities than average in the county.

The Environmental Health Disparities index utilized the Washington Tracking Network (WTN, 2022) assigns each census tract in the state a score from 1 to 10, with each value representing a percentile that includes 10 percent of all Washington census tracts. A low score indicates that few census tracts have a lower (negative) impact or value in said category than the census tract being evaluated. The Fall City census tract was given an overall environmental health disparities score of 1, indicating that this area has very few environmental health concerns compared to other census tracts around the state. The environmental health disparities score includes a number of subcategories that are also scored that contribute to the overall environmental health disparities score. While Fall City ranks very low for their overall environmental health score, the census tract received a score of 8 for percentage of residents without a high school diploma, which was significantly higher than surrounding census tracts. It also scored a 6 for unaffordable housing, which suggests that it is slightly harder to find affordable housing around Fall City compared to other census tracts in the state.

4. HYDRAULIC MODEL RESULTS

The following section describes the source(s) of the hydraulic data, which is used to define the boundaries of the study area, and then to estimate flood damages based on the hydraulic models' depth grid outputs. For a detailed discussion of the hydraulic models, and their development, refer to NHC's Flood Hazard Analysis Report (NHC 2022).

4.1. Depth Grids

Output files from the developed hydraulic models were provided by NHC which included depth grids for three different flooding scenarios. For each of the flood scenarios depth grids were provided for the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% AEP floods (2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year events, respectively), in addition to the 1% and 0.2% AEP (100- and 500-year events, respectively) future conditions climate change flood events, which are based on existing hydrologic and hydraulic conditions. A brief description of each of the hydraulic scenarios is provided below:

- "Baseline" depth grids – the depth grids for this scenario are utilized in the economic FDA modeling to reflect existing conditions in cases where no levee breaches are assumed.
- "Breach Location 3" depth grids – the depth grids for this scenario are utilized in the economic FDA modeling to reflect existing conditions depths for each flood event given a breach along the left bank levee at the breach location 3 point (see Map 3 for assumed breach location points).
- "Breach Location 6" depth grids – the depth grids for this scenario are utilized in the economic FDA modeling to reflect existing conditions depths for each flood event given a breach along the left bank levee at the breach location 6 point, which is upstream of breach location 3 (see Map 4).

It should be noted that the names for these hydraulic models (NHC 2022) are slightly different than the economic model scenario names used herein. This is because the "baseline" hydraulic results for the seven modeled flood events are not strictly their own complete scenario. Based on other assumptions developed for this study, some substitutions of hydraulic model events have been made in one economic scenario. Section 5.2.4 discusses the economic scenario names, and how the hydraulic models are incorporated into the economic and FDA analysis in more detail.

4.2. Stage-Discharge Curves

The hydraulic data includes stage-discharge relationships that are key inputs to the economic modeling. These stage-discharge curves also present relevant data points in helping assess the results of the flood damage modelling. Table 5 presents the stage discharge curves for each of the modeled flood events, including the two future conditions (FC) models, at the two breach locations.

Table 5 – Stage-Discharge Curves at Breach Locations

AEP (Recurrence Interval)	***Peak Flow (cfs)***	***BL3 Stage (feet, NAVD88)***	***BL6 Stage (feet, NAVD88)***
50% (2-year)	2,020	111.19	126.80
20% (5-year)	2,980	112.39	127.94
10% (10-year)	3,650	113.12	128.57
4% (25-year)	4,510	113.94	129.37
2% (50-year)	5,160	114.53	129.95
1% (100-year)	5,830	115.06	130.50
0.4% (250-year)	6,730	115.64	131.14
0.2% (500-year	7,440	115.92	131.60
1% FC (100-year FC)	7,400	115.91	131.59
0.2% FC (500-year FC)	10,480	116.42	132.81

4.3. Levee Details (Heights and Fragility)

Key levee information required for running FDA such as levee heights, channel invert elevations, and failure probabilities were taken from both NHC's hydraulic report (NHC 2022) and Shannon & Wilson's Stability Analysis Report (Shannon & Wilson 2022). Table 6 provides the invert and levee crest elevation for the two breach locations, which are input requirements to the FDA model.

Table 6 – Channel Invert and Levee Height Elevation Parameters

Breach Scenario	***Channel Invert Elevation (ft NAVD88)***	***Levee Height Elevation (ft NAVD88)***
Breach Location 3	105.70	115.77
Breach Location 6	121.20	132.01

(Source: NHC 2022)

Table 7 provides the levee failure probability data, and these failure probabilities are assumed to apply to both breach locations. The probability of failure was then cross referenced with the relative height below the levee crest such that the failure probabilities can be applied to the different levee breach locations after accounting for varying levee heights.

Table 7 – Levee Fragility Curve Percentages

River Stage	*Height Below Levee Crest (ft)*	*Probability of Failure*
127.4	5.1	0.006%
128.7	3.8	0.004%
129.4	3.1	0.003%
130.2	2.3	0.003%
130.8	1.7	0.003%
131.3	1.2	0.003%
132.5	0.0	0.700%

(Source: Shannon and Wilson 2022)

4.4. Floodplain Maps

NHC's hydraulic report contains floodplain inundation maps for each of seven flood events, and for each of the modeled scenarios. However, to present a relative comparison of inundation magnitude, Map 4 through Map 6 show the 1% AEP (100-year event) modeled depth grids for the three different hydraulic scenarios. The inundation shown in these figures does not reflect any probabilities of levee failure or other limiting probabilistic parameters, but rather the potential extent of flooding should a breach occur. The extent of inundation for the 1% AEP (100-year event) for the baseline (no breach) scenario also shows the extent of landward flooding due to overtopping at the low point in the levee system. For the two breach scenarios the inundation extent assumes a levee breach, however there is a very low probability of a breach occurring.

5. ECONOMIC MODEL ASSUMPTIONS

5.1. Index Locations and Reaches

The FDA model allows for the floodplain to be divided into damage areas or reaches. Reaches are defined in FDA as a set of floodplain grid cells all tied to the same index location. For each reach, a point along the channel must be selected as the index location for the damage area, and this point is used as a representative location for the entire reach. FDA performs the computation of flood risk for each damage area separately, and each damage area is assigned key hydraulic and levee information specific to that reach, based on the information at the index point.

The initial approach to this project assumed that there would be two reaches, one for the left bank and one for the right bank. There would also be two index points corresponding to the two modeled breach locations as developed by the hydraulic analysis. However, upon reviewing initial hydraulic and economic damage results, the original left bank reach has been divided into two reaches. The primary reasoning for this is because of the hydraulic complexity of the left floodplain area, wherein there is a point along the left bank levee, near the confluence with the Snoqualmie River, where a mixture of flood flows from the Raging and Snoqualmie Rivers is overtopping the levee prior to either of the designated breach locations being overtopped (see Map 7). Therefore, the section of the study area near the confluence of the two rivers has been separated into a third reach, to account for the differing levee parameter requirements in the FDA model, as well as to allow for separating out damages from this "mixed flow" area. Map 8 provides the extents of the Left Bank, Left Bank mix, and Right Bank reaches in the study area. Discussion of the left bank reaches is presented below with further discussion of the right bank in Sections 145.3 and 12.2.

5.2. Economic Damage Scenarios

The following section describes three independent damage scenarios that have been modeled in FDA, and includes a comparison of hydraulic model use, failure assumptions, and other key differentiators between the scenarios. The three independent scenarios are named, Overtop-then-Breach, Breach Location 3, and Breach Location 6.

5.2.1. Overtop-then-Breach

The basic assumption for the Overtop-then-Breach scenario is that this is inundation under existing conditions with no breaches of the levees occurring, prior to the levees being overtopped. For this scenario, the “baseline” hydraulic model depth grids (see Section 4.1) were used in development of the necessary water surface profile data for input into FDA. The “baseline” hydraulic model does show flood flows overtopping the low point on the levee at the 4% annual exceedance probability (AEP) (see Map 7). As noted above, this area of low point overtopping has been separated into its own reach (the Left Bank mix), such that separate levee parameters can be input into the FDA model to accurately account for this low point in the Overtop-then-Breach scenario.

Also, the input water surface profile data into FDA have been modified based on one key assumption used for this study. It has been determined that for the purpose of inducing breaches for this study the levees are assumed to fail once overtopped due to erosion on the backside of the levee after the overtopping has occurred at the selected breach locations. Assessing backside failure modes is outside the project scope, therefore assuming failure due to backside erosion after overtopping occurs is a conservative estimate and is not based on any definitive geotechnical results (per communications with Shannon & Wilson). To incorporate this assumption, the economic analysis assumes that once one of the breach location points (see Map 3) is overtopped by 0.1-feet of water, then that levee is assumed to breach only at that designated breach location.

For the Overtop-then-Breach scenario, Breach Location 3 is shown to overtop first when considering floodwaters solely from the Raging River, and this overtopping is estimated to occur at flood event between the 1% and the 0.2% AEP events. Therefore, within the FDA model for this scenario, depths at the structure points were substituted with depth data from the Breach Location 3 depth grid outputs for the 0.2% AEP event. As this scenario is accounting only for overtopping and then breaching of the levee, no levee fragility data was included in this scenario for water surface elevations below the levee crest.

5.2.2. Breach Location 3

This scenario analyzes the potential damage from a levee breach at Breach Location 3 only. As this scenario is an independent scenario designed to analyze flood risk only from the possibility of breaching at Breach Location 3, the FDA model does not account for any of the overtopping at the low point, as discussed in the Overtop-then-Breach scenario. The FDA model for this scenario incorporates only the depth information from the Breach Location 3 hydraulic models. But this scenario incorporates the levee failure probabilities (see Section 4.3) prior to overtopping the levee. Then, once water exceeds the levee height by 0.1-feet, the levee is assumed to fail.

5.2.3. Breach Location 6

This scenario analyzes the potential damage from a levee breach at Breach Location 6 only. As with the Breach Location 3 scenario, this scenario is an independent scenario designed to analyze flood risk only from a breach at Breach Location 6. As such, the FDA model does not account for any of the overtopping at the low point as discussed in the Overtop-then-Breach scenario and does not include potential failure at Breach Location 3. The FDA model incorporates only the depth information from the Breach Location 6 hydraulic models. As with Breach Location 3, this scenario incorporates levee failure probabilities for water surface elevations below the top of levee. But again, once water exceeds the levee height by 0.1-feet, the economic model assumes the levee fails.

5.2.4. Hydraulic Model Use

Table 8 summarizes which hydraulic model results are used in each economic model scenario. As discussed previously, the only modification is in the hydraulic model assumption used for the 0.2 AEP (500-year event) in the Overtop-then-Breach economic model.

Table 8 – Hydraulic Model Used for Each Flood Event by Scenario

Flood Event Magnitude	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
50% AEP (2-year)	Baseline	Breach Location 3	Breach Location 6
20% AEP (5-year)	Baseline	Breach Location 3	Breach Location 6
10% AEP (10-year)	Baseline	Breach Location 3	Breach Location 6
4% AEP (25-year)	Baseline	Breach Location 3	Breach Location 6
2% AEP (50-year)	Baseline	Breach Location 3	Breach Location 6
1% AEP (100-year)	Baseline	Breach Location 3	Breach Location 6
0.2% AEP (500-year)	Breach Location 3	Breach Location 3	Breach Location 6

5.3. Right Bank Analysis

The hydraulic model results present some flooding along the right bank of the Raging River Levee system. However, upon further review of the hydraulic results, it was found that this right bank flooding was not due to any deficiencies or issues with the existing levee system. The right bank levees are not overtopped in the modeling, and the right bank levees were not included in the breach analysis. It was determined that the flooding shown in the modeling comes from either Snoqualmie River flooding (ex. flooding at golf course on right bank near confluence), interior drainage issues, and/or breakout of flows upstream of the existing levee system. Since the intent of this study is to analyze levee risk with inclusion for the possibility of levee breaches of the Raging River levees, and the hydraulic modeling provided for use in this study does not present any existing levee risk absent the Snoqualmie and drainage issues, the FDA models' levee parameters have been adjusted to prevent calculation of EAD for the right bank under all three scenarios.

It should be noted that even though the right bank is excluded from the levee overtop and/or breach EAD estimates, there is still relevant flood risk on the right bank within the study limits. Section 12 presents a discussion of the existing flood risk from sources outside of the Raging River levees along the right bank, with inclusion of individual flood event damages and EAD for informational purposes.

5.4. FDA Requirements for Fragility Data

The levee fragility curve shown in Table 7 presents probability of failures that are decreasing as the water stage is increasing along the levee, until the stage reaches the levee crown. This decreasing probability as water levels increase causes errors when trying to run an FDA model. Upon further discussions with the study's geotechnical engineers, it was determined to modify the lowest stage probabilities to be consistent with the probabilities of the next closest stage. This proposed change can readily be seen in Table 9, where the lowest two stage elevation's failure probabilities, at each breach location, are adjusted to be consistent with 0.003 percent failure probabilities of the next highest stages. A sample fragility curve for the BL3 scenario is then presented in Figure 4.

Table 9 – FDA Fragility Curve Data at Breach Location Points

Breach Location 3			***Breach Location 6***		
Stage Elevation (feet NAVD88)	**Probability of Failure from Stability Report**	**Probability of Failure Used in FDA Model**	**Stage Elevation (feet NAVD88)**	**Probability of Failure from Stability Report**	**Probability of Failure Used in FDA Model**
110.67	0.006%	0.003%*	126.91	0.006%	0.003%*
111.97	0.004%	0.003%*	128.21	0.004%	0.003%*
112.67	0.003%	0.003%	128.91	0.003%	0.003%
113.47	0.003%	0.003%	129.71	0.003%	0.003%
114.07	0.003%	0.003%	130.31	0.003%	0.003%
114.57	0.003%	0.003%	130.81	0.003%	0.003%
115.77 (levee top elevation)	0.7%	0.7%	132.01	0.7%	0.7%
115.87	N/A	100%	132.11	N/A	100%

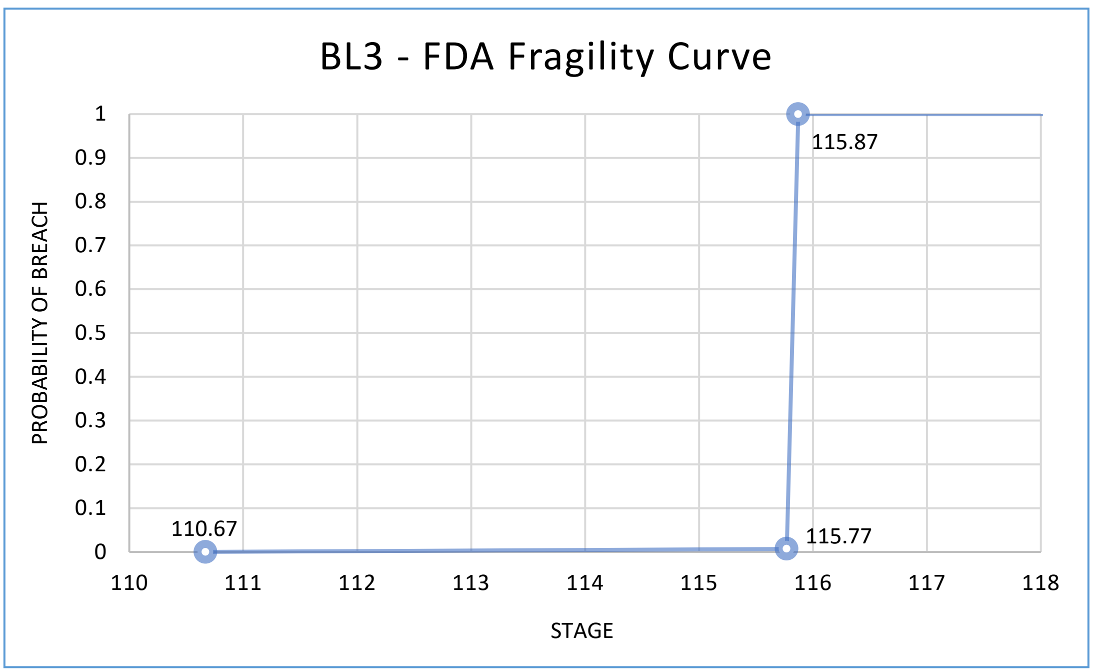


Figure 4 – Modified Fragility Curve at Breach Location 3

5.5. Uncertainty Parameters

The FDA program allows for uncertainty to be included on various inputs into the model. These uncertainty parameters are incorporated by entering distribution types and key value parameters for a given input value. The typical distributions used in this analysis are normal and triangular distributions, with standard deviation and maximum and minimum values input according to the distribution type.

Incorporating uncertainty into the FDA model allows for a more robust estimate of damages through the program's Monte Carlo sampling process. For this study, uncertainty parameters were included for the following primary inputs in the FDA models, and it should be noted that the FDA program also estimates uncertainty around several key data points and curves developed while running the model:

- Structure values, and other values input for the pseudo-structure points developed for many of the other damage categories to be discussed in Section 6.
- First Floor elevations
- Discharge rates for given exceedance probabilities
- Stage elevations for given discharge rates
- Depth to damage percent assumptions

6. EXPECTED ANNUAL DAMAGE WITH EQUITY AND SOCIAL JUSTICE IMPACTS

This section identifies the damage categories included in the FDA modeling to calculate monetary damages in the event of a breach, or levee failure. Each subsection presents key inventory information, damage function assumptions, expected annual damage results, and equity and social justice assessments based on the existing conditions hydraulic models (see Section 11 for future condition damages that account for climate change). The ESJ component of each of the damage categories is also considered in following sections. An overview of the many potential damage categories organized by damage type and potential impact is presented in Table 10.

Table 10 – Damage & Impact Categories

	Summary Categories			
	Direct Physical Damages	**Response and Restoration Costs**	**Implicit Costs**	**Public Health and Safety**
Impact Categories	Structures, Contents, and Inventory	Debris Removal	Transportation Detour and Delay	Residential Evacuation, Subsistence, and Reoccupation
	Direct Vehicle	Building Cleanup	Business Disruption	Public Services and Critical Facilities
	Direct Road	Emergency Response	Recreation Loss	Utility Loss of Service Impacts
	Direct Bridge	Landscape Restoration	Lost Worker Productivity	Mental Stress and Anxiety
	Direct Critical Utilities			
	Agricultural Loss			

6.1. Direct Physical Damages and ESJ Impacts

This section discusses direct physical damages which include damages to buildings, vehicles, roads, bridges, other facilities, and agriculture. These items are directly impacted due to flood waters inundating the physical item. Each of the damage categories below include an analysis of the potential ESJ impacts from the physical damages.

6.1.1. Structures and Contents

This category covers the building-related losses associated with direct contact with floodwaters. Structure damage is an estimated dollar value of damage to structural components of a building, such as foundation, walls, and utilities. Content damage is an estimated dollar value of damage to the non-structural components of a building, such as furniture, fixtures, cabinetry, and other personal property or commercial equipment.

6.1.1.1. Inventory

As referenced in Section 3.2, the primary data source for this damage category was detailed parcel data provided by King County Department of Assessment. The parcel data provided several key attributes required for running HEC-FDA, and a detailed assessment of the structures was completed to determine other required inputs. Key structure inventory inputs include structure occupancy type, depreciated replacement value, and first floor elevation. For estimation of contents values, these were estimated as a ratio of structure value to content value, and these ratios were taken from HEC-LifeSim model.

6.1.1.2. Damage Function

The use of depth-damage functions is the primary methodology employed by federal agencies such as FEMA and the U.S. Army Corps of Engineers to estimate flood damages. The depth-damage functions used in this analysis, for each occupancy type, were taken from USACE's HEC-LifeSim program (USACE 2021). This program includes depth-damage functions for 40 different structure occupancy types, which more than covers the occupancies developed for this study area. The depth-damage functions used for each of the structure occupancy types in the study area are provided in Attachment 1.

6.1.1.3. Expected Annual Damages – Structures, Contents, and Inventory

Table 11 shows the results for structure and contents EAD by each of the three breach scenarios.

Table 11 – Expected Annual Damages – Structures and Contents

Scenario	***Reach***	***Commercial***	***Industrial***	***Out Building***	***Public***	***Residential***	***Total EAD***
Overtop-then-breach	Left Bank	$835	$0	$357	$120	$1,399	$2,711
	Left Bank mix	$1,238	$0	$1,243	$0	$9,996	$12,477
	Right Bank	$0	$0	$0	$0	$0	$0
	Total	**$2,073**	**$0**	**$1,600**	**$120**	**$11,395**	**$15,188**
Breach Location 3	Left Bank	$874	$0	$363	$118	$1,428	$2,783
	Left Bank mix	$1,089	$0	$380	$0	$3,045	$4,514
	Right Bank	$0	$0	$0	$0	$0	$0
	Total	**$1,963**	**$0**	**$742**	**$118**	**$4,473**	**$7,296**
Breach Location 6	Left Bank	$186	$2	$97	$515	$858	$1,659
	Left Bank mix	$76	$0	$43	$0	$363	$482
	Right Bank	$0	$0	$0	$0	$0	$0
	Total	**$263**	**$2**	**$140**	**$515**	**$1,221**	**$2,141**

6.1.1.4. ESJ Analysis – Structures and Contents

Some of the low-income housing structures along the Lower Raging River include mobile homes and manufactured homes that may not have the proper elevation or structure to withstand flooding. Damages caused by flooding to these structures and their content can have a greater overall and economic impact on low-income, or ESJ households. While low-income residential structures typically have lower monetary values than their higher end counterparts, the value of low-income homes often surpass their monetary value as a source of pride and refuge (Camilo 2006). Homeowners in ESJ communities can potentially lose their life's savings to flood damages, especially if their home is their primary financial asset. Extensive coverage for flood damages is expensive, so these homeowners often pay for cheaper options with less coverage, meaning these groups lose even more in a flooding event than those who can afford better flood insurance.

In Fall City, the estimated home ownership rate in 2020 was 74.1 percent, indicating that around a quarter of Fall City residents rent their housing unit (USCB 2020). Unlike homeowners, renters do not have to be made aware of flood risks to their dwelling, and most renters insurance policies do not cover flood damage (Social 2020). Even renters that are aware of the flood risk to their home may not be able to afford additional flood insurance, particularly low-income ESJ community members. This puts low-income renters at real risk for high damage costs sustained in a potential flooding event. Additionally, renters typically suffer higher flood damages than homeowners in floods of comparable size due to general poor construction and maintenance of rental units (Camilo 2006). Rental units and other low-income housing can be built on flood plains so long as they comply with King County code and submit a floodplain development permit (King County 2021). The addition of homes to floodplain areas will only add to the burden of ESJ communities who are often forced to take bigger risks to find affordable housing, including choosing old and flood prone homes.

Breaches at Location 3 can disproportionately impact ESJ communities under all flooding scenarios

Breaches at Location 6 can disproportionately impact ESJ communities under one scenario

Potential Disproportionate Risk to ESJ communities:

- *Property and structure damage*
- *Loss of homes*
- *Loss of belongings*
- *Pressure on social services*
- *Homelessness*

There are three clusters of low-income housing units within the economic study area. These clusters are highlighted by white circles in Map 9. The cluster located just west of the junction between the Snoqualmie River and the Lower Raging River in the Northeastern area of the economic study area (in the Left Bank Mixed reach) will likely experience flood damage in the event of a breach at location 3. The location of this ESJ population makes them prone to overtopping at the low point (see Map 7), though the flooding would come from both the Snoqualmie and Lower Raging rivers. ESJ populations tend to live in hazardous areas, or floodplains like this, often because these areas offer affordable housing or because these individuals work in water recreation and look for the least expensive housing nearby (Camilo 2006).

In addition, given the high cost of housing and home repairs, there is a potential of increase in short- or long-term homelessness in the area, which can disproportionately affect the low-income and other ESJ populations. Such developments can also divert social services and other resources from existing programs geared toward ESJ communities.

It is anticipated that both renters and owners of low-income houses in the economic study area, particularly the ESJ community near the junction of the Snoqualmie and Raging rivers, could potentially bear a greater negative impact from damage to structures, contents, and inventory than those with extensive flood insurance and more earning power. While it has been established that any flood damage caused to ESJ populations can result in some negative effects for this group, the team also assessed what portion of the flood damages will fall on ESJ community members relative to other Fall City residents in the economic study area.

For the purpose of this analysis, low-income housing units are identified as RES 2, RES3A, and RES3B (hereafter RES2&3). These housing units are the manufactured homes (RES2), duplexes (RES3A) and multi-family homes (RES3B). A review of the parcel database confirms that units classified in these categories are, on average, lower valued structures. It is important to note that low-income is different than low home value, however, the two are strongly correlated, and the research team is using this as a proxy for the quantitative analysis of low income, ESJ populations.1 The advantage of using this proxy is that it is available at the parcel level, while other data is available only at larger geographic units (see Economics Methodology Memo).

Using the RES2&3 category for analysis, the goal of the ESJ analysis is to evaluate whether or not this group experiences disproportionate flood impacts compared to the other populations in the study area. As a starting point, Table 12 shows the number of low-income housing units (RES2&3) compared to the total number of housing units in the economic study area. The table also shows the total structural value of the low-income housing units compared to the value of all the housing units in the potential flood impact area.

Table 12 - Residential Inventory Low-Income Housing Units

Structure Category	***Sum of Number of Structures***	***Sum of Total Value***
RES 1	236	$53,206,800
RES 2 & 3	91	$6,260,250
All Residential Units	327	$59,467,050
Percentage of RES 2 & 3 compared to all Residential Units	**27.8%**	**10.5%**

The results show that 27.8 percent of all housing structures are RES2&3 in the economic study area, and 10.5 percent of the total residential structure and contents value in this area. Therefore, flood impacts from the three modeled scenarios that affect greater than 27.8 percent of the number of low-income housing units or greater than 10.5 percent of low-income structure and content value would disproportionately affect ESJ community members. It should be noted that there is an extremely low probability of a breach prior to overtopping at the more frequent events. With a probability of occurrence below 0.01 percent, the risk to low-income homes, or rather all homes, under the frequent events for BL3 and BL6 is negligible.

Table 13 shows the percent of potential inundated structures in the RES2&3 group as a share of all residential structures inundated by flood event and scenario. Where these percentages exceed 27.8 percent of all structures, this may be considered a disproportionate impact. Combinations of flood event and scenarios that have the potential for a disproportionate impact on these low-income households are shaded*.* For clarity, the metric for each event and scenario is as follows:

- Table 13 - The number of low-income residential structures inundated in the event divided by the total number of residential structures in the study area inundated by that event.

[1] Home value has been used as a proxy for socioeconomic status in flooding contexts for several case studies (Masozera et al. 2006 and Lee and Jung, 2014). For example, Mazozera et al. used housing value as a proxy for socioeconomic status in an analysis of the impacts of Hurricane Katrina. Also, Lee and Jung noted the positive correlation between income and property values and determined that those living in floodplains in Austin, Texas had lower income and lower-value housing (Lee and Jung 2014).

Table 13 - Percent of Damaged Structures Considered Low-Income by Flood Event and Scenario

Scenario/AEP	***50%***	***20%***	***10%***	***4%***	***2%***	***1%***	***0.2%***
Overtop then Breach	NA	NA	NA	NA	18%	19%	36%
Breach Location 3	30%	25%	24%	14%	16%	14%	36%
Breach Location 6	NA	5%	4%	4%	9%	10%	18%

As seen in the table, the numbers of structures affected by each event and scenario is typically under the 27.8 percent threshold for disproportionate impact. For the 50% AEP (2-year event) and the 0.2% AEP (500-year event) there is a slightly disproportionate impact, with 30 percent of structures inundated in the 50% AEP (2-year event) for scenario BL3 being RES2&3, and with 36 percent of inundated structures in the 0.2% AEP (500-year event) being RES2&3 for both the overtop and BL3 scenarios. Again, though low-income homes could be disproportionately impacted under the 50% AEP (2-year event) at BL3, this scenario is exceedingly unlikely. Therefore, there is next to no risk for a disproportionate impact to low-income homes in this situation.

Table 14 shows the EAD for all residential housing structures by reach and by overtopping and then breach, a Breach at Location 3, and a breach at location 6. The table also shows the resulting percentages for the total value of low-income housing units (including contents) affected by all three flood scenarios relative to the total value of damages to all residential structures in the economic study area under each of the AEPs (flood-year events) evaluated. Table 14 shows that the EAD under the overtop then breach and BL3 scenarios will result in disproportionate impacts to low-income homes when the left bank is breached. The BL6 scenario left bank mixed could result in disproportionate impacts to low-income individuals as well. However, when considering the total EAD under each scenario, only a breach at location 3 could impact greater than 10.5% of low-income structures. Results for the left bank suggest a disproportionate impact to the ESJ community. When considering impacts to both banks, low-income homes could experience disproportionate EAD under the BL3 scenario. Percentages that have been highlighted orange indicate a disproportionate impact for ESJ (greater than 10.5 percent), or low-income, community members. For clarity, the percentage value in the table is as follows:

- Table 14 – the value of low-income residential structure and content damages divided by the total value of residential structure and content damages in the study area.

Table 14 – Percent of Residential Structure EAD by Occupancy Type

Scenario	***Reach***	***RES1***	***RES 2 & 3***	***Total***
Overtop-then-Breach	Left Bank	$914 (65.3%)	$485 (34.6%)	$1,399 (100.0%)
	Left Bank mix	$9,471 (94.8%)	$524 (5.2%)	$9,996 (100.0%)
	Right Bank	$0 (0.0%)	$0 (0.0%)	$0 (0.0%)
	Total	**$10,385 (91.1%)**	**$1,010 (8.9%)**	**$11,395 (100.0%)**
Breach Location 3	Left Bank	$988 (63.5%)	$569 (36.5%)	$1,557 (100.0%)
	Left Bank mix	$2,761 (90.7%)	$284 (9.3%)	$3,045 (100.0%)
	Right Bank	$0 (0.0%)	$0 (0.0%)	$0 (0.0%)
	Total	**$3,749 (81.5%)**	**$853 (18.6%)**	**$4,602 (100.0%)**
Breach Location 6	Left Bank	$1,055 (91.8%)	$94 (8.2%)	$1,149 (100.0%)
	Left Bank mix	$310 (85.4%)	$52 (14.6%)	$363 (100.0%)
	Right Bank	$0 (0.0%)	$0 (0.0%)	$0 (0.0%)
	Total	**$1,365 (90.3%)**	**$146 (9.7%)**	**$1,512 (100.0%)**

6.2. Direct Vehicle

This category estimates losses in vehicle value due to contact with floodwater. Vehicle impacts are modeled similar to building impacts, using a depth-damage function that relates depth of flooding to a percentage loss of vehicle value.

6.2.1.1. Inventory and Valuation

The vehicle inventory was developed based off the structure inventory reference previously. Typically, for each structure category a determination is made as to how many vehicles are located at each structure type. However, simply using this calculation does not accurately reflect residents and employees having the capability of moving vehicles prior to large flood events, or vehicles not being located in the floodplain at time of flooding, or night-time versus day-time differences in vehicle counts. In order to simplify all these assumptions, one vehicle has been assumed at each residential unit, and two vehicles are assumed at each non-residential structure.

In terms of vehicle value, FEMA has developed standard vehicle value information based on relative rates of new versus used vehicles, and percentages of sedans, pickup trucks, and heavy trucks in use. Current escalated costs for vehicles led to a weighted value of $29,200 per vehicle.

6.2.1.2. Damage Function

The depth-damage function from HEC-LifeSim was used for vehicles. The depth-damage function is provided in Table 15.

Table 15 – Depth-Damage Function for Vehicles

Depth (ft)	***Percent Damage***
0.0	0%
0.5	7.5%
1.0	15%
1.5	20%
2.0	40%
2.5	60%
3.0	100%
3.5	100%

6.2.1.3. Expected Annual Damages – Direct Vehicle

The vehicle inventory and depth damage function were utilized within FDA to estimate vehicle damages. Table 16 provides the expected annual damages for vehicles for each of the three modeled scenarios.

Table 16 – Expected Annual Damages – Direct Vehicle

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$2,247	$2,410	$420
Left Bank mix	$9,404	$3,174	$372
Right Bank	$0	$0	$0
Total Scenario EAD	**$11,651**	**$5,584**	**$792**

6.2.1.4. ESJ Analysis – Direct Vehicle

Fall City has very limited public transit options available to its residents. Other than the valley shuttle from North Bend to Duvall and the door-to-door ride-share bus offered by Snoqualmie Valley Transportation (Fall City 2023), residents need to determine their own mode of transport. Fall City is approximately 18 miles east of Bellevue and 24 miles east of Seattle, two major employment hubs in the county. Personal vehicles are the primary mode of transportation to major employment hubs. Every household in Fall City owns a minimum of one vehicle. Over 93 percent of Fall City households have two to four vehicles (USCB 2020), highlighting the importance of personal vehicles as modes of transportation for Fall City residents. As noted in Section 6.2.1.2, even flood levels as low as 0.5 feet can cause damage to a vehicle and flood levels of three feet or higher could result in damages equivalent to the value of the vehicle submerged during the flood.

Potential Disproportionate Risk to ESJ communities:
- Property/Vehicle damage
- Loss of vehicle
- Cost of vehicle repairs/replacement
- Loss of income
- Job loss
- Loss of access to services
- Pressure on social services

Vehicle losses due to flood damage can impact some ESJ populations disproportionately, especially those who need to work hourly and onsite. Without a working vehicle, these individuals would likely be unable to reach their worksite and, thus, lose valuable income opportunities. Just over 22 percent of Fall City residents have occupations that likely pay per hour and require employees to be onsite (10.6 percent have personal care and service occupations, 5.98 percent have food preparation and serving related occupations, and 5.64 percent have sales and related occupations) (USCB 2020). For these individuals, car damage can be detrimental and result in significant loss of income either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities. It can also be a challenge when it comes to accessing health and other services.

In addition, the expense of repairing car damage can disproportionately affect ESJ populations due to their lower earning power. ESJ populations also might not have the ability to move their vehicle to higher ground during a flood warning. They may not have an elevated surface on their property, or a flood protected area and may have no place to live if evacuated. Fall City has twelve vehicle maintenance structures within the potential flood impact zone that would experience some degree of flooding in the event of a severe flood. Limited access to a repair shop could disproportionately affect ESJ populations, who might need their vehicle repaired quickly to return to work and also may not be able to afford to have their vehicles towed to a repair shop in another town.

6.2.2. Direct Road

This category estimates damage to roads based on previously developed depth-to-dollar damage functions per mile of roadway.

6.2.2.1. Inventory

A detailed road network for the study area was exported from HEC-LifeSim. This program uses OpenStreetMap data and extracts each roadway type within a delineated area. All roads extracted from the OpenStreetMap data is presented in Map 10. This data was then further separated into segments to assign depths and damages to a point that reflects a reasonable length of road that still accounts for hydraulic complexity of flood flows. Several different segment lengths were analyzed to determine the reasonable length, which turned out to be 100-foot road segments. Map 11 presents the 100-foot road segment points used in this analysis.

For FDA to calculate damages for these points a “value” of the roadway must be assigned. For this purpose, a value of $4,000 per 100-ft roadway point was used. This value is a price level escalated cost of the maximum damage value for a two-lane street per USACE’s infrastructure damage relationship data (USACE 2012)

6.2.2.2. Damage Function

A depth-to-dollar damage function for roadways was developed from USACE’s detailed infrastructure damage report (USACE 2012). The damage function has been escalated to current prices, and
Table 17 shows the original and escalated values used to develop a depth damage function. For depths in between those listed in the table, a linear interpolation was used.

Table 17 – Depth-to-Dollar Damages per Mile of Two-Lane Road

Year	***Damages at 2-ft Depth***	***Damages at 5-ft Depth***	***Damages at 12-ft Depth***
2012	$44,418	$118,545	$162,946
2023	$57,743	$154,109	$211,830

6.2.2.3. Expected Annual Damages – Direct Road

The road inventory and depth damage function were utilized within FDA to estimate damages to roadways. Table 18 provides the expected annual damages for direct roads for each of the three modeled scenarios.

Table 18 – Expected Annual Damages – Direct Road

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$118	$123	$42
Left Bank mix	$1,685	$355	$59
Right Bank	$0	$0	$0
Total Scenario EAD	**$1,803**	**$478**	**$101**

6.2.2.4. ESJ Analysis – Direct Road

Road flooding and, consequently, road closures could disproportionally affect ESJ populations in the Lower Raging River impact area. The low-income housing cluster located just East of Preston Fall City Road SE, the main road running North to South through Fall City, nestled on the western bank of the Lower Raging River, would likely experience disproportionately negative effects due to flooded roads. A breach at location 3 could result in flooding to Preston Fall City Road SE. While this is the main road running North to South in Fall City, other residents would have the option to take detour routes. Under severe flooding conditions, this ESJ population would likely be unable to travel anywhere via road. This would greatly impact those in the ESJ community needing to work hourly and onsite. A breach at location 6 would also result in the flooding of roadways, though the damage would be less extreme and is anticipated to have a smaller impact than a breach at location 3.

> ***Potential Disproportionate Risk to ESJ communities:***
> *- Loss of income*
> *- Job loss*
> *- Loss of access to services*
> *- Pressure on social services*

Road closures can be detrimental and result in significant loss of income for these individuals, either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities. Additionally, road closures can be a challenge when it comes to accessing healthcare and other services.

There is also great potential for Route 202, running East to West and connecting to Route 203 which runs North, to experience flooding conditions under each modeled scenario. It offers the most direct route East to Snoqualmie, a town with many hospitality and service jobs that pay their workers hourly wages. The flooding of this route could impact ESJ populations that use Route 202 to travel to and from work. Transportation Detour and Delay will be further discussed in Section 6.4.1.

6.2.3. Direct Bridge

This damage category accounts for the potential structural damage to bridges from flooding. Based on review of existing inventory and damage function data, no monetary bridge damages are currently included in this study.

6.2.3.1 Inventory

The only bridge in the study area is the Preston-Fall City Road bridge, for which the continuation of Preston-Fall City Road is the separation line between the two reaches on the left bank. This bridge is two lanes running north-south through the study area and is located along one of the two major roadways leading into and out of Fall City.

6.2.3.2 Damage Function

Review of FEMA's technical manual notes that bridge damages are primarily a function of scour risk (FEMA 2022a), and this scour risk is based off the National Bridge Inventory (NBI) database assessments (FHWA 2023). The NBI scour assessment for this bridge is currently rated a 5, which is defined as "bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles."

With the NBI assessment, plus the very low probability of embankment failure from the levee fragility analysis, it is assumed that this bridge would not fail during a flood event. There are no other detailed depth-damage datasets readily available for bridge damage modeling. It should be noted however, that for this study, bridge damages are not included but that does not mean that this bridge would not incur some damages during a high flow event.

6.2.3.3 Expected Annual Damages – Direct Bridge

Based on the available damage estimation methodologies, no monetized damages for bridges are included at this time.

6.2.3.4 ESJ Analysis – Direct Bridge

There is one bridge located within the potential flood impact zone, the Preston Fall City Bridge. The bridge crosses the Lower Raging River in the Northern section of the economics study area next to the levee at Location 3. Preston Fall City Road SE runs over this bridge and, as mentioned in section 6.2.2.4, this road is the main road that runs north to south in Fall City. Under all flooding scenarios, this bridge will experience flooding conditions and may be closed to traffic due to floodwaters or flood damage. The closure of the Preston Fall City bridge may cause delays and lower work productivity for those who need to alter their routes, especially ESJ community members that work onsite and on hourly schedules.

Potential Disproportionate Risk to ESJ communities:
- Loss of income
- Job loss
- Loss of access to services
- Pressure on social services

Bridge closures can be detrimental and result in significant loss of income for these individuals, either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities. Additionally, it can be a challenge when it comes to accessing healthcare and other services.

These topics will be further discussed in the Transportation Detour and Delay section and the Lost Worker Productivity section. However, it should be noted that no disproportionate impacts are anticipated in this case due to the structural sturdiness of the Preston Fall City Bridge and the unlikelihood of a breach at location 3.

6.2.4. Direct Critical Utilities

This category is intended to address direct impacts to critical utility infrastructure not already addressed in the previous damage categories. Critical utilities typically refer to key critical facility infrastructure such as water treatment plants, electrical substations, etc.

6.2.4.1 Inventory

A review of available geospatial data was completed, and no critical facilities were found in the economic study area. Therefore, no monetary damages have been estimated for this category. It should be noted that the scope of this study did not include assessing potential loss of service impacts from buried arterial utility lines. A community septic drain field is planned to be built in the mixed flow area and future analysis may be needed to assess any flooding impacts to the completed field.

6.2.4.2 Damage Function

No damage function has been developed at this time, as no critical utility structures are in the study area.

6.2.4.3 Expected Annual Damages – Direct Critical Utilities

No monetized benefits have been estimated at this time.

6.2.4.4 ESJ Analysis – Direct Critical Utilities

Given that there are no damages to any utilities, there is no ESJ impact.

6.2.5. Agricultural Loss

This damage category is intended to estimate damages caused by flooding to crops and pasture lands.

6.2.5.1 Inventory

Aerial imagery for the economic study area was reviewed along with agricultural area data sets, and it was determined that no significant agricultural land is found in the study area.

6.2.5.2 Damage Function

No damage function has been developed at this time, as no agricultural land or facilities are present in the study area.

6.2.5.3 Expected Annual Damages – Agricultural Loss

Based on the available inventory and damage function assessments, no monetized damages for agricultural losses have been included.

6.2.5.4 ESJ Analysis – Agricultural Loss

Given that there are no damages to any agricultural properties, there are no ESJ impacts anticipated.

6.2.6. Direct Physical Damages EAD Summary

Table 19 presents a summary of the total scenario EAD for each of the direct physical damage categories that have been included in the monetized damage estimates.

Table 19 – EAD Summary for Direct Physical Damages

Damage Category	***Expected Annual Damages by Scenario***		
	Overtop-then-breach	**Breach location 3**	**Breach Location 6**
Direct Structures and Contents	$15,188	$7,296	$2,141
Direct Vehicle	$11,651	$5,584	$792
Direct Roadway	$1,803	$478	$101
Total EAD	**$28,642**	**$13,358**	**$3,034**

6.3. Response and Restoration Costs and ESJ Impacts

This section discusses response and restoration costs for ancillary actions that communities are expected to take during, and post-flood events include debris removal, building cleanup, emergency response delays, and landscape restoration. Each of the damage categories below include an analysis of the potential ESJ impacts from the responses and restoration costs.

6.3.1. Debris Removal

This category estimates debris removal after a flood event. The potential debris post-flood is related to building debris and natural debris, consisting of vegetation and sediment. The estimation of debris cost removal costs has been developed from FEMA HAZUS model assumptions as documented below.

6.3.1.1. Inventory

The inventory for debris removal is a function of the structure inventory. FEMA's HAZUS program contains depth-to-debris-tonnage relationships for various structure occupancy types. These depth-to-debris relationships create a multiplier of tons per building square footage, as listed in

Table 20. To generate monetary damages, an assumed $50 per ton for debris removal has been used which is consistent with previous USACE studies (USACE 2020) and is reasonable based on current market conditions for this type of effort. Therefore, for each structure a pseudo-point was created with a value input as the maximum amount of tonnage multiplied by the $50 per ton for removal.

Table 20 – Depth-to-Debris Functions in Tons per 1,000-sf of Building Area

Depth (ft)	*0*	*0.5*	*1*	*1.5*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Commercial	0.0	1.5	3.0	4.5	6.0	9.0	10.2	11.5	12.8	14.0	14.6	17.9	21.1	24.4	25.8
School	0.0	0.3	0.7	1.0	1.3	2.0	2.6	3.0	3.3	3.7	4.0	4.7	5.3	6.0	6.6
Government	0.0	0.3	0.6	0.9	1.2	1.7	2.3	2.5	2.8	3.0	3.2	3.9	4.5	5.2	5.8
Industrial	0.0	0.1	0.3	0.4	0.5	0.8	1.0	1.1	1.2	1.3	1.4	1.8	2.2	2.6	3.0
Out Building	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.9	1.1	1.3	1.5
Church	0.0	0.1	0.3	0.4	0.5	0.8	1.0	1.1	1.2	1.2	1.3	1.7	2.1	2.4	2.8
Single Family Residential	0.0	0.5	1.0	1.5	2.1	3.1	4.1	4.	5.5	6.1	6.8	6.8	6.8	6.8	6.8
Manufactured Home	0.0	2.1	4.1	4.2	4.3	4.5	4.8	5.0	5.2	5.4	5.6	5.8	6.1	6.3	6.5
Duplex	0.0	0.5	1.0	1.5	2.1	3.1	4.1	4.8	5.5	6.1	6.8	7.0	7.3	7.5	7.8

6.3.1.2. Damage Function

A damage function was developed from the information in Table 20. The generated damage function is based on the maximum damage (100%) occurring at 12-feet of depth, and the remaining percent damages being calculated as a ratio of debris tons at a depth relative to the maximum. A sample percent-damage function for single family residential structures is presented in Table 21.

Table 21 – Single Family Residential Depth-to-Damage Percent for Debris Removal

Depth (ft)	***Percent Damage***
0	0.0%
0.5	7.5%
1.0	15.1%
1.5	22.6%
2.0	30.1%
3.0	45.2%
4.0	60.3%
5.0	70.2%
6.0	80.1%
7.0	90.1%
8.0	100%
9.0	100%
10.0	100%
11.0	100%
12.0	100%

6.3.1.3. Expected Annual Damages – Debris Removal

The debris removal inventory and depth damage function were utilized within FDA to estimate expected damages. Table 22 provides the expected annual damages for debris removal for each of the three modeled scenarios.

Table 22 – Expected Annual Damages – Debris Removal

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$56	$60	$16
Left Bank mix	$168	$55	$6
Right Bank	$0	$0	$0
Total Scenario EAD	**$224**	**$115**	**$22**

6.3.1.4. ESJ Analysis – Debris Removal

According to FEMA's flood debris removal webpage, 15.1 percent of fatalities that occur due to floods in the US take place during the post impact phase and are mainly related to cleanup operations (FEMA 2023). FEMA also notes that private citizens face a significant risk of injury during cleanup. A "second wave" of injuries following a natural disaster occurs when citizens remove debris and repair

Potential Disproportionate Risk to ESJ communities:
- Injuries that could lead to disabilities or death
- Long-term health issues due to exposure to toxins
- Loss of income due to injury
- Job loss due to injury
- Pressure on social services

buildings themselves. As mentioned in section 6.1.1.4, the ESJ analysis for structural damage, the ESJ community near the junction of the Snoqualmie River and Lower Raging River will likely experience structural damage in either levee breach scenario, and the ESJ community in the western part of the impact zone would likely experience damage if there was a severe flooding incident.

As part of the response to floods in Washington State in 2021, most of cleanup was conducted by private citizens, volunteers, and first responders (Monthei 2021). The County can also request assistance from the Department of Ecology's Washington Conservation Corps (WCC). The WCC crews assist with flood response efforts by "installing sandbags, operating pumps clearing debris and more" (WSDOE 2023). These crews have been deployed all over the US in response to floods and assisted both Skagit County and Clallam County respond to flooding events in 2021.

While the first responders and WCC teams are aware of potential toxins in the flood water and are equipped with the proper protective gear, private citizens and volunteers might not have the appropriate knowledge of the dangers these toxins and flood waters pose. According to the CDC, floodwaters can contain downed power lines, waste, bacteria, household/medical/industrial hazardous waste, contaminants, and carcinogenic compounds (CDC 2022).

ESJ populations may not know of the risks flood water and debris removal pose due to potential language barriers or lack of education. They also may not be able to afford the proper protective gear needed to safely remove debris from their homes and properties. In addition, paying for a professional debris removal team may be too expensive for ESJ communities, leading them to take more risk, which could result in "second wave" injuries, medical bills, and potentially time away from work. According to

Table 20, it costs $50 per ton of debris removal for various structure occupancy types. Depending on flood depths, the cost for cleaning debris from a duplex or manufactured home, both considered low-income housing units, can range from $25 to $390. Deep flood waters result in expensive debris cleanup that could significantly impact the financial stability of ESJ communities or encourage them to handle debris clean up privately, putting them at physical risk.

Debris removal by the ESJ community members could disproportionately affect these individuals due to the health and possible fatality risks associated with extensive debris removal without proper protective gear and/or training. For these individuals, health issues caused by debris removal can be detrimental and result in significant loss of income either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities.

The impact to the response teams and those working for crews removing debris will likely not have a disproportionate impact on ESJ communities in Fall City. Local firefighters make up a large portion of the flood response team, and these individuals are compensated well for their work. The emergency response team will be discussed further in Section 6.3.3.

6.3.2. Building Cleanup

This damage category addresses the cleanup costs that would be incurred at buildings for the extraction of floodwaters, drying out of buildings and contents, and any necessary decontamination treatments such as mold and mildew abatements.

6.3.2.1. Inventory

The inventory for building cleanup is based on the structure inventory. Pseudo-structure points were developed consisting of the full structure inventory in each reach with an estimated total value of cleanup input for structure values within the FDA model. The total value of cleanup costs is a function of structure square footage and an assumed escalated cost to cleanup of $10 per square foot. This value was taken from previous USACE studies (USACE 2020a).

6.3.2.2. Damage Function

Recent studies by USACE have developed a depth-damage function for cleanup costs, which assigns the full value of cleanup costs once depths at the structure reach 3 feet. The depth-damage function is interpolated at depths below 3-feet. The damage function used for this analysis is provided in Table 23.

Table 23 – Depth-Damage Function for Building Cleanup Costs

Depth (ft)	Percent Damage
0.0	0.0%
0.5	16.7%
1.0	33.3%
1.5	50.0%
2.0	66.7%
2.5	83.3%
3.0 and over	100.0%

6.3.2.3. Expected Annual Damages – Building Cleanup

The building cleanup inventory and depth damage function were utilized within FDA to estimate expected damages. Table 24 provides the expected annual damages for building cleanup costs for each of the three modeled scenarios.

Table 24 – Expected Annual Damages – Building Cleanup

Reach	Overtop-then-Breach	Breach Location 3	Breach Location 6
Left Bank	$1,451	$1,528	$278
Left Bank mix	$3,640	$1,291	$143
Right Bank	$0	$0	$0
Total Scenario EAD	**$5,091**	**$2,819**	**$421**

6.3.2.4. ESJ Analysis – Building Cleanup

Building cleanup includes flooded housing units and businesses affected by a breach at location 3 or 6 or overtopping along the Lower Raging River. A breach at location 3 will entail far more extensive building cleanup than a breach at location 6. Under both scenarios, ESJ populations will likely be affected. The time and cost associated with building cleanup can be more burdensome to ESJ communities due to their lower earning power. Spending time away from work to clean a building, residential or business, can also disproportionately impact ESJ populations that rely on consistent work and pay for their livelihoods.

> ***Potential Disproportionate Risk to ESJ communities:***
> *- Injuries that could lead to disabilities or death*
> *- Long-term health issues due to exposure to toxins*
> *- Loss of income due to injury or other health issues*
> *- Job loss due to injury or other health issues*
> *- Pressure on social services*

Not much information is available regarding the makeup of potential building cleanup crews for a Lower Raging River flood or levee breach. However, elsewhere in the country, these crews can include low-wage and marginalized employees. ESJ communities may not be able to afford these services and may opt to clean their buildings themselves. This could put them at risk of exposure to molds, asbestos, and other chemicals and toxins in the flood water. Potential exposure could occur not only during the cleaning process, but also later on. Poor building cleanup can result in wet wood, which promotes mold growth leading to major building and health concerns down the line. ESJ populations may not have the time, knowledge, or funds to properly clean their buildings, which could lead to far greater health and safety impacts for these individuals in the longer run.

In essence, building cleanup by the ESJ community members could disproportionately affect these individuals due to the health and possible fatality risks associated with cleanup without proper protective gear and/or training. For these individuals, health issues caused by building cleanup can be detrimental and result in significant loss of income either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities.

6.3.3. Emergency Response

This damage category includes costs resulting from a flood for emergency response operations which may include flood fighting and increased costs of police and/or fire services.

6.3.3.1. Inventory

The inventory data required to estimate emergency response costs came from the developed structure inventory. This inventory, based on USACE emergency cost analysis, has been narrowed to only include residential structures (USACE 2012). FDA requires input of a value for the pseudo-structure points developed from the residential structure inventory. The value input is the maximum cost of emergency response per residential unit. Therefore, for residential structures with multiple units, the costs taken from USACE's emergency cost analysis has been multiplied by the assumed number of units at that structure point. The values for each residential category in the inventory are presented in Table 25.

Table 25 – Emergency Response Inventory Values

Occupancy	*Description*	*Assumed Units*	*Inventory Value*
RES1	Single Family Residential	1	$2,782
RES2	Manufactured homes	1	$2,782
RES3A	Duplex	2	$5,564
RES3B	Multi Family - 3 to 4 units	3	$8,346

6.3.3.2. Damage Function

A depth-damage function was developed based off previous emergency response cost data by the USACE (USACE 2012). The previous USACE analysis presented increased emergency response costs for fire and police services, which have been escalated to current prices. Table 26 provides the primary depths, escalated dollar damages, and percent damages that were used to develop the depth-damage function input into FDA. Damages for depths below, and in between, the depths shown have been linearly interpolated.

Table 26 – Emergency Response Dollar Damages by Depth

Cost Category	*2-feet*	*5-feet*	*12-feet*
Police	$8	$304	$536
Fire	$185	$455	$2,246
Total	$192	$759	$2,782
Percent Damage	6.9%	27.3%	100%

6.3.3.3. Expected Annual Damages – Emergency Response

The emergency response inventory and depth damage function were utilized within FDA to estimate expected damages. Table 27 provides the expected annual damages for emergency response costs for each of the three modeled scenarios.

Table 27 – Expected Annual Damages – Emergency Response

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$9	$9	$1
Left Bank mix	$38	$16	$2
Right Bank	$0	$0	$0
Total Scenario EAD	**$47**	**$25**	**$3**

6.3.3.4. ESJ Analysis – Emergency Response

There are two clusters of low-income housing units that could require emergency response in the event of a levee breach on the Lower Raging River. The ESJ community near the junction of the Snoqualmie and Raging Rivers, in the Left Bank mix reach, could experience flooding in the event of a breach at location 3 along the Raging River. The ESJ community in the western portion of the impact zone, in the Left Bank reach, could experience flooding in the event of a breach at location 6 along the Raging River. Based on the number of structures impacted under all three flooding scenarios, the number of ESJ households potentially requiring emergency services will not be disproportionate to the rest of Fall City (see Section 6.1.1.4.)

First responders to a flood event would mainly consist of the fire station crews and local volunteers from the King County fire District 27, also located in the economic study area. According to the US Bureau of Labor Statistics, the annual mean wage for firefighters in Washington state is $76,280 (BLS 2021). These frontline workers are not low income, and though the crew includes a few individuals with racial and ethnic diversity, these front-line workers are not considered part of the ESJ community. However, they would be responsible for responding to ESJ populations in a flood emergency. There are a countless number of cases where emergency flood responses were inadequate and far slower for areas with ESJ populations. Hurricane Katrina is the most public and obvious example of ESJ populations receiving poorer and slower emergency response to an extreme flooding event (Moore 2005). The potential number of impacted households is far less in Fall City than in New Orleans. Fall City has less distinct, or isolated, ESJ populations and a smaller percentage of minority individuals as well. While there is the possibility for disparity in an emergency response to a flooding event, it is less likely to occur during the emergency response phase and more likely to occur during the rebuilding/reoccupation phase (Gerber 2006), which is discussed further in Section 6.5.1.4.

6.3.4. Landscape Restoration

This damage category accounts for the repair and/or re-landscaping of significant public facilities such as parks, golf courses and schoolyards, which would incur damages during a flood event.

6.3.4.1. Inventory

A review of aerial imagery was completed to assess and document the significant landscaped areas within the extents of the economic study. As shown in Map 12, there are only two large, landscaped areas present. One being the fields at the elementary school at the northwest section of the study area, and the second being portions of the golf course on the right bank of the river. These two areas represent approximately 6.8 acres of landscaped areas, which have been subsequently converted into points representing approximately 6,725 square feet of landscape. This was done to better refine the inputs into FDA such that the intricacies of the flooding are better represented in the assessment of damages. This resulted in 44 points being included in the FDA model. As with the other point information, a value for each point must be entered in FDA. This value is estimated as the area the point represents multiplied by a cost per square foot taken from USACE's value of $28,000 per acre for restoration and re-landscaping (USACE 2020). This value has not been escalated but based on a cost review, is a conservative value for the type of restoration and landscaping that would be required in this study area.

6.3.4.2. Damage Function

A damage curve used on previous USACE studies was used to reflect the damage as a percent of the total restoration cost and depth of flooding (USACE 2020). The basic parameters used to develop the depth-damage function are presented in Table 28.

Table 28 – Landscape Restoration Depth Damage Parameters

Depth (ft)	***Damage Percent***
0.0	0%
2.7	81%
4.3	92%
6.3+	100%

6.3.4.3. Expected Annual Damages – Landscape Restoration

The landscape restoration inventory and depth damage function were utilized within FDA to estimate expected damages. Table 29 provides the expected annual damages for landscape restoration costs for each of the three modeled scenarios.

Table 29 – Expected Annual Damages – Landscape Restoration

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$0	$0	$14
Left Bank mix	$0	$0	$0
Right Bank	$0	$0	$0
Total Scenario EAD	**$0**	**$0**	**$14**

6.3.4.4. ESJ Analysis – Landscape Restoration

Most of the study area is residential. According to the model results, EAD for landscape restoration hovers around $14 if there is a breach at location 6. Under the other scenarios the expected damages are $0. Therefore, landscape restoration costs accrued from a flooding event from the Lower Raging River would be minor and have no disproportionate effect on the ESJ population.

6.3.5. Response and Restoration EAD Summary

The response and restoration inventory and depth damage function were utilized within FDA to estimate expected damages.

Table 30 presents a summary of the total scenario EAD for each of the direct physical damage categories that have been included in the monetized damage estimates.

Table 30 – EAD Summary for Responses and Restoration Costs

Damage Category	*Expected Annual Damages by Scenario*		
	Overtop-then-breach	**Breach location 3**	**Breach Location 6**
Debris Removal	$224	$115	$22
Building Cleanup	$5,091	$2,819	$421
Emergency Response	$47	$25	$3
Landscape Restoration	$0	$0	$14
Total EAD	**$5,361**	**$2,959**	**$460**

6.4. Implicit Costs and ESJ Impacts

This section discusses the implicit costs account for damage categories that do not relate directly to a damage from water impacting a physical item. These categories relate primarily to ancillary monetary losses that flooding causes which includes transportation detours and delays, business disruptions, recreational activity losses and worker productivity decreases. A discussion of the ESJ impacts arising from the implicit costs are included in each of the damage categories below.

6.4.1. Transportation Detour and Delay

This damage category addresses impacts to users of roads, rail, and airport transportation. For this study area, the only impacted mode of transportation is for vehicles on roadways. No railroads or airports are in the study area.

6.4.1.1. Inventory

A review of local traffic county data was completed to determine availability of required data to develop the inventory for traffic delays. The closest point that provides recent traffic count data was obtained from Washington State Department of Transportation. No recent traffic data is available directly in the economic study area. However, Map 13 provides a figure directly from WSDOT that shows daily traffic count data on the north end of the State Route 202 bridge over the Snoqualmie River. This traffic count data at this point reflects traffic travelling north and south over the bridge. Thus, the traffic counts reflected in this data point would be impacted if the access to the bridge is blocked by flooding.

6.4.1.2. Damage Function

Using the intersection of Redmond-Fall City Road and Preston-Fall City Road as the key point of access for the State Route 202 bridge, a damage function can be estimated at this point in the floodplain using traffic count information, estimated detour times, and a monetized value of lost time per vehicle.

Looking at the traffic count data from WSDOT shows recent estimates of 12,473 average daily vehicles traveling across the SR 202 bridge (WSDOT 2023). This value is further refined to reflect that depending on time of day a flood event occurs, varying amounts of vehicles will be impacted. During a flood vehicle traffic patterns will likely change. So, the 12,473 vehicles estimate has been further reduced by 50% to estimate a daily number of vehicles travelling through the area.

Next, an assumption on the length of time required for the detour is developed to estimate how many vehicles would be impacted by a detour over the timeframe until the road could be passable. An assumption was made for each flood event magnitude, and the duration assumption was based on depth of flooding at the key reference point and understanding of detours from previous project assumptions. Lastly, an escalated detour route duration and value of $32.18 per hour was applied to each vehicle (FEMA 2020). The estimated detour route duration assumes that if the vehicles need to use a bridge to get over the Snoqualmie, they would be diverted well upstream or downstream of Fall

City to access the nearest bridges in Carnation or Snoqualmie. The results of these assumptions for each scenario are presented in Table 31.

Table 31 – Estimated Traffic Detour Costs by Flood Event

Scen.	Item	50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.2% AEP
Overtop-then-Breach	Flood and Detour Duration	0	0	0	0	0	0	24
	Vehicles Impacted	0	0	0	0	0	0	6,237
	Added Detour Route Time per Vehicle(min.)	0	0	0	0	0	0	30
	Added Detour Costs	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$100,353**
Breach Location 3	Flood and Detour Duration	1	2	4	6	8	12	24
	Vehicles Impacted	260	520	1,040	1,560	2,079	3,119	6,237
	Added Detour Route Time per Vehicle(min.)	30	30	30	30	30	30	30
	Added Detour Costs	**$4,183**	**$8,367**	**$16,734**	**$25,100**	**$33,451**	**$50,185**	**$100,353**
Breach Location 6	Flood and Detour Duration	0	2	4	6	8	12	24
	Vehicles Impacted	0	520	1,040	1,560	2,079	3,119	6,237
	Added Detour Route Time per Vehicle(min.)	0	30	30	30	30	30	30
	Added Detour Costs	**$0**	**$8,367**	**$16,734**	**$25,100**	**$33,451**	**$50,185**	**$100,353**

6.4.1.3. Expected Annual Damages – Transportation Detour and Delay

The traffic detour and delay inventory and depth damage function were utilized within FDA to estimate expected damages. Table 32 provides the expected annual damages for transportation detour and delay costs for each of the three modeled scenarios.

Table 32 – Expected Annual Damages – Transportation Detour and Delay

Reach	*Overtop-then-Breach*	*Breach Location 3*	*Breach Location 6*
Left Bank	$783	$365	$41
Left Bank mix	$0	$0	$0
Right Bank	$0	$0	$0
Total Scenario EAD	**$783**	**$365**	**$41**

6.4.1.4. ESJ Analysis – Transportation Detour and Delay

As discussed in Section 6.2.1.4., every household in Fall City has at least one vehicle with an average of four vehicles per household. With few public transit options, almost every household relies on personal vehicles to travel to and from work. As a result, flood impacts to every road in the economic study area have the potential to affect numerous Fall City residents' ability to travel to and from their homes.

Potential Disproportionate Risk to ESJ communities:
- Loss of income
- Job loss
- Delayed access to services
- Pressure on social services

In section 6.2.2.4, the direct road impacts were analyzed for ESJ populations within the community. It is important to note that the ESJ population located near the junction of the Snoqualmie and Lower Raging River are dependent on Preston Fall City Road SE for all travel. If this road were to sustain severe flooding conditions, which is likely if a breach at location 3 occurs, this population would not have any detour options available to them. A breach at location 6 would also result in flooding throughout the economic study area and likely impact a more diverse group of Fall City residents.

It is important to note that while the entire community may have to deal with transportation detours and delays, traffic detours and delays can result in disproportionate impacts to some ESJ populations, especially those who need to work hourly and onsite. As noted in the Business Disruption Section 6.4.2.4, 75 percent of racial and ethnic working minorities have occupations in industries that typically offer hourly wages. Delays and detours cut into the valuable time these individuals, who often make up the majority of ESJ communities, can work and make a living.

For these individuals, traffic detours and delays can be detrimental and result in significant loss of income either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities. It can also be a challenge when it comes to accessing health and other services.

Travel disturbances have a much smaller effect on those with higher income, salaried positions, or the option to work from home as time spent travelling does not equate to lost work opportunities and income. ESJ populations are low-income and may live paycheck to paycheck. Therefore, lost income opportunities have larger consequences for ESJ populations than those with greater financial stability and more work flexibility.

6.4.2. Business Disruption (Regional Economic Impacts)

This damage category is included to reflect losses to non-residential properties due to flooding which could cause temporary closures of businesses. During a closure, businesses would experience losses in sales and revenue. In addition to direct revenue losses, other indirect losses would be incurred, tax revenue could decrease, plus there is potential for job losses due to business shutting down for an extended period of time.

It should be noted that this damage category is often a stand-alone damage estimate for reference to help gauge relative losses to the specific business in this area, and is not included in standard benefit-cost analyses. This is because these losses are considered Regional Economic Development (RED) losses, and do not fully reflect losses to the greater economy of the United States as a whole, but are a transfer between regions. Because of this most Federal agencies do not include these benefits for benefit-cost analysis.

6.4.2.1. Inventory

The inventory was developed from the structure inventory referenced previously. Commercial and industrial structures, which are assumed to generate sales and revenue were extracted for this damage category. To account for the direct and indirect business losses, tax losses, and job losses, three pseudo-structure points were created for each of the commercial and industrial structures. For each of these structure points, a total estimated yearly revenue value was input into the FDA model. This yearly revenue value is a function of a dollars per square foot per year multiplier. At this time, an assumption of $400 revenue per square foot per year was used for all commercial structures and $560 revenue per square foot per year for all industrial structures. These values were determined after reviewing FEMA's standard values, which saw wide swings in values per square foot between updates from 2020 to 2023 data. Also, no other readily available sources could be found to help document the value multiplier. In the end, the two values listed here are within the range of values found in FEMA's standard value documents.

6.4.2.2. Damage Function

The damage functions for the business losses (direct, indirect, and induced), tax losses and job losses have all been developed relative to the total annual revenue input into the structure inventory for each structure point in this category. The depth-damage percentages were developed based on several key assumptions. One was a determination of the direct losses to a business due to having to shut down post flood event. This is a time-based estimation, where a depth-to-closure duration was developed from review of existing assumptions in FEMA's HAZUS technical manual (FEMA 2022a), which are relatively long, and previous project assumptions which present shorter closure periods post flood (Tetra Tech 2014). Table 33 provides the assumptions used to estimate business down times based on flood depth at the structure. With these assumptions a ratio of annual sales loss can be estimated and factored into the depth damage function.

Table 33 – Business Closure Assumptions Relative to Depth

Min. Flood Depth (ft)	*Max. Flood Depth (ft)*	*Assumed Closure Time (days)*
0	0.25	15
0.25	0.5	30
0.5	1.0	45
1.0	2.0	60
2.0	3.0	90
3.0	Over 3.0	180

Another of the key inputs to the damage function estimation is outputs from IMPLAN. IMPLAN is an industry-standard input-output model that can predict the economic impacts of a change in one or several economic activities within an economy. For this study, IMPLAN was used to estimate the adverse impacts from indirect and induced business losses, tax revenue losses, and job loses which are caused by business closures due to flooding. IMPLAN was used to model a suite of losses for different representative industry mixes found in the floodplain, to develop estimated loss ratios relative to the direct loss for indirect, induced, taxes and jobs. These ratios are then included into the damage functions such that the damage function calculates the indirect, induced, taxes and job losses in accordance with the direct loss referenced above.

Resulting damage functions were developed for three categories which include a combined business or sales loss (direct, indirect, and induced), tax losses, and job losses for each of the business occupancy types. A sample depth-damage function for the COM1 occupancy type is provided in Table 34.

Table 34 – Sample Depth Damage Function for COM1 Business Disruption Losses

Category	*0.0-ft*	*0.5-ft*	*1.0-ft*	*1.5-ft*	*2.0-ft*	*3-ft*	*4-ft*	*5-ft+*
Job Loss	0%	3.96E-07	5.94E-07	5.94E-07	7.92E-07	1.19E-06	2.38E-06	2.38E-06
Sales Loss	0%	11.9%	17.9%	17.9%	23.8%	35.7%	71.4%	71.4%
Tax Loss	0%	1.9%	2.8%	2.8%	3.7%	5.6%	11.1%	11.1%

6.4.2.3. Expected Annual Damages – Business Disruption

The business disruption inventory and depth damage function were utilized within FDA to estimate expected damages. Table 35 provides the expected annual damages for business sales (direct and indirect), tax losses, and estimated job losses for each of the three modeled scenarios.

Table 35 – Expected Annual Damages – Business Disruption

Scenario	*Reach*	*Job Losses*	*Sales Losses*	*Tax Losses*	*Combined Losses*
Overtop-then-Breach	Left Bank	0.08	$21,242	$2,806	$24,048
	Left Bank mix	0.03	$6,384	$804	$7,188
	Right Bank	0.00	$0	$0	$0
	Scenario Total	**0.11**	**$27,626**	**$3,609**	**$31,236**
Breach Location 3	Left Bank	0.09	$21,949	$2,897	$24,846
	Left Bank mix	0.02	$3,931	$475	$4,406
	Right Bank	0.00	$0	$0	$0
	Scenario Total	**0.11**	**$25,880**	**$3,372**	**$29,252**
Breach Location 6	Left Bank	0.01	$3,040	$423	$3,463
	Left Bank mix	0.00	$355	$43	$398
	Right Bank	0.00	$0	$0	$0
	Scenario Total	**.01**	**$3,396**	**$466**	**$3,862**

6.4.2.4. ESJ Analysis

As noted in Section 6.2.1.4, just over 22 percent of Fall City residents work in industries that have hourly wages. Racial and ethnic minorities make up 27.8 percent of Fall City's population. This group is composed of individuals who identify as Hispanic, Latino, Asian, and multi-racial. Of these minority workers, 75 percent in Fall City have hourly paying jobs (USCB 2020), and a far greater percentage of minority individuals work hourly paying jobs compared to the

Potential Disproportionate Risk to ESJ communities:
- Loss of income
- Loss of livelihood due to business closure
- Pressure on social services

entire Fall City population. A flood from the Lower Raging River could impact 34 of the 45 businesses located within the economic study area. Flood damages could result in the temporary, long-term, or permanent closure of local businesses. The Fall City ESJ communities, including the hourly wage minority individuals described above, will be disproportionately impacted by a flooding event due to business disruption. These community members generally do not have the financial backing to support them for extended periods without income. A long-term business closure due to flood damage could detrimentally impact ESJ communities who rely on these businesses for their livelihood.

Small business owners from ESJ communities could also face disproportionate impacts from business disruption caused by a flood from the Lower Raging River. Of the 45 businesses located within the potential impact zone, 34 could endure damage from a breach at location 6 or location 3 along the Lower Raging River. Due to smaller profit margins and smaller gross income, small businesses often struggle to recover from closures, and may not have the funds to pay for building repairs. Fall City is home to a number of small businesses, including a women-owned coffee shop, a family-Mexican restaurant, a local farmhouse market, a vintage flea shop, and burger stand to name a few. Deep flood waters could result in the closure of these businesses, resulting in loss of livelihood for the owners and employees.

For such business owners and employees, business disruptions can be detrimental and result in significant loss of income either in the form of less income or no income altogether (loss of livelihood). In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities.

6.4.3. Recreation Loss

This damage category is intended to account for impacts to recreational opportunities caused by flooding to recreational and natural land resource areas.

6.4.3.1 Inventory

A review of the study area was conducted, and no significant recreational areas were found within the economic study's footprint. As such no monetized damages are included in the FDA modeling. However, it should be noted that local recreational opportunities are likely to be impacted, whether those are local sidewalk and trails being inundated, or smaller park areas, which were not proposed to be studied for the EAD analysis.

6.4.3.2 Damage Function

No damage function has been developed as not significant recreational areas are found in the study area.

6.4.3.3 Expected Annual Damages – Recreation Loss

No monetized damages are currently included based on the inventory and damage function assessments.

6.4.3.4. ESJ Analysis – Recreation Loss

Fall City Memorial Park, the only recognized recreational area within the potential flood impact zone, is not located in the vicinity of any low-income housing units. Since it is the only park in the economic study area, flood impacts to this recreation site are unlikely to disproportionately impact ESJ populations. The park is adjacent to Fall City Elementary School, so it is also unlikely to host a homeless population that could be affected by flood damage to the park. The park would see no flooding under the overtopping then breach scenario or a breach at location 3. Only a breach at location 6 would result in any flooding, and even that appears to be minor. There is another park located just

> ***Potential Disproportionate Risk to ESJ communities:***
> *- Loss of subsistence fishing opportunities*
> *- Loss of income from recreation- and river-related jobs*
> *- Job loss*
> *- Pressure on social services*

north of the economic study area. Though it is outside the study area for flooding from the Lower Raging River, it would certainly experience substantial flooding from the Snoqualmie River, thus eliminating the closest alternative recreation site for Fall City residents.

The Raging River and Snoqualmie River are known fly fishing rivers and contain chinook salmon, steelhead and coho (King County 2016). Flooding could impact both subsistence fishing and river-related livelihoods. While fishing can be viewed as a fun pastime, some ESJ populations and Tribes may rely on subsistence fishing as a regular source of food. In fact, the Tulalip Tribe holds Usual and Accustomed tribal treaty fishing rights in this area. Others may be part of the local fishing industry and rely on good fishing conditions for their income. Depending on the season, flooded riverbanks could make the rivers unfishable and greatly impact ESJ communities that rely on the fish as a steady source of food or income. Other ESJ community members that work as river guides could lose valuable income and livelihood due to flooded river conditions.

For these individuals, flooding into some of these areas can be detrimental and result in loss of income either in the form of under employment or job loss altogether. In cases where new employment is difficult to find, this could also divert resources from social services and other programs geared towards ESJ communities.

6.4.4. Lost Worker Productivity

This damage category is intended to characterize worker productivity impacts that arise due to adverse human health impacts following a flood event. FEMA BCA methodology for their Hazard Mitigation Assistance grant program establishes a standard dollar value per affected resident that experiences a flood event.

6.4.4.1. Inventory

The inventory for this damage category is applicable to the residential structures in the structure inventory. A pseudo-structure was developed based on the residential structure inventory. An estimated number of units per structure was incorporated for multi-family residential structure points. Then an estimate number of residents per unit was developed from comparing several levels of data extracted from available Census Data (USCB 2020). For this damage category, depending on source and scale of data used, the range of residents per unit varied between 2.3 and 2.9. Therefore, it was assumed each residential unit has 2.5 residents each. Then, to determine number of employed persons per residential unit, a ratio of total employed persons in King County (FRED 2022) compared to overall population in the county was developed. The estimated ratio of employed persons to overall population in the County was estimated as 50%, which was then applied to each residential unit to estimate the employed persons per unit.

Lastly, for input into FDA, a monetary value of the loss productivity was applied. A current value of $8,736 per employed person was taken directly form FEMA’s BCA Toolkit (FEMA 2022). The input damage values by residential structure type are presented in Table 36.

Table 36 – Lost Productivity Value by Residential Structure Type

Occupancy	***Description***	***Assumed Units***	***Employed Persons per Unit***	***Inventory Value***
RES1	Single Family Residential	1	1.25	$10,920
RES2	Manufactured homes	1	1.25	$10,920
RES3A	Duplex	2	1.25	$21,840
RES3B	Multi Family - 3 to 4 units	3	1.25	$32,760

6.4.4.2. Damage Function

The damage function for this category is simply a function of whether an employed person's residential structure is inundated by flooding. The available data for this damage category does not classify a depth-damage function. The FDA model is set-up such that if water inundates a residential unit, that unit incurs the value of lost productivity referenced in Table 36.

6.4.4.3. Expected Annual Damages – Lost Worker Productivity

The lost worker productivity inventory and depth damage function were utilized within FDA to estimate expected damages. Table 37 provides the expected annual damages for lost worker productivity costs for each of the three modeled scenarios.

Table 37 – Expected Annual Damages – Lost Worker Productivity

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$426	$421	$122
Left Bank mix	$2,835	$840	$98
Right Bank	$0	$0	$0
Total Scenario EAD	**$3,261**	**$1,261**	**$220**

6.4.4.4. ESJ Analysis – Lost Worker Productivity

There are two ESJ communities that will likely experience the negative impacts from a levee breach at location 3 or 6 along the Lower Raging River. While the number of ESJ households will not be disproportionately impacted, the value of the total damages will be greater for ESJ populations compared to other Fall City residents (see section 6.1.1.4.). The negative impacts include structural damage to their homes and vehicles alongside burdensome road damage, detours and other obstacles that may prevent them from working and receiving income. Socially and economically vulnerable ESJ populations can be affected more by mental health and anxiety issues caused by a flooding event due to the more direct and immediate effects of job losses, loss of homes, loss of access to resources, transportation disruptions, etc. After experiencing a flooding event, some turn to substances to help them cope. "In 2010, researchers found that approximately one-third of Hurricane Katrina survivors who had been displaced to Houston, Texas had increased their tobacco, alcohol, or marijuana use after the storm" (Sheikh 2018). Increased mental stress, anxiety, and potential substance use could all impact a person's ability to work productively. There is a greater potential for these stressors to impact ESJ communities' work productivity because they have additional burdens to consider. For example, the financial impacts of a flood are far more stressful for a household with little to no savings and no insurance than they would be for a household with a stronger financial standing. ESJ populations are also more likely to become displaced and can struggle to find alternative housing, adding additional stress to these community members. Finally, the ESJ populations in Fall City may also have reduced access to both physical and mental health resources, thus prolonging their inability to work productively. This will be further discussed in section 6.5.4. Mental Stress and Anxiety.

> ***Potential Disproportionate Risk to ESJ communities:***
> *- Loss of income due to lower productivity*
> *- Job loss*
> *- Higher incidence of stress-related issues, including mental health issues*
> *- Pressure on social services*

6.4.5. Implicit Costs EAD Summary

Table 38 presents a summary of the total scenario EAD for each of the direct physical damage categories that have been included in the monetized damage estimates for the implicit cost category.

Table 38 – EAD Summary for Implicit Costs

Damage Category*	***Expected Annual Damages by Scenario***		
	Overtop-then-breach	**Breach location 3**	**Breach Location 6**
Transportation Detour and Delay	$783	$365	$41
Business Disruption	$31,236	$29,252	$3,862
Recreation Loss	$0	$0	$0
Lost Worker Productivity	$3,261	$1,261	$220
Total EAD	**$35,280**	**$30,878**	**$4,123**
Job Losses (not included in EAD)	0.11	0.11	0.01

**Damage categories for implicit costs include local/regional impacts*

6.5. Public Health and Safety and ESJ Impacts

This section discusses the public health and safety damages during and after a flood event, as well as the impact to residents' well-being after a flood. Damage categories for this include residential evacuation and subsistence costs, public and critical facility service impacts, utility loss of service, and mental stress and anxiety impacts to residents. A discussion of the ESJ impacts arising from the public health and safety impacts are included in each of the damage categories below.

6.5.1. Residential Evacuation, Subsistence and Reoccupation

This damage category addresses the potential need for residents to evacuate their homes, subsist following evacuation (food, lodging, etc.), and then reoccupy their residence.

6.5.1.1. Inventory

The inventory for this category is based on the residential structures from the structure inventory. For each residential unit, a maximum damage value was input per unit. This maximum damage value was taken from previous USACE reporting (USACE 2012). For structures with multiple units, the escalated maximum value of $7,136 was multiplied by the number of residential units. Table 39 presents the inventory values used by residential structure type.

Table 39 – Lost Productivity Value by Residential Structure Type

Occupancy	***Description***	***Assumed Units***	***Inventory Value***
RES1	Single Family Residential	1	$7,136
RES2	Manufactured homes	1	$7,136
RES3A	Duplex	2	$14,272
RES3B	Multi Family - 3 to 4 units	3	$21,408

6.5.1.2. Damage Function

A depth-damage function was developed based off previous emergency response cost data by the USACE (USACE 2012). The previous USACE analysis presented costs for evacuation, subsistence and reoccupation based on depth of flooding at a residential unit, which have been escalated to current prices. Table 40 provides the primary depths, escalated dollar damages, and percent damages that were used to develop the depth-damage function input into FDA. Damage percentages for depths below, and in between, the depths shown were linearly interpolated for input into the FDA model.

Table 40 – Evacuation, Subsistence and Reoccupation Dollar Damages by Depth

Cost Category	***2-feet***	***5-feet***	***12-feet***
Damages	$1,616	$3,602	$7,136
Percent Damage	6.9%	27.3%	100%

6.5.1.3. Expected Annual Damages – Residential Evacuation, Subsistence and Reoccupation

The residential evacuation, subsistence and reoccupation inventory and depth damage function were utilized within FDA to estimate expected damages. Table 41 provides the expected annual damages for residential structure evacuation, subsistence, and reoccupation costs for each of the three modeled scenarios.

Table 41 – Expected Annual Damages – Evacuation, Subsistence and Reoccupation

Reach	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Left Bank	$57	$58	$8
Left Bank mix	$291	$110	$13
Right Bank	$0	$0	$0
Total Scenario EAD	**$347**	**$168**	**$21**

6.5.1.4. ESJ Analysis - Residential Evacuation, Subsistence and Reoccupation

Evacuations within the economic study area will likely begin if flooding were to rise above two feet of water, though damages at this level would be minimal. For inundated structures, the damages for Evacuation, Subsistence and Reoccupation fall between $1,676 and $7,136 for a two foot, to a 12-foot flood. ESJ community members forced to evacuate may not have the funds to pay for an extended stay at a hotel or other available housing that requires payment. They may also struggle to provide subsistence for themselves and families if their workplace was damaged in the flood or they are unable to physically get to their workplace to receive income. These communities are often reliant on the county, state, federal government, or nonprofit organizations for alternate housing and subsistence depending on the severity of the flood. The quality of this alternative housing can vary. For example, when Grand Forks, North Dakota flooded back in 1997, FEMA provided trailers for low-income households left homeless during the flood (Gerber 2006). In the immediate aftermath of the flooding caused by Hurricane Katrina, thousands of low-income people were evacuated into the Superdome and were locked in without food and water for days (History.com 2009). The potential number of affected low-income households in Fall City will more closely match that of Grand Forks and the three flooding scenarios for Fall City would have a smaller overall impact than that of Hurricane Katrina. However, the

Potential Disproportionate Risk to ESJ communities:

- Loss of income due to displacement
- Job loss
- Permanent loss of homes
- Lower quality of life in temporary housing
- Higher incidence of stress-related issues, including mental health issues
- Pressure on social services

treatment of ESJ populations during and after the hurricane and floods in New Orleans highlight the systemic inequality built into the planning and actions of governmental agencies.

Since that time, awareness of how natural disasters affect different populations has grown, but many low-income communities still struggle to return to their homes after a flood. Not everyone is eligible for flood relief grants, and often grants do not fully cover the cost of damages sustained during a flood. ESJ communities may also not be aware of all the grant and federal aid available to them. For ESJ communities to successfully evacuate, rebuild, and return, adequate resources will need to be set aside to meet their needs and supply them with the proper information so that they can eventually return to their homes. If this does not occur, like many other ESJ communities post flood, they may be evicted from their homes or unable to afford rent after renovations are complete.

In essence, ESJ populations are also more likely to become displaced and can struggle to find alternative housing, adding additional stress to these community members. Their quality of life would become worse with temporary housing and potential loss of housing and even unemployment. This could lead to financial and emotional stress for such communities, including increased mental stress, anxiety, and potential substance use, due to the additional burdens these communities need to consider. For example, the financial impacts of a flood are far more stressful for a household with little to no savings and no insurance than they would be for a household with a stronger financial standing. Finally, the ESJ populations in Fall City may also have reduced access to both physical and mental health resources, thus prolonging their woes.

6.5.2. Public Services and Critical Facilities

This damage category is included to account for the many public services and critical facilities that benefit a community but may be subject to flooding. The list of items that could be included under this heading include schools, libraries, community centers, hospitals, water treatment facilities, hazardous storage facilities, and others. This category is aimed at accounting for the adverse impacts of the loss of service, while not double counting the impact to the structure and contents of the facility, which are accounted for under a different damage category.

6.5.2.1 Inventory

A review of this study area showed limited public services and critical facility structures being inundated. The primary public service facilities inundated under any scenario are the Fall City Elementary School, King County Fire District 27 fire station, and a King County Road Construction facility. These three facilities are already included in the structure inventory and any structure and content damages are included under that specific damage category (see Section 6.1.1). Also, loss of fire services is one of the damage values included under the emergency response damage category. Therefore, no additional monetized damages have been included at this time.

6.5.2.2 Damage Function

No damage function was generated for this damage category, as the primary damages for the facilities in the inventory are accounted for in other damage categories.

6.5.2.3 Expected Annual Damages – Public Services and Critical Facilities

Based on the structure inventory and damage function assessments (see Section 6.1.1), no monetized damages are included for the public services and critical facilities damage category.

6.5.2.4 ESJ Analysis – Public Services and Critical Facilities

The economic study area is relatively small, covering only 0.40 square miles. As a result, there are not many public services or critical facilities to consider. Within the economic study area, there is one elementary school, one library, one post office, and two churches. None of these services or facilities are located near a low-income housing cluster. As the entire study area is served by these facilities and services, there are no suspected disproportionate impacts to Fall City ESJ communities.

6.5.3. Utility Loss of Service Impacts

This damage category is intended to evaluate the potential for interruption of utility services to residents in the floodplain.

6.5.3.1. Inventory

Based on review of the study area, and the previous damage category inventories, no critical utility infrastructure is located in the study area. Therefore, since no critical infrastructure is assumed to be damaged, and a detailed assessment of smaller utility service lines are not a part of the scope of this study, no monetary damages for loss of utilities are included.

6.5.3.2. Damage Function

No damage function has been developed based on the lack of critical utility infrastructure located in the study area.

6.5.3.3. Expected Annual Damages – Utility Loss of Service Impacts

No monetary damages are currently included based on the inventory and damage function assessments.

6.5.3.4. ESJ Analysis – Utility Loss of Service Impacts

Though no critical utility facilities are within the potential flood impact area, loss of power and water utility services may occur following substantial flooding to buildings within the area. FEMA estimates the need for around 45 days to restore building function per foot of flooding above the first floor. This estimate means that housing units could go months without utility services if flooding extends greater than 2 feet above the first floor. Based on the results in section 6.1.1.4, and the numbers of ESJ housing units affected under all three scenarios, this group will not be disproportionately impacted. Therefore, the number of ESJ households that may experience utility loss is actually lower than the percentage of other Fall City residents who may experience utility loss. However, the value of damages to ESJ housing units with a breach at location 3, is relatively greater for ESJ populations, indicating that flood depths are likely higher in these areas and could result in an extended loss of utilities. From this perspective, there is a possibility that ESJ communities could experience disproportionate impacts in terms of length of utility loss.

> ***Potential Disproportionate Risk to ESJ communities:***
> *- Loss of income due to lost power over extended periods of time*
> *- Lower disposable income due to higher expenses for alternative power sources, drinking water, and other related necessities*
> *- Lower quality of life*

Electricity is a vital utility. While some households might have a backup generator to supply electricity during a power outage, these are expensive commodities and might be ineffectual if exposed to flood water. Full home generators and their installation generally cost between $6,000 and $11,000, standby backup generators cost between $2,400 and $8,000, and portable generators cost between $900 and $4,500 (HomeGuide 2023). The cost of these products makes them inaccessible for low-income homeowners and are not usually supplied to low-income rental units either. Without a generator, or the financial ability to purchase one, these households could be disproportionately impacted if flooding results in the loss of electricity. It is important to note that generators affected by flooding could become dysfunctional and result in equal impacts across the Fall City community.

In essence, disruption of power, water, and other utility services could possibly disproportionately affect the ESJ communities, especially if that disruption continues for extended periods of time. These effects could manifest in lost income due to not being able to work efficiently and effectively, less disposable income due to higher cost of alternatives, and generally experiencing a lower quality of life.

6.5.4. Mental Stress and Anxiety

This damage category is intended to characterize human health impacts following a flood that may result in a decreased quality of life through adverse impacts of mental health.

6.5.4.1. Inventory

The inventory input into FDA was developed as a reflection of the residential structures in the floodplain. Pseudo-structures were developed for each residential structure, and a value for mental stress and anxiety was developed. This monetary value is based on the residents of an inundated residential unit multiplied by FEMA's valuation of $2,443 per person impacted by flooding. Table 42 provides the value calculation assumptions for each residential structure type.

Table 42 – Mental Stress and Anxiety Value by Residential Structure Type

Occupancy	*Description*	*Assumed Units*	*Employed Persons per Unit*	*Inventory Value*
RES1	Single Family Residential	1	1.25	$10,920
RES2	Manufactured homes	1	1.25	$10,920
RES3A	Duplex	2	1.25	$21,840
RES3B	Multi Family - 3 to 4 units	3	1.25	$32,760

6.5.4.2. Damage Function

The damage function for this category is simply a function of whether a residential structure is inundated by flooding. The available data for this damage category does not classify as a depth-damage function. The FDA model is set-up such that if water inundates a residential unit, that unit incurs the full value of lost productivity as referenced in Table 42.

6.5.4.3. Expected Annual Damages – Mental Stress and Anxiety

The mental stress and anxiety inventory and damage function were utilized within FDA to estimate expected damages. Table 43 provides the expected annual damages for mental stress and anxiety costs for each of the three modeled scenarios.

Table 43 – Expected Annual Damages – Mental Stress and Anxiety

Reach	*Overtop-then-Breach*	*Breach Location 3*	*Breach Location 6*
Left Bank	$119	$118	$34
Left Bank mix	$793	$235	$27
Right Bank	$0	$0	$0
Total Scenario EAD	**$912**	**$353**	**$62**

6.5.4.4. ESJ Analysis – Mental Stress and Anxiety

Mental stress and anxiety are common human health impacts brought on by a natural disaster such as a flood. Both the flood itself and the damage it leaves behind can cause great mental anguish for those left dealing with the aftermath. "Low-income populations, the elderly, people of color, women,

Potential Disproportionate Risk to ESJ communities:
- Loss of income due to lower productivity
- Job loss; loss of livelihood
- Prolonged stress-related issues, including mental health issues, due to less access to resources and services
- Pressure on social services

and children are especially vulnerable to the mental health-related impacts of natural disasters" (Sheikh 2018). Unlike those with stronger social support networks and greater financial reserves, ESJ populations bounce back slower from the mental stress induced by a natural disaster than those with robust means of support. Based on the potential flood levels and damages left by a breach at location 3, location 6, or overtopping, ESJ populations will be affected by mental health and anxiety issues brought on by floods from the Lower Raging River. The event itself can be traumatizing, especially if the flood causes personal loss in property, items of sentimental value, jobs, important documents, etc. Post-traumatic stress disorder (PTSD), anxiety, and depression are common consequences brought on or triggered by a flooding event and are more likely to occur in those with low income and a lower socioeconomic class (Mason 2010). ESJ populations often bear these burdens because they lack financial and social support and, therefore, struggle to cope with the potentially devastating aftermath of a flood.

It may also be more challenging for ESJ populations to gain access to mental health resources to help manage mental stress and anxiety. These resources may be too expensive or only be available during critical work hours, thus making it very challenging for ESJ populations to receive mental health help. See section 6.4.4.4., the ESJ analysis for lost worker productivity, for a detailed discussion on how mental stress and anxiety can impact the work performance, and livelihoods of ESJ populations.

6.5.5. Public Health and Safety EAD Summary

Table 44 presents a summary of the total scenario EAD for each of the public health and safety damage categories that have been included in the monetized damage estimates.

Table 44 – EAD Summary for Public Health and Safety

Damage Category	***Expected Annual Damages by Scenario***		
	Overtop-then-breach	**Breach location 3**	**Breach Location 6**
Evacuation and Subsistence	$347	$168	$21
Mental Stress and Anxiety	$912	$353	$62
Total EAD	**$1,259**	**$521**	**$82**

6.6. Flood Risk Damage and Impact Summary

The following tables present a summary of total EAD from the standard monetized damage categories, as discussed above, for each of the damage scenarios. Table 45 provides a summary that includes each of the damage categories from Table 10 for the Overtop-then-Breach scenario, and Table 46 and present the results for Breach Location 3 and Breach Location 6 scenarios respectively. These tables present the individual damage category EADs, in addition to summed damages for each of the summary categories referenced in Table 10.

Table 45 – Total EAD Summary – Overtop-then-Breach Scenario

Damage Category	*Left Bank*	*Left Bank mix*	*Right Bank*	*Total*
Direct Physical Damages	**$5,075**	**$23,566**	**$0**	**$28,642**
Structures and Contents	$2,711	$12,477	$0	$15,188
Direct Vehicle	$2,247	$9,404	$0	$11,651
Direct Road	$118	$1,685	$0	$1,803
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$1,516**	**$3,846**	**$0**	**$5,361**
Debris Removal	$56	$168	$0	$224
Building Cleanup	$1,451	$3,640	$0	$5,091
Emergency Response	$9	$38	$0	$47
Landscape Restoration	$0	$0	$0	$0
Implicit Costs	**$25,257**	**$10,023**	**$0**	**$35,280**
Transportation Detour	$783	$0	$0	$783
Business Disruption	$24,048	$7,188	$0	$31,236
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$426	$2,835	$0	$3,261
Public Health and Safety	**$176**	**$1,083**	**$0**	**$1,259**
Evacuation and Subsistence	$57	$291	$0	$347
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$119	$793	$0	$912
Total	**$32,024**	**$38,518**	**$0**	**$70,542**
Job Losses (not included in EAD total above)	0.08	0.03	0.00	0.11

Table 46 – Total EAD Summary – Breach Location 3 Scenario

Damage Category	*Left Bank*	*Left Bank mix*	*Right Bank*	*Total*
Direct Physical Damages	**$5,315**	**$8,043**	**$0**	**$13,358**
Structures and Contents	$2,783	$4,514	$0	$7,296
Direct Vehicle	$2,410	$3,174	$0	$5,584
Direct Road	$123	$355	$0	$478
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$1,596**	**$1,362**	**$0**	**$2,959**
Debris Removal	$60	$55	$0	$115
Building Cleanup	$1,528	$1,291	$0	$2,819
Emergency Response	$9	$16	$0	$25
Landscape Restoration	$0	$0	$0	$0
Implicit Costs	**$25,632**	**$5,246**	**$0**	**$30,878**
Transportation Detour	$365	$0	$0	$365
Business Disruption	$24,846	$4,406	$0	$29,252
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$421	$840	$0	$1,261
Public Health and Safety	**$176**	**$344**	**$0**	**$521**
Evacuation and Subsistence	$58	$110	$0	$168
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$118	$235	$0	$353
Total	**$32,719**	**$14,996**	**$0**	**$47,715**
Job Losses (not included in EAD total above)	0.09	0.02	0.00	0.11

Table 47 – Total EAD Summary – Breach Location 6 Scenario

Damage Category	*Left Bank*	*Left Bank mix*	*Right Bank*	*Total*
Direct Physical Damages	**$2,121**	**$913**	**$0**	**$3,034**
Structures and Contents	$1,659	$482	$0	$2,141
Direct Vehicle	$420	$372	$0	$792
Direct Road	$42	$59	$0	$101
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$309**	**$151**	**$0**	**$460**
Debris Removal	$16	$6	$0	$22
Building Cleanup	$278	$143	$0	$421
Emergency Response	$1	$2	$0	$3
Landscape Restoration	$14	$0	$0	$14
Implicit Costs	**$3,627**	**$497**	**$0**	**$4,123**
Transportation Detour	$41	$0	$0	$41
Business Disruption	$3,463	$398	$0	$3,862
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$122	$98	$0	$220
Public Health and Safety	**$42**	**$41**	**$0**	**$82**
Evacuation and Subsistence	$8	$13	$0	$21
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$34	$27	$0	$62
Total	**$6,098**	**$1,601**	**$0**	**$7,699**
Job Losses (not included in EAD total above)	0.01	0.00	0.00	0.01

7. SYSTEM-WIDE WEIGHTED EAD

This section discusses the calculation and results of the weighted EAD analysis. A weighted EAD value has been calculated to combine the independent scenario EADs into one integrated estimate for the study area. This has been done due to the fact that FDA is not capable of running multiple breach locations, with overlapping floodplains, and calculating reasonable EAD estimates. Therefore, a post-processing of the FDA results is required to generate a system-wide EAD that takes into account annual probabilities of flooding, and the levee fragility probabilities, for each of the three modeled scenarios.

7.1. Scenario Weight Calculations

The weighting calculation is primarily based on an assessment of annual probability of failure for the three scenarios, where failure means either overtopping or breaching. To calculate the annual probability of failure for each scenario, the fragility analysis input into FDA must be transformed from a stage-to-failure probability to an exceedance-to-failure probability. This was done by first associating a relative discharge rate for each of the three stages input into FDA for the levee failure probabilities (see Section 4.3 previously). Next, by analyzing outputs from the FDA model an associated exceedance probability was estimated for the newly calculated discharge rates. With the assigned discharge rates, an estimated annual probability of failure can be calculated, which is simply the area under the curve for the exceedance-to-failure probability chart. Table 48 provides the results of each of the steps referenced to calculate the annual probability of failure for each of the three scenarios, and Figure 5 provides a graph of the scenarios exceedance-to-failure probability charts.

Table 48 – Annual Probability of Failure Calculation Summary

Levee Fragility Stage (ft)	*Discharge at Stage (cfs)*	*Annual Exceedance Probability at Discharge*	*Probability of Failure at stage*	*Contribution to Annual Probability of Failure*
Overtop-then-Breach				
113.5	4,049	0.0655	1.0	6.554%
		Estimated Annual Probability of Failure		**6.554%**
Breach Location 3				
110.67	1,848	0.5717	0.00003	0.001%
111.97	2,644	0.2804	0.00003	0.000%
112.67	3,234	0.1538	0.00003	0.000%
113.47	4,017	0.0677	0.00003	0.000%
114.07	4,653	0.0347	0.00003	0.000%
114.57	5,211	0.0191	0.00003	0.006%
115.77	7,159	0.0027	0.007	0.023%
115.87	7,346	0.0022	1.0	0.222%
		Estimated Annual Probability of Failure		**0.253%**
Breach Location 6				
126.91	2,113	0.4615	0.00003	0.001%
128.21	3,267	0.1490	0.00003	0.000%
128.91	4,016	0.0678	0.00003	0.000%
129.71	4,891	0.0270	0.00003	0.000%
130.31	5,559	0.0129	0.00003	0.000%
130.81	6,284	0.0063	0.00003	0.002%
132.01	8,823	0.0006	0.007	0.006%
132.11	9,160	0.0004	1.0	0.045%
		Estimated Annual Probability of Failure		**0.054%**

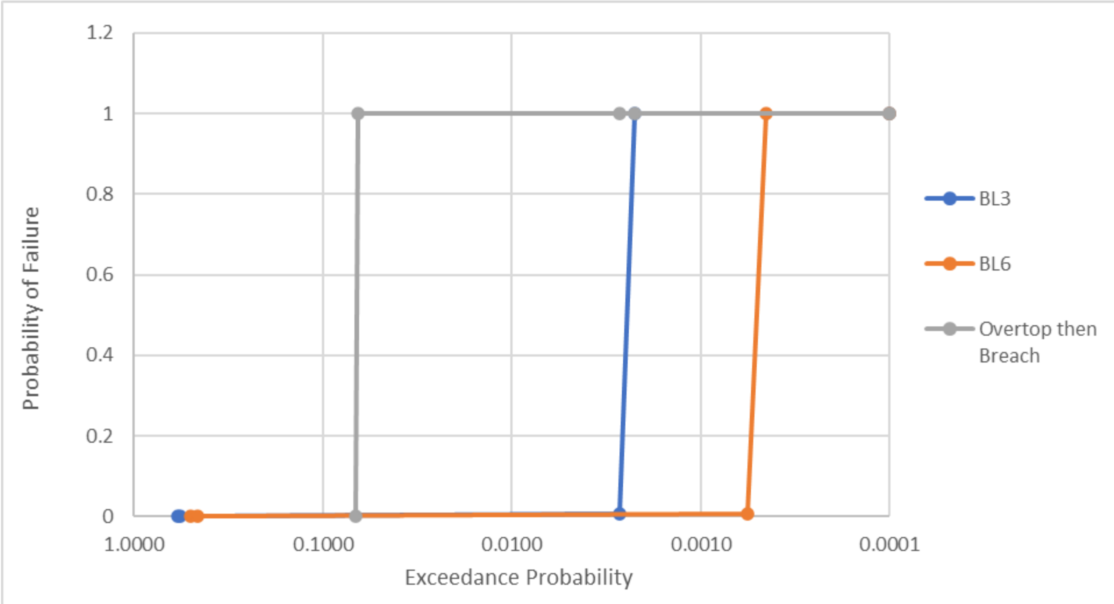


Figure 5 – Exceedance-to-Failure Probability Curves

7.2. System Weighted EAD

To finalize the weighted EAD value, the estimated annual probability of failure numbers from above were standardized to generate a scenario weight. This scenario weight was then multiplied by the EAD for each scenario, with the sum of those weighted EAD values calculating the final weighted EAD for the system. The overall weighted EAD is a representation of total flood risk that accounts for the possibility of breaching before overtopping based on the relative likelihood of a breach occurring at either of the two representative breach locations. Table 49 provides the standardized weights, the scenario EADs, and the final system-wide EAD value.

Table 49 – System-Wide Weighted EAD Calculation

Item	***Overtop-then-Breach***	***Breach Location 3***	***Breach Location 6***
Estimated Annual Probability of Failure	6.55%	0.25%	0.05%
Standardized Weighting	95.5%	3.7%	0.8%
Scenario EAD	$70,542	$47,715	$7,699
Weighted EAD	$67,368	$1,756	$61
System-wide weighted EAD		**$69,185**	

8. LEVEE PERFORMANCE STATISTICS

8.1. FDA Levee Performance Statistics

In addition to expected (mean) annual damage, HEC-FDA can report levee project performance statistics that describe the likelihood that a levee will contain certain flood events over a long term period of time. The levee performance analysis was performed along the left bank only, with the top of levee input as the “target stage” within the FDA model. However, to account for the fact that the overtop-then-breach scenario is accounting for the relative low-point in the levee found in the Left Bank mix reach, an approximate levee height consistent with the elevation at which overtopping occurs has been input for that scenario. Results, as presented in Table 50, report long-term risk of levee failure over 10, 30 and 50 years for each of these scenarios. For example, for Breach Location 3 scenario, there is a 14.66 percent chance of experience flooding over the next 30 years, and a 23.22 percent chance over 50 years.

Table 50 – Long-Term Risk of Levee Failure

Scenario	***Target Stage (Top of Levee)***	***Target Stage Annual Exceedance Probability***		***Long-Term Risk (years)***		
		Median	**Expected (Mean)**	**10**	**30**	**50**
Existing Conditions						
Overtop-then-Breach	113.50	6.54%	7.00%	51.6%	88.67%	97.34%
Breach Location 3	115.77	0.38%	0.53%	5.15%	14.66%	23.22%
Breach Location 6	132.01	0.08%	0.12%	1.18%	3.51%	5.79%

Table 51 then provides the conditional non-exceedance probabilities that were also computed for the 10%, 4%, 2%, 1%, 0.4% and 0.2% events within FDA. These conditional non-exceedance probabilities refer to the probability of withstanding a given flood event without the levee either overtopping or failing. For example, for the Breach Location 3 scenario, given a 1% AEP event, the system is estimated to have an 84.94% probability of not allowing floodwaters into the protected area.

Table 51 – Conditional Non-Exceedance Probabilities by Flood Event

Scenario	***Target Stage (Top of Levee)***	***Conditional Non-Exceedance Probability by Flood Event***					
		10%	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Existing Conditions							
Overtop-then-Breach	113.50	80.32%	21.54%	6.97%	3.80%	0.65%	0.16%
Breach Location 3	115.77	99.66%	99.47%	96.89%	84.94%	67.71%	54.45%
Breach Location 6	132.01	99.77%	99.66%	99.46%	98.25%	96.25%	94.19%

8.2. NFIP Levee Assurance Statistics

Also, assurance statistics have been estimated. These levee assurance statistics are currently required for National Flood Insurance Program (NFIP) levee system accreditation requirements. Based on current Engineering and Construction Bulletin (ECB) 2019-11, the levee assurance statistics must include computation of the 1% annual exceedance probability (USACE 2019). The 1% annual exceedance probability for a levee refers to the probability that a levee has a 1% chance of overtopping or being breached in any given year. Therefore, assurance of the 1% annual exceedance probability is the probability that the levee will prevent flooding of the leveed area for the 1% annual exceedance probability event, considering geotechnical performance and uncertainty in flow and stage across the full range of floods. ECB 2019-11 states that levees with assurance of the 1% annual exceedance probability greater than 85% should generally be recommended for accreditation. Table 52 presents the results of the assurance statistics analysis.

Table 52 – NFIP Levee Assurance Statistics

Scenario	***Assurance Statistics***		
	Annual Exceedance Probability	**Frequency**	**1-Frequency (Assurance)**
Existing Conditions			
Overtop-then-Breach	0.01	96.33%	3.67%
Breach Location 3	0.01	17.12%	82.88%
Breach Location 6	0.01	1.39%	98.61%

9. EQUITY AND SOCIAL JUSTICE

Based on the evaluation of residential structures in the study area presented in Section 6.1.1.4., ESJ populations may potentially bear a disproportionate impact in terms of damage sustained to the structures, content, and inventory of their residential household units under the three potential flood scenarios. The analysis focuses on the numbers and values of structures labeled as manufactured homes (RES2), duplexes (RES3a) and multifamily homes (RES3b). Collectively these residences represent 27.8 percent of the number of structures in the study area, and 10.5 percent of the residential value. An analysis of the different flood impacts would therefore be deemed disproportionately to impact ESJ populations compared to the rest of the Fall City residents if greater than 27.5 percent of the number of structures damaged are low-income units or if greater than 10.5 percent of the value damaged comes from low-income housing units. The pathway utilized by the team to reach these two values is laid out in Section 6.1.1.4.

Using this rubric, the results suggest that under the BL3 scenario, a slightly disproportionate impact falls to the low-income populations at the 50% AEP (2-year event), with 30 percent of the inundated structures being low income. However, the actual proportion of low-income housing in the study area is 27.8 percent and so this result is not greatly disproportionate. It should also be noted that the probability of a breach at location 3 for a 50% AEP (2-year event) is almost negligible, so it is exceedingly unlikely that low-income populations will be disproportionately impacted under this scenario. None of the other flood events and scenarios show a disproportionate impact and in fact, most show a smaller share of low-income structures becoming inundated compared to the 27.8 percent share of residences in the study area. Only in the 0.2% AEP (500-year event) do we see that, for the Overtop then Breach Scenario and the BL3 scenario, the low-income share of residences inundated is 36 percent – so again higher than 27.8 percent, but the disproportion is less than 10 percent.

Using the EAD metric, the RES2 and 3 residences represent 10.5 percent of the study area property values, and so a disproportionate impact may be seen if the share of damage in the scenarios falls to the RES2 and 3 structures at a rate that is higher than 10.5 percent. For overtopping, the low-income populations experience 8.9 percent of the damages, for BL3, this group sees 18.6 percent, and for BL6, the group experiences 9.6 percent of the damages. Low-income units will experience a disproportionate impact only under the BL3 scenario, as this is the only scenario in which the EAD to low-income structures is greater than 10.5 percent.

Table 53 – EAD for Residential Structures by Scenario

Scenario	***RES1***	***RES2 & 3***	***Total***
Overtop then Breach	$10,385 (91.1%)	$1,010 (8.9%)	$11,395 (100.0%)
Breach Location 3	$3,749 (81.5%)	$853 (18.6%)	$4,602 (100.0%)
Breach Location 6	$1,365 (90.3%)	$146 (9.6%)	$1,512 (100.0%)

While the other modeled scenarios do not suggest there will be a measurably greater impact to these community members, (that is, these structures only experience between nine and 18 percent of expected damages), there are several other ways in which ESJ populations could bear greater negative impacts in the event of levee breach along the Lower Raging River. These topics were discussed at length in Section 6 and the following high-level summaries will touch on the possible ways in which ESJ community members in the study area could be affected in the event of a flood along the Lower Raging River.

- Structures, Content, Inventory: As mentioned above, ESJ community members could bear a disproportionate impact in terms of value damaged to their homes under all scenarios. Low-income rental units are more likely to sustain greater flood damages than other homes in nearby locations due to poor maintenance and construction. In addition, they are less likely to have robust flood insurance. Renters do not have to be made aware of the flood risks to their residential unit even though low-income housing is often built-in cheaper flood plain areas. Repaired rental units may also be upgraded, making it challenging for low-income tenants to afford the new rent. Due to this, low-income renters among the ESJ community are particularly vulnerable to flood damages.
- Direct Vehicle: All households in Fall City own a minimum of one vehicle, highlighting the importance of personal vehicles as a mode of transportation in the economic study area. Vehicle loss or damage caused by flood damage can disproportionately impact ESJ community members that work for hourly wages and need to be onsite to work, especially if local car repair shops are affected by flood waters as well. The cost of repairs or towing can disproportionately impact ESJ populations due to their lower earning power and weaker financial standing.
- Direct Road: The low-income housing cluster near the junction of the Snoqualmie and Lower Raging River could be greatly impacted by road damages and closures along Preston Fall City Road SE, the main road running north to south through town. Other ESJ community members could be impacted in the event of a severe flood that damages or closes road more extensively and limits this group's ability to reach hourly paid job sites. However, it is important to note that under all three scenarios the damage to roads should not be significant.
- Debris Removal: Debris removal can be dangerous, especially if those removing the debris have no experience and have not been educated on the proper protective gear or potential dangers that accompany debris removal. ESJ community members may be more likely to remove debris personally to avoid the cost of hiring a professional, and also may not be able to afford the appropriate equipment. Debris cleanup crews could consist of ESJ community members, and therefore add a greater burden to this community. However, our initial findings do not indicate that cleanup crews or response teams are disproportionately made up of minority groups or low-income individuals.
- Building Cleanup: While the number of structures that may require cleanup in the event of a flood will not disproportionately impact ESJ community members, building cleanup can be more

burdensome for ESJ populations than it is for others with more resources and support. For example, the time and cost associated with building cleanup can be more burdensome to ESJ populations due to their lower earning power. Spending time away from work to clean a residence or business can result in significant loss of income to those working hourly wages, potentially living paycheck to paycheck. Poor cleanup jobs can also result in long term negative impacts like the growth of mold, which can be detrimental to the health of those residing in a building and the structural integrity of the building itself. Though most view building cleanup as a time-consuming hassle, it can lead to long term problems for those without the education, time, and financial power to complete the job effectively.

- Emergency Response: There are a countless number of cases in which emergency flood responses were inadequate and far slower for areas with ESJ populations across the US. However, modeled flood scenarios for the Lower Raging River are not severe and the ESJ communities are small and fairly spread out throughout the economic study area. It is therefore unlikely that Fall City ESJ community members would receive slower or inadequate help in the event of an emergency. There is also the possibility that first responders could consist of ESJ community members and thus disproportionately impact the ESJ community. However, first responders, including the local fire station crews, are paid above the median wage in Washington state. The analysis team determined it is highly unlikely that the ESJ community will be disproportionately impacted in any way during an emergency response to a flood event.
- Transportation Detour and Delay: As noted in the direct vehicle summary, all Fall City residents own vehicles. However, delays and detours could have a greater negative impact on ESJ populations who may not have the option to work from home, and who may need to be onsite to receive payment for their work. Any delay or detour then becomes a lost opportunity for income, which can be critical to these low-income households.
- Business Disruption: Flood damages could result in the temporary, long-term, or permanent closure of local businesses. 75 percent of racial and ethnic working minorities in Fall City have occupations in industries that typically offer hourly wages. These individuals cannot earn an income if they have no place to work, which can be detrimental to ESJ households with minimal to no savings to support them during business closures. Fall City is also home to a number of small businesses including a women-owned coffee shop, a family-Mexican restaurant, a local farmhouse market, a vintage flea shop and burger stand to name a few. ESJ community business owners could also struggle to find funds to repair flood damages more so than other businesses with more financial support. Severe flood damages are therefore more likely to close a small business owned by an ESJ community member than a larger organization with substantial support.
- Recreation Loss: There are no predicted negative impacts to recreation areas in the economic study area. However, the quantitative analysis fails to capture the potential loss of income and livelihoods for those who work on the river. These jobs could include recreation like fishing or traveling along the Lower Raging River and the Snoqualmie River. ESJ community members may also rely on the river for subsistence fishing. Flooded banks may make it impossible to work recreational jobs on the river, which are typically paid by the hour and may make it impossible to fish for food. Though fishing is generally thought of as a fun pastime, it could be a serious source of income and sustenance for ESJ populations.
- Lost Worker Productivity: Socially and economically vulnerable ESJ populations can be affected more by mental health and anxiety issues caused by a flooding event due to the more direct and immediate effects of job losses, loss of homes, loss of access to resources, transportation disruptions, etc. There is a greater potential for these stressors to impact ESJ communities' work productivity because they have additional burdens to consider. For example, the financial impacts of a flood are far more stressful for a household with little to no savings and no insurance than they would be for a household with a stronger financial backing. ESJ populations are also more likely to become displaced and can struggle to find alternative housing, adding additional stress to these community members. Finally, the ESJ populations in Fall City may

also have reduced access to mental health resources, thus prolonging their inability to work productively.

- Residential Evacuation, Subsistence, Reoccupation: ESJ community members forced to evacuate during a flood may not have the funds to pay for an extended stay at a hotel or other available housing that requires payment. They may also struggle to provide subsistence for themselves and families if their workplace was damaged in the flood or they are unable to physically get to their workplace to receive income. These communities are often reliant on the county, state, federal government, or nonprofit organizations for alternate housing and subsistence depending on the severity of the flood. They may also need information regarding resources available to them. For example, ESJ communities may not know of the grant and federal aid available to them. For ESJ communities to successfully evacuate, rebuild, and return, adequate resources need to be set aside to meet their needs and supply them with the proper information so that they can eventually return to their homes. However, it should be noted that extreme flood depths are not expected under the three flood scenarios, so evacuation is not likely.
- Utility Loss of Service: Though no utility facilities are within the potential flood impact area, loss of power, water, and wastewater utility services may occur following substantial flooding to buildings within the area. Though the number of housing units impacted by flood waters do not indicate that ESJ community members will be disproportionately impacted, the loss of utilities could create a larger burden for this population. It may be more challenging for ESJ community members to afford alternative sources of electricity, water, and wastewater management. This could result in added mental stress and anxiety due to the financial burden utility loss could place on this community.
- Mental Stress and Anxiety: Unlike those with stronger social support and greater financial reserves, ESJ populations bounce back slower from the mental stress induced by a natural disaster than those with robust means of support. It can also be more challenging for ESJ populations to access mental health services as well. These resources may be too expensive or only be available during typical work hours. The additional financial and potentially traumatic burdens put on ESJ community members during and after a flood event can result in additional stress and anxiety that then impacts their work performance, which adds to the mental stress and anxiety. This perpetual cycle can be exceedingly hard to break, especially when mental health resources may not be readily and easily accessible for this population. The modeled flood depths do not indicate severe flooding, however even minimal flood damages have the potential to bring on mental stress and anxiety, especially for ESJ populations with lower earning power and less support.

The modeled scenarios indicate that overtopping then a breach, a breach at location 3 and a breach at location 6 are not likely to occur, and thus have relatively low expected annual damages. However, any flood damages have the potential to disproportionately impact ESJ populations in the Fall City economic study area (see Map 4, Map 5, and Map 6). This group is more reliant on roads, working vehicles and operating businesses than other Fall City residents. ESJ populations also have lower earning power, which can make paying for damages and cleanup incredibly challenging. It is important to consider how these potential impacts could affect ESJ populations so that in the event of a flood along the Lower Raging River, the proper plans and support are in place to ensure that ESJ community members are treated equitably.

10. EVENT-BASED CHARACTERIZATION OF IMPACTS

This section presents a comparison of individual flood event results for the modeled flood magnitudes, and then further provides other damage metrics for a standardized flood event for the existing conditions only (not including future conditions with climate change in this section). This is presented to provide additional risk information that may not have been included in the EAD analysis, and to present relative levels of flood risk for the scenarios. It should be noted that the following damages and other results presented in this section are independent of probabilistic inputs, and are considered theoretical, "what-if" failure occurred during a given flood event.

10.1. Flood Damages by Event

For this section, all tables and values are presented for the suite of flood events modeled for the existing hydraulic conditions, and for the left bank only. It should be noted the following tables in this section do not include any failure probabilities, and are theoretical, "what-if" failure occurred during a given flood event. The tables also list the water surface elevations and the levee height at the index location for the specific scenario. These data points provide valuable context into the previously discussed EAD values, by demonstrating that these levees are not likely to be overtopped or fail (see Section 4.3), thus the relatively low EAD values.

Table 54 – Flood Damages by Event – Overtop-then-Breach Scenario

AEP	Index WSE	Direct Physical Damages	Responses & Restoration Costs	Implicit Costs	Public Health & Safety	Total Event Damages
50%	111.19	$245	$0	$0	$0	**$245**
20%	112.39	$762	$0	$0	$0	**$762**
10%	113.12	$1,070	$0	$0	$0	**$1,070**
4%	113.94	$8,304	$0	$0	$0	**$8,304**
2%	114.53	$381,891	$48,288	$127,011	$12,909	**$570,098**
1%	115.06	$771,108	$118,555	$229,699	$37,445	**$1,156,807**
0.2%	115.92	$3,147,640	$726,142	$6,896,208	$125,302	**$10,895,293**
Note: Levee height at this location is overtopped at the low point prior to the 4% AEP event.						

Table 55 – Flood Damages by Event – Overtop-then-Breach Scenario

AEP	Index WSE	Direct Physical Damages	Responses & Restoration Costs	Implicit Costs	Public Health & Safety	Total Event Damages
50%	111.19	$552,731	$93,898	$1,338,864	$32,040	**$2,017,532**
20%	112.39	$853,269	$167,566	$2,091,011	$40,054	**$3,151,900**
10%	113.12	$1,029,720	$210,177	$2,495,707	$45,164	**$3,780,768**
4%	113.94	$1,314,905	$259,177	$2,944,689	$51,211	**$4,569,982**
2%	114.53	$1,575,809	$321,289	$3,518,319	$61,406	**$5,476,823**
1%	115.06	$2,053,857	$449,566	$5,083,373	$79,527	**$7,666,322**
0.2%	115.92	$3,147,640	$726,142	$6,896,208	$125,302	**$10,895,293**
Note: Levee height at this location is 115.77-ft (NAVD88).						

Table 56 – Flood Damages by Event – Overtop-then-Breach Scenario

AEP	Index WSE	Direct Physical Damages	Responses & Restoration Costs	Implicit Costs	Public Health & Safety	Total Event Damages
50%	126.80	$239	$0	$4,183	$0	**$4,422**
20%	127.94	$397,490	$58,186	$842,523	$2,284	**$1,300,483**
10%	128.57	$859,419	$100,269	$1,615,137	$9,759	**$2,584,584**
4%	129.37	$1,582,724	$173,452	$2,753,500	$18,138	**$4,527,815**
2%	129.95	$2,317,408	$273,723	$3,781,944	$35,030	**$6,408,105**
1%	130.50	$3,154,162	$389,488	$4,502,069	$66,010	**$8,111,728**
0.2%	131.60	$5,145,810	$717,913	$6,570,435	$133,382	**$12,567,541**
Note: Levee height at this location is 132.01-ft (NAVD88).						

10.2. Standardized Flood Event

For this section, all tables, values, and figures have been developed for the 1% AEP event on the left bank only to be consistent with the EAD analysis, which is intended to present flood risk due to overtopping and/or breaching for the existing levees. It should be noted that the information presented in this section does not account for levee failure probabilities or probability of the given high flow event. The results presented here provide a "what-if" scenario for the individual scenarios. For example, the results presented for Breach Location 3 and 6 illustrate what would happen if the levee breached at those points during a 1% AEP event, even though the probability of a breach occurring for that event, based on the levee fragility information, is very low.

However, for the Overtop-then-Breach scenario, these results do not reflect a breach, as Breach Location 3 and 6 are not overtopped under the existing conditions 1% AEP models. But this scenario does reflect the 1% AEP overtopping at the low point near the confluence of the Raging and Snoqualmie Rivers. Figures presenting the 1% AEP inundation depths are presented in Map 4 through Map 6.

10.2.1. Summary of Other Damage Metrics

The following tables provide relative damage information between the three scenarios as discussed above. All monetized damage values presented in the tables are inclusive of all monetized benefit categories.

Table 57 provides the overall event damages for each of the scenarios.

Table 57 – 1% AEP Flood Damages by Reach and Scenario

Scenario	***Left Bank***	***Left Bank mix***	***Scenario Total***
Overtop-then-Breach	$2,079	$1,154,729	$1,156,808
Breach Location 3*	$5,550,413	$2,115,928	$7,666,341
Breach Location 6*	$7,032,920	$1,078,808	$8,111,728
* Note: The damages shown here for the two breaches do not account for the low probability of failure as previously discussed in this report. As such, the damages here show the damages during a 1% event with a levee breach.			

Based strictly on the outputs of the hydraulic models, it is expected that the Breach Location 6 scenario would have the most flood damages for a 1% AEP breach scenario, followed by Breach Location 3, then the Overtop-then-Breach scenario. In terms of relative comparison, a levee failure at Breach Location 6 is estimated to have 36% more damages than a breach occurring at Breach Location 6, and 268% more damages than the Overtop-then-Breach Scenario. The difference in event damages becomes more apparent when analyzing the inundation area statistics, including overall inundation square miles (see Table 58).

Table 58 – Inundation Area and Average Depth for 1% AEP Events

Scenario	***Area (sf)***	***Area (sq. mi.)***	***Avg. Depth***	***Std. Dev.***
Overtop-then-Breach	806,994	0.029	2.25	1.58
Breach Location 3*	1,396,314	0.050	1.88	1.50
Breach Location 6*	3,342,573	0.120	0.97	1.15
* Note: The damages shown here for the two breaches do not account for the low probability of failure as previously discussed in this report. As such, the damages here show the damages during a 1% event with a levee breach.				

Based on the overall inundated areas, Breach Location 6 is approximately 2.4 times larger than Breach Location 3's inundation area, and over 4.1 times larger than the Overtop-then-Breach scenario. The interesting thing to note from Table 58 is the depths are greatest in the Overtop-then-Breach scenario, followed by Breach Location 3, then Breach Location 6 has the lowest average depth. This is primarily due Breach Location 6 being located upstream and having more surface area for flows to spread. Whereas the Overtop-then-Breach and Breach Location 3 inundations are confined to the confluence area (see Left Bank mix reach), where the water tends to pool against the backside of the Raging River and Snoqualmie River levees.

Given the inundation areas referenced above, the overall number of structures inundated show the same relative impacts between the scenarios. Table 59 provides a summary of the overall number of structures inundated with corresponding structure and content damage values. See Attachment 2 for a more detailed summary of structure counts and damages broken out by structure occupancy type for the 1% AEP event.

Table 59 – Structures Inundated and Estimated Damages by Structure Category for 1% AEP Event

Scenario	*Category*	*Count*	*Estimated Damage*
Overtop-then-Breach	Commercial	1	$11,539
	Public	0	$0
	Industrial	0	$0
	Out Buildings	5	$43,994
	Residential	19	$366,463
	Total	**25**	**$421,996**
Breach Location 3*	Commercial	14	$318,866
	Public	4	$28,804
	Industrial	0	$0
	Out Buildings	15	$121,896
	Residential	41	$737,402
	Total	**74**	**$1,206,967**
Breach Location 6*	Commercial	19	$231,763
	Public	8	$429,675
	Industrial	1	$251
	Out Buildings	30	$166,906
	Residential	101	$1,616,720
	Total	**159**	**$2,445,315**
* Note: The damages shown here for the two breaches do not account for the low probability of failure as previously discussed in this report. As such, the damages here show the damages during a 1% event with a levee breach.			

Using the detailed structure inundation information, estimated persons impacted can be estimated. Using the number of residential structures inundated, and an assumed 2.5 persons per residential unit referenced previously (see Section 6.4.4.), the number of residents impacted from flooding of their residence is estimated in

Table 60. This estimate of population impacted does not account for potential of other people being inundated in other non-residential structures, but presents an estimate of the number of residents may be displaced due to their place of residence being flooded

Table 60 – Estimated Population Impacted by 1% AEP Event

Scenario	***Left Bank***	***Left Bank mix***	***Estimated Population Impacted***
Overtop-then-Breach	0	48	48
Breach Location 3*	58	55	113
Breach Location 6*	225	45	270
* Note: The damages shown here for the two breaches do not account for the low probability of failure as previously discussed in this report. As such, the damages here show the damages during a 1% event with a levee breach.			

Lastly, an estimate of the length of roadways inundated is presented in Table 61. The estimated length comes from the developed roadway inventory as discussed in Section 6.2.2. Many of the inundated roads are residential surface streets. However, the two main throughways into this section of Fall City are Preston-Fall City Road and Redmond-Fall City Road, which are both inundated in some form under the two breach scenarios. The primary location for the inundation of these two roads is near the intersection of the Preston-Fall City and Redmond-Fall City Roads.

Table 61 – Inundated Road Lengths by Scenario for 1% AEP Event

Scenario	***Left Bank***	***Left Bank mix***	***Total Length (ft)***	***Miles***
Overtop-then-Breach	100	3,900	4,000	0.76
Breach Location 3*	3,400	3,700	7,100	1.34
Breach Location 6*	6,900	1,600	8,500	1.61
* Note: The damages shown here for the two breaches do not account for the low probability of failure as previously discussed in this report. As such, the damages here show the damages during a 1% event with a levee breach				

10.2.2. Event Based Flood Maps

A suite of flood damage maps have been prepared to reflect the total monetary damages for the 1% AEP event in each of the three economic scenarios. The suite of maps have been designed to represent various findings from the event-based damages discussed in this section. The different metrics presented in these maps have all been aggregated to a "feature bin," which uses hexagonal grids to aggregate damages in the study area. This was done to provide a spatial representation of damages, without singling out individual structures. Below is a discussion of what each of the map sets represent:

- Map 14 through Map 16 – These three maps present the 1% AEP total damages for all monetized damage categories for each of the three economic scenarios.
- Map 17 through Map 19 – These three maps present the 1% AEP total structure and content damages for residential structures only.
- Map 20 through Map 22 – These three maps present the 1% AEP total structure and content damages for the RES2 and RES3 occupancy types, which represent the basis for the ESJ analysis discussed previously.

11. CLIMATE CHANGE CONSIDERATIONS

Climate change is expected to exacerbate flood risk. Based upon research by the University of Washington Climate Impacts Group (Mauger, et al. 2020), climate change will result in future increases in peak flow and volume. For the LBAMRA, future conditions flood risk was estimated given a future hydraulic condition scenario that includes climate change effects. This section discusses the implementation of climate change into the FDA models and presents results for two hydraulically modeled conditions (1% and 0.2% AEP flood events).

11.1. Hydraulic Model Changes

NHC's hydraulic report (NHC 2022) documents the results of their future conditions (climate change) analysis on expected discharge rates, as well as modeling future conditions 1% and 0.2% AEP hydraulic models. The hydraulic report notes that hydrographs for the future conditions were developed by scaling the existing conditions hydrographs with climate change project factors, in which the resulting hydrographs were used as hydrologic inputs for the existing conditions hydraulic models. NHC's report summarizes potential future conditions peak flows which are presented in Table 62.

Table 62 – Existing and Future Condition Frequency Flow Rates

AEP	***Existing Conditions Flows (cfs)***	***Future Conditions Flows (cfs)***
50%	2,020	2,240
20%	2,980	-*
10%	3,650	4,120
4%	4,510	-*
2%	5,160	6,300
1%	5,830	6,730
0.2%	7,440	10,480

* Note: Recurrence intervals not evaluated as part of future conditions H&H scope.

The flow rates are a required input to the FDA model. Therefore, the missing flows for the 20% and 4% AEP events were interpolated to be 3,305-cfs and 5,091-cfs, respectively. NHC also provided hydraulic model depth grid data for the future condition 1% and 0.2% AEP events for the baseline, Breach Location 3 and Breach Location 6 hydraulic models. These hydraulic models also provided the stage information required for FDA (see Table 63). The depth grids from these models were incorporated directly into the water surface profile information required for FDA.

Table 63 – Future Conditions Hydraulic Model Stage Elevations at Breach Locations

AEP	***BL3 Stage (ft, NAVD88)***	***BL6 Stage (ft, NAVD88)***
1%	115.91	131.59
0.2%	116.42	132.81
Levee Crest	115.77	132.01

11.2. FUTURE CONDITIONS DAMAGE RESULTS

Due to the uncertainties around the climate change hydrologic and hydraulic data, and FDA requiring key data inputs that would have to be interpolated, no EAD results for future conditions have been calculated. Instead, this section provides results for the two flood events (1% and 0.2% AEP events) with the most complete data for input into FDA. The following tables present the total left bank damages for all the impact categories based on the future conditions hydraulic models. The tables also provide a side-by-side comparison of the existing conditions and future conditions results. Again, it should be noted that the subsequent damages for the two breach scenarios are hypothetical scenarios that do not incorporate any failure probabilities into the damage results, and are intended to be used as a relative gauge of future damages (assumed to be 30 years from now) from modeled increased water surface levels.

Table 64 – Future Conditions Event Damages Comparison – Overtop-then-Breach Scenario

Damage Categories	*Existing Hydraulic Conditions*		*Future Hydraulic Conditions*	
	1% AEP	**0.2% AEP**	**1% AEP**	**0.2% AEP**
Direct Physical Damages	**$771,108**	**$3,147,640**	**$3,083,270**	**$7,955,904**
Structures and Contents	$421,996	$1,761,611	$1,727,403	$5,312,742
Direct Vehicle	$295,402	$1,274,916	$1,245,979	$2,532,049
Direct Road	$53,710	$111,113	$109,889	$111,113
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$118,555**	**$726,142**	**$707,261**	**$1,370,400**
Debris Removal	$5,977	$27,883	$27,093	$59,114
Building Cleanup	$111,642	$692,343	$674,379	$1,266,477
Emergency Response	$936	$5,916	$5,789	$16,689
Landscape Restoration	$0	$0	$0	$28,119
Implicit Costs	**$229,699**	**$6,896,200**	**$6,673,302**	**$12,316,929**
Transportation Detour	$0	$100,345	$50,185	$100,345
Business Disruption	$123,993	$6,495,118	$6,328,933	$11,661,411
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$105,706	$300,737	$294,185	$555,173
Public Health and Safety	**$37,445**	**$125,302**	**$122,768**	**$247,166**
Evacuation and Subsistence	$7,885	$41,202	$40,500	$91,913
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$29,560	$84,100	$82,268	$155,253
Total	**$1,156,807**	**$10,895,285**	**$10,586,601**	**$21,890,399**
Job Losses	0.7	25.7	25.0	46.1

Table 65 – Future Conditions Event Damages Comparison – Breach Location 3

Damage Categories	*Existing Hydraulic Conditions*		*Future Hydraulic Conditions*	
	1% AEP	**0.2% AEP**	**1% AEP**	**0.2% AEP**
Direct Physical Damages	**$2,053,857**	**$3,147,640**	**$3,083,270**	**$8,034,545**
Structures and Contents	$1,206,967	$1,761,611	$1,727,403	$5,312,742
Direct Vehicle	$767,128	$1,274,916	$1,245,979	$2,532,049
Direct Road	$79,763	$111,113	$109,889	$189,754
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$449,566**	**$726,142**	**$707,261**	**$1,370,400**
Debris Removal	$17,096	$27,883	$27,093	$59,114
Building Cleanup	$429,526	$692,343	$674,379	$1,266,477
Emergency Response	$2,943	$5,916	$5,789	$16,689
Landscape Restoration	$0	$0	$0	$28,119
Implicit Costs	**$5,083,373**	**$6,896,208**	**$6,698,386**	**$12,316,937**
Transportation Detour	$50,185	$100,353	$75,269	$100,353
Business Disruption	$4,827,892	$6,495,118	$6,328,933	$11,661,411
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$205,296	$300,737	$294,185	$555,173
Public Health and Safety	**$79,527**	**$125,302**	**$122,768**	**$247,166**
Evacuation and Subsistence	$22,116	$41,202	$40,500	$91,913
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$57,411	$84,100	$82,268	$155,253
Total	**$7,666,322**	**$10,895,293**	**$10,611,685**	**$21,969,048**
Job Losses	19.2	25.7	25.0	46.1

Table 66 – Future Conditions Event Damages Comparison – Breach Location 6

Damage Categories	*Existing Hydraulic Conditions*		*Future Hydraulic Conditions*	
	1% AEP	**0.2% AEP**	**1% AEP**	**0.2% AEP**
Direct Physical Damages	**$3,154,162**	**$5,145,810**	**$4,930,165**	**$9,022,456**
Structures and Contents	$2,445,315	$3,740,898	$3,619,642	$6,460,694
Direct Vehicle	$623,741	$1,215,158	$1,185,608	$2,367,142
Direct Road	$85,106	$189,754	$124,915	$194,620
Direct Bridge	$0	$0	$0	$0
Direct Critical Utilities	$0	$0	$0	$0
Agricultural Loss	$0	$0	$0	$0
Response and Restoration Costs	**$389,488**	**$717,913**	**$685,232**	**$1,374,821**
Debris Removal	$23,672	$37,411	$36,417	$61,306
Building Cleanup	$363,772	$667,044	$644,459	$1,270,400
Emergency Response	$1,373	$4,471	$4,357	$14,995
Landscape Restoration	$671	$8,988	$0	$28,119
Implicit Costs	**$4,502,053**	**$6,570,435**	**$6,388,359**	**$11,116,416**
Transportation Detour	$50,185	$100,353	$75,269	$100,353
Business Disruption	$4,257,273	$6,112,562	$5,972,386	$10,378,771
Recreation Loss	$0	$0	$0	$0
Lost Worker Productivity	$194,594	$357,521	$340,704	$637,291
Public Health and Safety	**$66,010**	**$133,382**	**$127,734**	**$264,720**
Evacuation and Subsistence	$11,592	$33,403	$32,457	$86,504
Public Services and Critical Facilities Losses	$0	$0	$0	$0
Utility Loss of Service	$0	$0	$0	$0
Mental Stress and Anxiety	$54,418	$99,980	$95,277	$178,217
Total	**$8,111,712**	**$12,567,541**	**$12,131,491**	**$21,778,413**
Job Losses	15.3	22.6	22.1	39.5

Based on the totals in the previous tables, the future conditions models that account for climate change are showing significant increases in damages for the 1% and 0.2% AEP events. Water surface elevations for the two future conditions models are higher thus causing more damage, and if thinking about EAD, the future conditions flood events would trigger damages and potential breaches (as defined in this report) earlier than the existing conditions.

Additionally, the 0.2% AEP events for the future conditions scenarios are all roughly the same. This is pointing to the magnitude of water for this level of flood event, and how the levee system would be inundated regardless of where breaches and low points are located along the levee. The resulting differences in floodplain areas and depths are presented in Table 67.

Table 67 – Future Conditions - Inundation Areas and Average Depths

AEP	***Economic Scenario***	***Area (sf)***	***Area (sq. mi.)***	***Avg. Depth***	***Std. Dev.***
1%	Overtop-then-Breach	1,267,092	0.045	2.46	1.94
	Breach Location 3	1,671,354	0.060	2.31	1.82
	Breach Location 6	3,961,008	0.142	1.23	1.47
0.2%	Overtop-then-Breach	4,018,122	0.144	1.77	1.58
	Breach Location 3	4,178,466	0.150	1.89	2.24
	Breach Location 6	4,903,020	0.176	1.75	2.08

As with the existing conditions models, Breach Location 6 is showing the largest floodplains for the future conditions models. However, the difference between the economic scenarios in area has been lessened substantially in the 0.2% AEP models. With the increased floodplain areas, population impacts are expected to increase as well. The following tables present a comparison of residential population impacts for the future conditions models as compared to the existing results.

Table 68 – Future Conditions – 1% Estimated Population Impacted

Economic Scenario	***Existing Conditions***		***Future Conditions***	
	Residential Structures Impacted	**Estimated Population Impacted**	**Residential Structures Impacted**	**Estimated Population Impacted**
Overtop-then-Breach	19	48	53	143
Breach Location 3	41	113	53	143
Breach Location 6	101	270	133	350

Table 69 – Future Conditions – 0.2% Estimated Population Impacted

Economic Scenario	***Existing Conditions***		***Future Conditions***	
	Residential Structures Impacted	**Estimated Population Impacted**	**Residential Structures Impacted**	**Estimated Population Impacted**
Overtop-then-Breach	53	143	145	380
Breach Location 3	53	143	145	380
Breach Location 6	136	356	168	438

12. EXISTING FLOOD RISK IN STUDY AREA (OTHER SOURCES OF RISK)

This section further discusses the other sources of flood risk in the study area, with a focus on the right bank. This section will define the sources of flooding, and then present damage estimates and EAD for reaches not previously discussed.

12.1. Other Flood Sources

The provided hydraulic models used in this analysis (see Section 4) show inundation in areas not included in the EAD analysis presented in Section 6. For the two left bank reaches, the hydraulic models represent flood risk from the existing Raging River levees. However, the hydraulic model results show inundation on the right bank reach, which as noted previously, is not caused from flooding due to any deficiencies or failures in the existing right bank levee of the Raging River. The flooding shown on the right bank has been determined to be caused from several different issues. The first is flooding strictly from high flows overtopping the banks of the Snoqualmie River. The Snoqualmie River floods much of Twin Rivers Golf Course, located on the right bank, in many of the model flood events. Since this study is looking at flood risk for the existing Raging River levees, the significant flooding just from the Snoqualmie River, that does not overtop Raging River levees, was removed early on in the analysis and is reflected in the study area extent shown in Figure 2.

Another potential source of flooding on the right bank comes from what could be classified as interior drainage issues. Some of the inundation areas on the right bank consist of water entering and flowing through remnant channels, water backing up at existing culverts, and other drainage problems where there is no defined channel. These interior drainage issues may also be impacted from a third source, which is a breakout of flood water upstream of the existing levee. In the 0.2% AEP event it becomes evident that water breaks out upstream of the 328th Way SE Bridge, which is the upstream limit of the study area.

12.2. Right Bank

Since the right bank shows flooding in all the hydraulic models, but the flooding source was not from overtopping or a modeled breach of the Raging River levees, the right bank was omitted from the previous EAD and damage estimation. However, there is still flood risk in this area, and estimated damages and EAD have been calculated for the structures other damage categories in the right bank reach to present existing flood risk to this area. These damages are independent from any levee parameters as the flooding occurs regardless of levee height or any potential breach fragility probabilities. Also, only one economic scenario has been modeled for the right bank as no breach scenarios were identified along the right bank.

12.2.1. Right Bank Individual Flood Event Damages

The same monetized damage categories were included in the right bank analysis. Table 70 presents the estimated damages by flood event for each of the monetized damage categories. The results of the hydraulic modeling show flood waters in the reach starting at the 50% AEP event, which is consistent with the damages presented in the table.

Table 70 – Right Bank Monetized Damages by Individual Flood Event

Damage Category	***50% AEP***	***20% AEP***	***10% AEP***	***4% AEP***	***2% AEP***	***1% AEP***	***0.2% AEP***
Structures and Contents	$11,901	$65,422	$150,564	$276,635	$328,620	$373,881	$720,976
Direct Vehicle	$263	$6,920	$11,373	$37,580	$61,232	$79,307	$122,421
Direct Road	$3,128	$6,376	$8,605	$11,789	$14,618	$17,564	$32,939
Debris Removal	$7	$209	$384	$721	$927	$1,197	$2,707
Building Cleanup	$0	$0	$3,637	$20,114	$32,593	$44,221	$93,983
Emergency Response	$0	$0	$37	$222	$346	$428	$735
Landscape Restoration	$0	$0	$0	$0	$6,849	$16,684	$31,262
Transportation Detour	$0	$0	$0	$0	$0	$0	$0
Lost Worker Productivity	$0	$0	$8,518	$32,760	$32,760	$33,852	$51,761
Evacuation and Subsistence	$0	$0	$317	$1,860	$2,883	$3,591	$5,875
Mental Stress and Anxiety	$0	$0	$2,382	$9,161	$9,161	$9,467	$14,475
Event Totals	**$15,298**	**$78,928**	**$185,816**	**$390,843**	**$489,989**	**$580,191**	**$1,077,135**

12.2.2. Right Bank Expected Annual Damages

EAD values for each of the monetized structure categories are presented in Table 71. Given the results of the individual event damage estimates and noting that there are no levee fragility parameters or levee heights reducing probability of flooding, the EAD is higher for the right bank than any of the left bank scenarios. This is predominantly because damages are expected to occur at a much more frequent event, even though overall damages per event are lower than some of the left bank scenarios.

Table 71 – Right Bank Expected Annual Damages

Damage Category	***EAD***
Structures and Contents	$42,146
Direct Vehicle	$6,035
Direct Road	$3,417
Debris Removal	$125
Building Cleanup	$2,474
Emergency Response	$24
Landscape Restoration	$401
Transportation Detour	$0
Lost Worker Productivity	$2,789
Evacuation and Subsistence	$200
Mental Stress and Anxiety	$780
EAD Total	**$58,393**

Regarding the business disruption losses, the right bank does not have nearly the proportion of commercial or industrial structures as the left bank. There are some non-residential structures inundated that would lead to loss in business and tax revenue. The EAD results for the business losses are estimated at $204 and lost tax revenue of $27, with no appreciable job loss impacts. These numbers, as a ratio of the other damage categories, are significantly less than those estimated for the left bank.

12.3. Right Bank Climate Change Impacts

The right bank analysis has been updated with the climate change adjustments referenced in Section 11. Similar results, as presented in Table 72, to the previous analysis occurred in that significant increases to individual damages and EAD occurred. After accounting for climate change impacts to the hydraulic inputs, the right bank EAD increased 2.1 times over the existing conditions model. The business disruption items, not included in the table, also increased substantially from climate change. The estimated EAD for business sales revenue increased to $4,635, with a tax loss of $614, and a minimal job loss estimate.

Table 72 – Right Bank Expected Annual Damages with Climate Change

Damage Category	*EAD*
Structures and Contents	$86,683
Direct Vehicle	$14,257
Direct Road	$4,676
Debris Removal	$311
Building Cleanup	$6,751
Emergency Response	$63
Landscape Restoration	$854
Transportation Detour	$0
Lost Worker Productivity	$6,350
Evacuation and Subsistence	$491
Mental Stress and Anxiety	$1,776
EAD Total	**$122,211**

12.4. Gabion Retaining Wall

Another area of risk in the study area is regarding the existing gabion retaining wall located along the left bank downstream of the Preston-Fall City Road Bridge. This retaining wall was not analyzed in the geotechnical analysis, and therefore was not incorporated into the levee failure probabilities. Future analysis could be completed looking at failure probabilities for the wall, which could lead to changes in EAD for the Left Bank mix reach. This retaining wall also directly abuts a low-income neighborhood, as shown in the circle just downstream of Preston-Fall City Road Bridge in Map 9. Failure to the gabion wall would likely have adverse impacts to low-income populations.

13. SUMMARY AND CONCLUSIONS

This section presents some overarching conclusions and relevant comparison information based on the results of the various damage estimates and other data generated throughout this report.

13.1. EAD Results

Overall, the existing conditions models reflect relatively low monetized EAD values for the standard monetized damage categories in the left bank levee system floodplain. This was an expected result based on the hydraulic data, levee fragility parameters, and relatively small study area. Based on preliminary conceptualization of the three modeled scenarios, the Overtop-then-Breach scenario was anticipated to have the largest EAD and would be the driver of the final system-wide EAD calculation. This was all due to the higher probability of annual flooding occurring in this scenario because of the overtopping issue, which the hydraulic modeling shows occurring at the 4% AEP (25-year event). The Overtop-then-Breach scenario generates over 2 times as much EAD as the Breach Location 3 scenario, and over 8.5 times the EAD of the Breach Location 6 scenario.

Table 73 – Relative Comparison of EAD Values by Scenario

Scenario	*Reach*	*Expected Annual Damages*	*Percent EAD by Scenario*	*Percent of Overtop-then-Breach EAD*
Overtop-then-Breach	Left Bank	$32,024	45.4%	-
	Left Bank mix	$38,518	54.6%	
	Right Bank	$0	0.0%	
	Scenario Total	**$70,542**	**100.0%**	
Breach Location 3	Left Bank	$32,719	68.6%	67.6%
	Left Bank mix	$14,996	31.4%	
	Right Bank	$0	0.0%	
	Scenario Total	**$47,715**	**100.0%**	
Breach Location 6	Left Bank	$6,098	79.2%	10.9%
	Left Bank mix	$1,601	20.8%	
	Right Bank	$0	0.0%	
	Scenario Total	**$7,699**	**100.0%**	

Furthermore, the Overtop-then-Breach scenario is calculated to have an estimated annual probability of failure magnitudes larger than the other two scenarios. The estimated 6.55% annual probability of failure approximation is almost 15 times more probable than failure at Breach Location 3, and over 140 times more likely to occur than the Breach Location 6 failure. This again is driven by the likelihood of overtopping at the low point of the levee being far more probable to occur than any failure or overtopping at the two breach locations. As such, the system-wide EAD is driven by the EAD of the Overtop-then-Breach scenario. As shown in Section 7.2, over 95% of the $69,185 system-wide EAD value comes from the Overtop-then-Breach scenario.

The two breach scenarios are relevant data points for the study area even though the failure probabilities are very low. Breach Location 3 is shown to be overtopped in a flood event between the 1% and 0.2% AEP events. However, based on the levee height at Breach Location 6, overtopping is not likely to occur except for an event well in excess of a 0.2% AEP event. Therefore, even with Breach Location 6 hydraulic modeling showing vastly more inundated area and structures, Breach Location 3 scenario has a higher EAD, and higher estimated annual probability of failure.

13.2. ESJ Results

Based on the number of low-income homes compared to the total number of residential structures, only for the 0.2% AEP (500-year event) do we see that, for the Overtop then Breach Scenario and the BL3 scenario, the low-income share of residences inundated is 36 percent, which is higher than the representative 27.8 percent. Under both these scenarios, the number of low-income homes could potentially be disproportionately impacted, increasing the potential burden on ESJ community members. Based on EAD, low-income homes are disproportionately impacted under the BL3 scenario. For BL3, EAD for low-income units could potentially be 18.6 percent, which is almost double the representative value for low-income units (10.5 percent). In terms of both number of structures inundated and EAD, ESJ communities could be disproportionately impacted under the BL3 scenario.

13.3. CLIMATE CHANGE

Based on general understanding of climate change, and how it will impact future flood events, the results of this analysis show substantial increases to potential flood damages for the 1% and 0.2% AEP events. For all three economic scenarios damages increased substantially from the existing conditions. This was due to the flow increases represented in the hydraulic analysis, which both increased depths in areas, and shifted the anticipated flood event for which the levee would be overtopped and/or breached. These underlying assumptions in the FDA models were all accounted for which led to the increases in relative damage as represented in Table 74.

Table 74 – Comparison of Existing and Potential Future Conditions by Scenario

AEP	Economic Scenario	Existing Conditions Damages	Future Conditions Damages	Percent Increase
1%	Overtop-then-Breach	$1,156,807	$10,586,601	815%
	Breach Location 3	$7,666,322	$10,611,685	38%
	Breach Location 6	$8,111,712	$12,131,491	50%
0.2%	Overtop-then-Breach	$10,895,285	$21,890,399	101%
	Breach Location 3	$10,895,293	$21,969,048	102%
	Breach Location 6	$12,567,541	$21,778,413	73%

The large increase in the 1% AEP for the Overtop-then-Breach scenario is due primarily to the levee being overtopped at Breach Location 3 given the water surface elevation in Table 63. Thus, given the parameters of this study, once overtopped, the levee is assumed to breach. So there is a substantial increase in damages from this change, as compared to the existing conditions results.

13.4. LEVEE PERFORMANCE

The levee performance data was generated for the existing and future conditions models, and as expected the future conditions models saw substantial decreases in all areas referencing non-exceedance and assurance metrics. It is interesting to look at the existing conditions levee performance data, as that gives a snapshot of the current levee system, but these statistics are limited by the assumptions and inputs developed explicitly for this study.

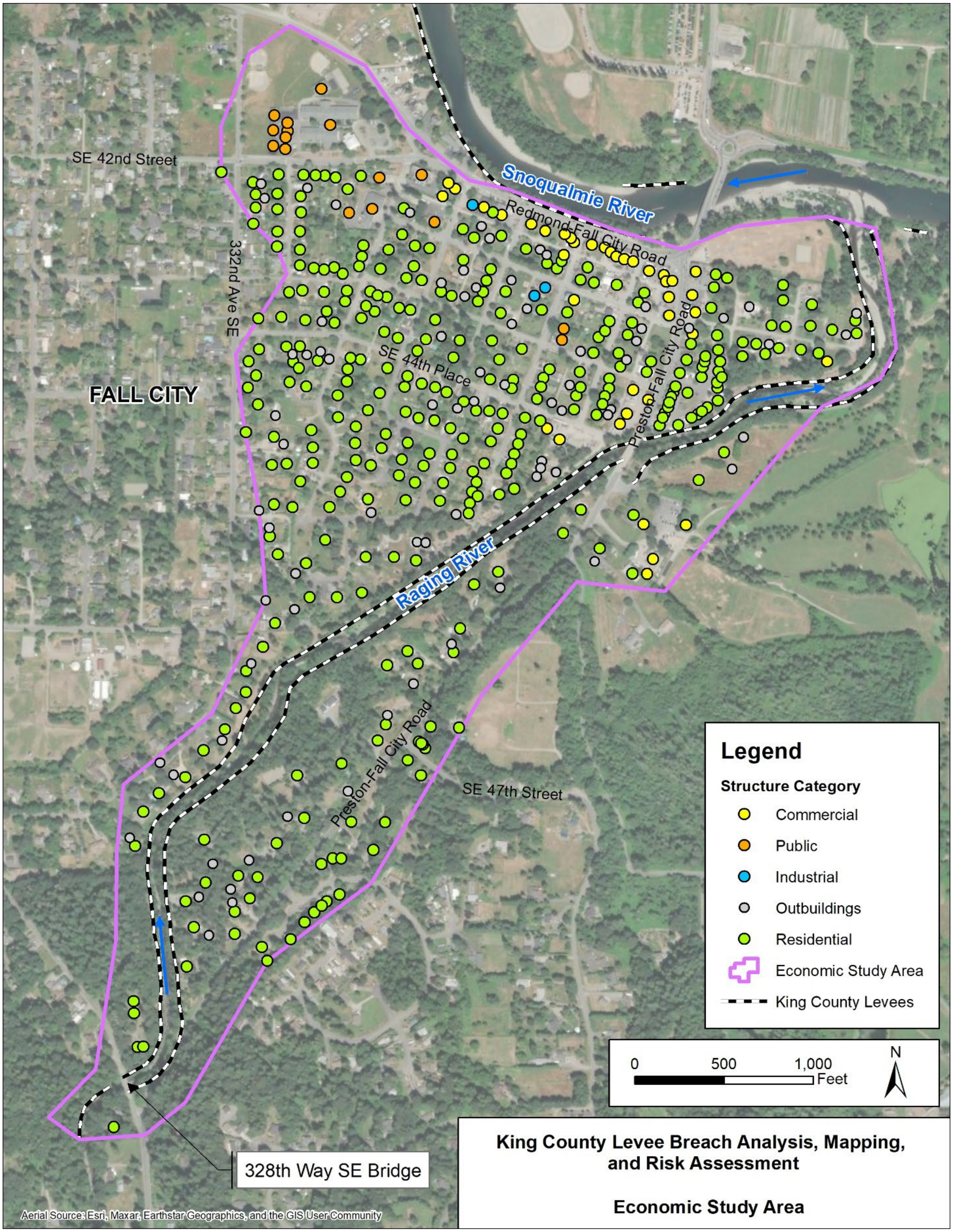
But the results of the existing system show that there is an obvious issue at that low point on the levee, which is driving the results of the Overtop-then-Breach scenario. In this scenario the levee is estimated to have approximately 21.5% chance of containing a 4% AEP flood event, and approximately 80% chance of containing a 10% AEP event. Future analysis for this section of the levee could better analyze the potential risk that is apparent near the confluence of the Raging and Snoqualmie Rivers, as well as at the location of the gabion retaining wall.

For the two breach location points, the levee performance information is relatively positive. Breach Location 3 has a roughly 84% chance to withstand flooding, whether from failure or overtopping, during a 1% AEP event, and Breach Location 6 has over 98% chance to pass those flows with no overtopping or failure. For the slightly different assurance analysis, Breach Location 3 has an 82.8% chance of not overtopping or failing, and Breach Location 6 is still at 98%. These assurance numbers are used for the NFIP accreditation requirements. As currently modeled, it appears the upstream sections of the levee system are more robust in terms of both overtopping and failure. Thus, the levee performance analysis further illustrates that the downstream portions of the levees would be an area of interest for future analysis within this system.

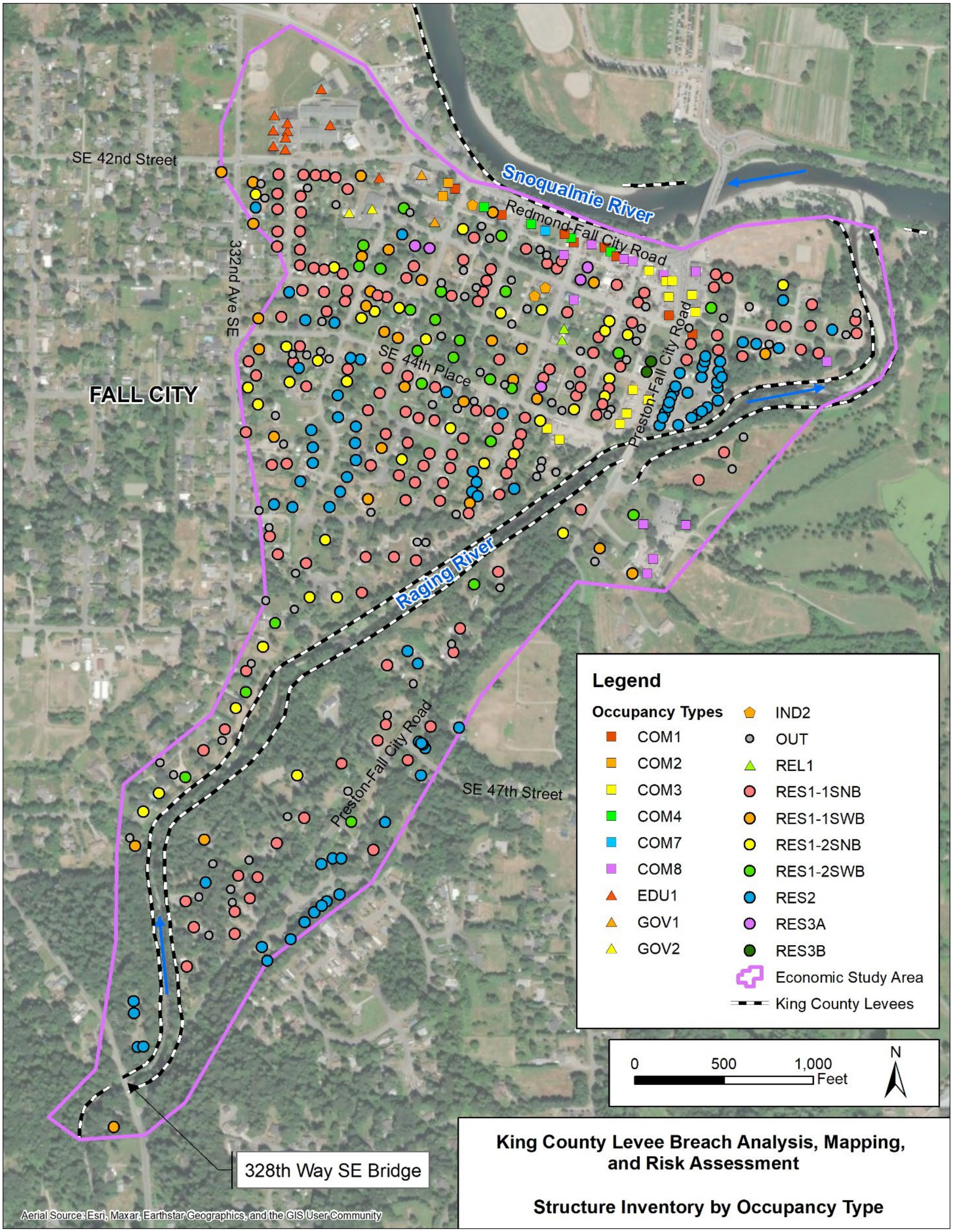
13.5. RIGHT BANK FLOODING

As described in Section 5.3, much of the analysis aimed at analyzing flood risk due to overtopping and/or breaching did not include analysis for the Right Bank. Future analysis of flooding along the right bank might look at opportunities to reduce flooding in the area from breakout upstream of the existing levee system, assess flooding from the Snoqualmie River, and/or better characterize interior drainage issues in this area.

14. MAPS



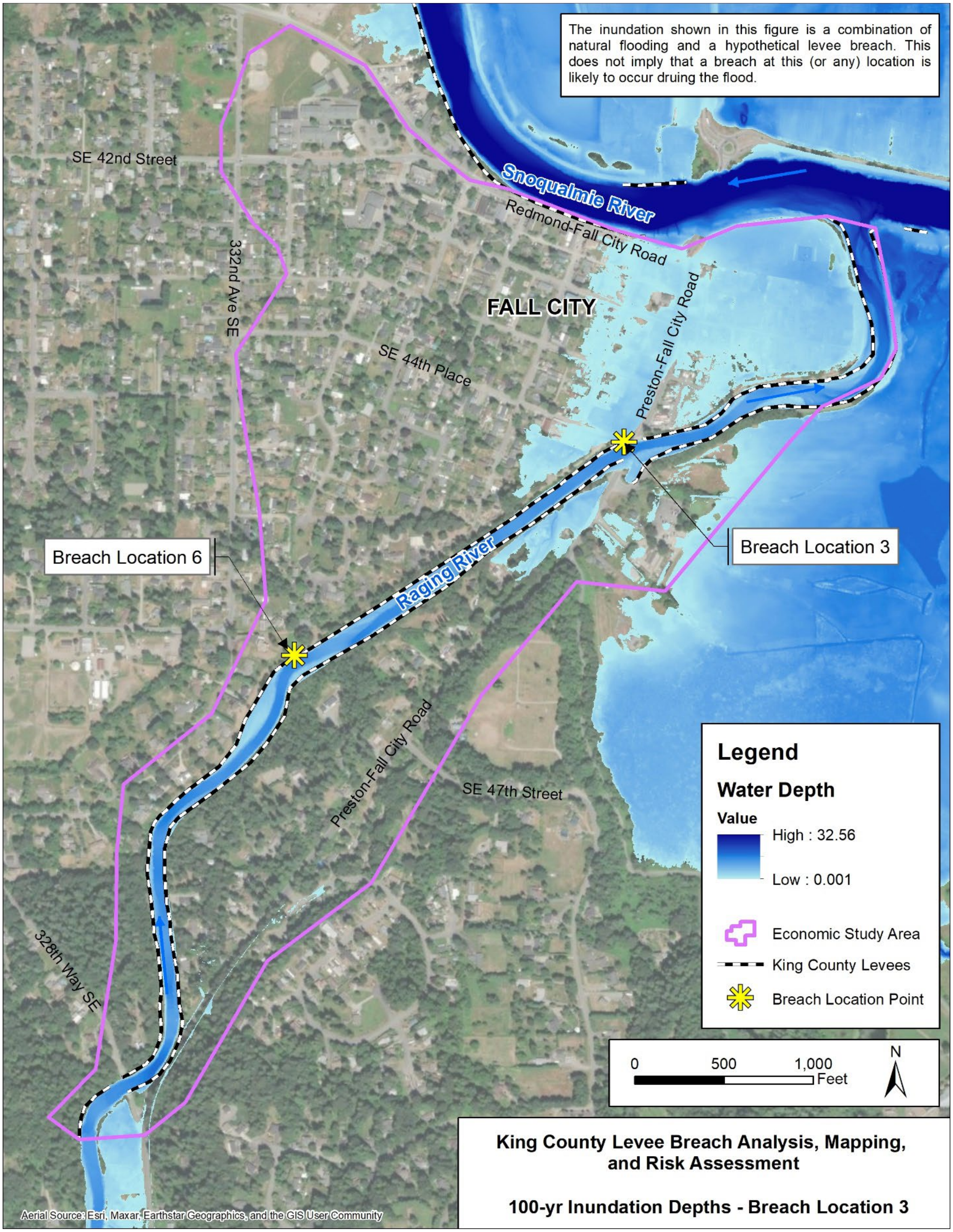
Map 1 – Structure Inventory by Category



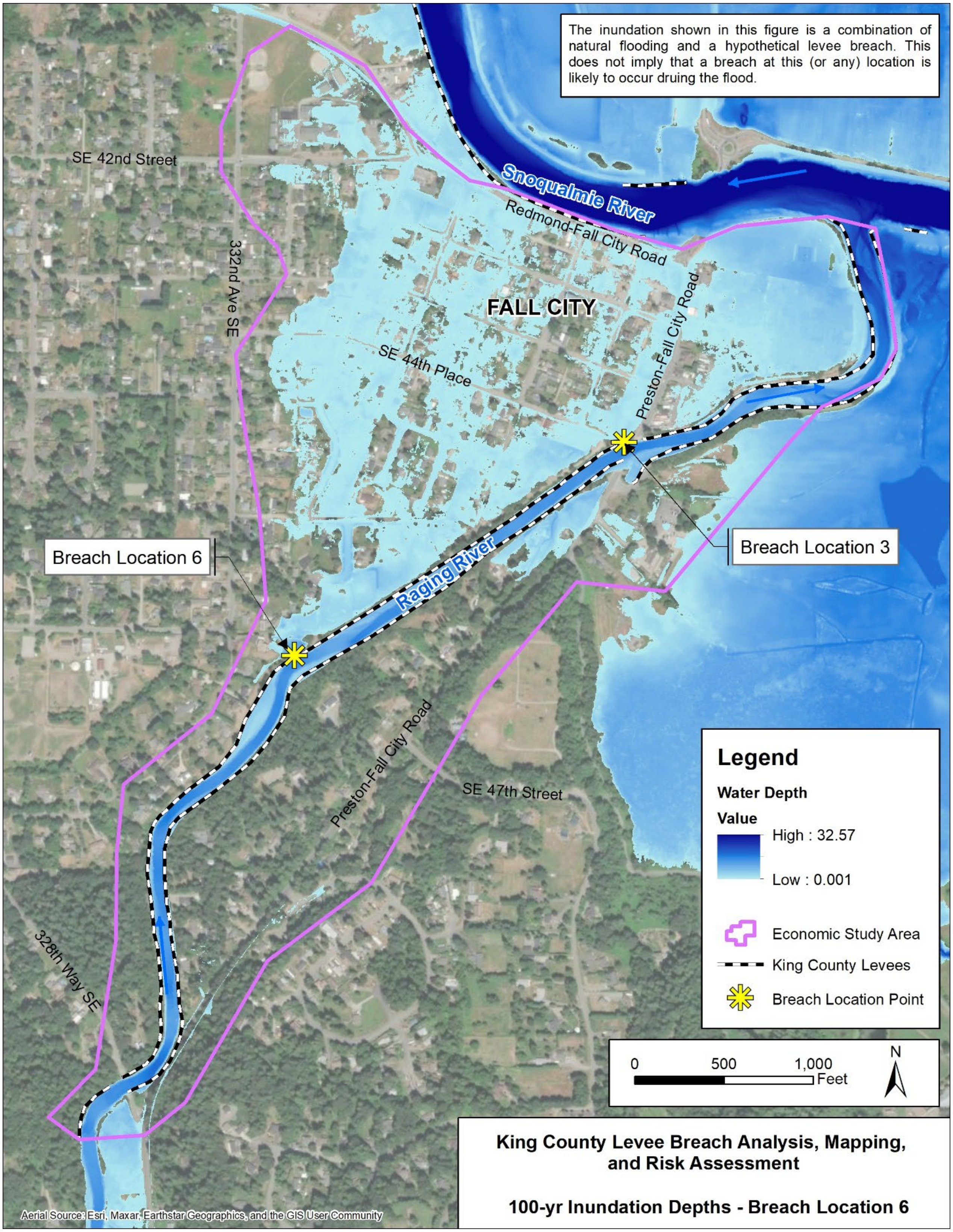
Map 2 – Structure Inventory by Occupancy Type

Map 3 – Hydraulic Model Breach Location Points

Map 4 – 100-yr Inundation Depths – Baseline Hydraulic Model

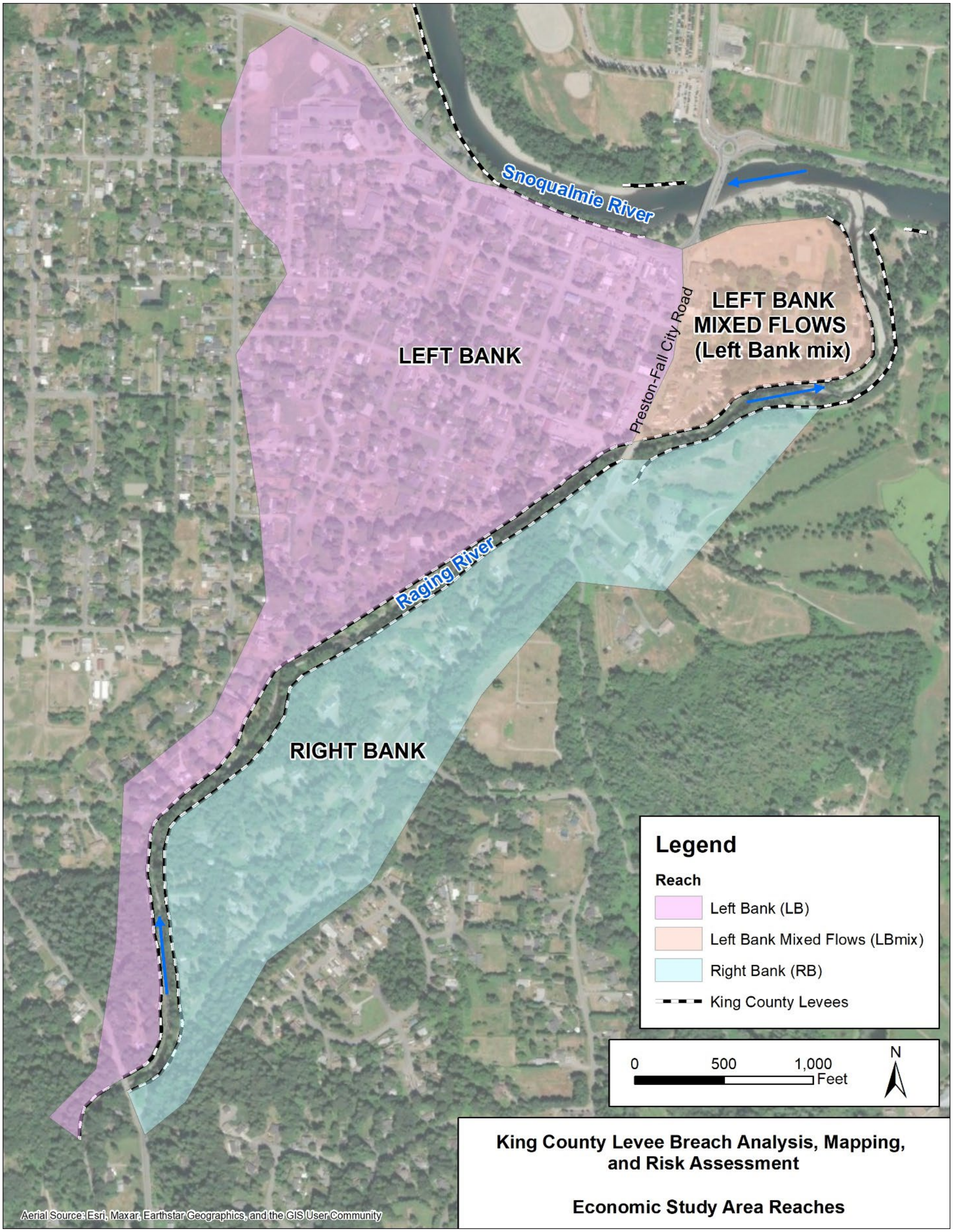


Map 5 – 100-yr Inundation Depths – Breach Location 3 Hydraulic Model

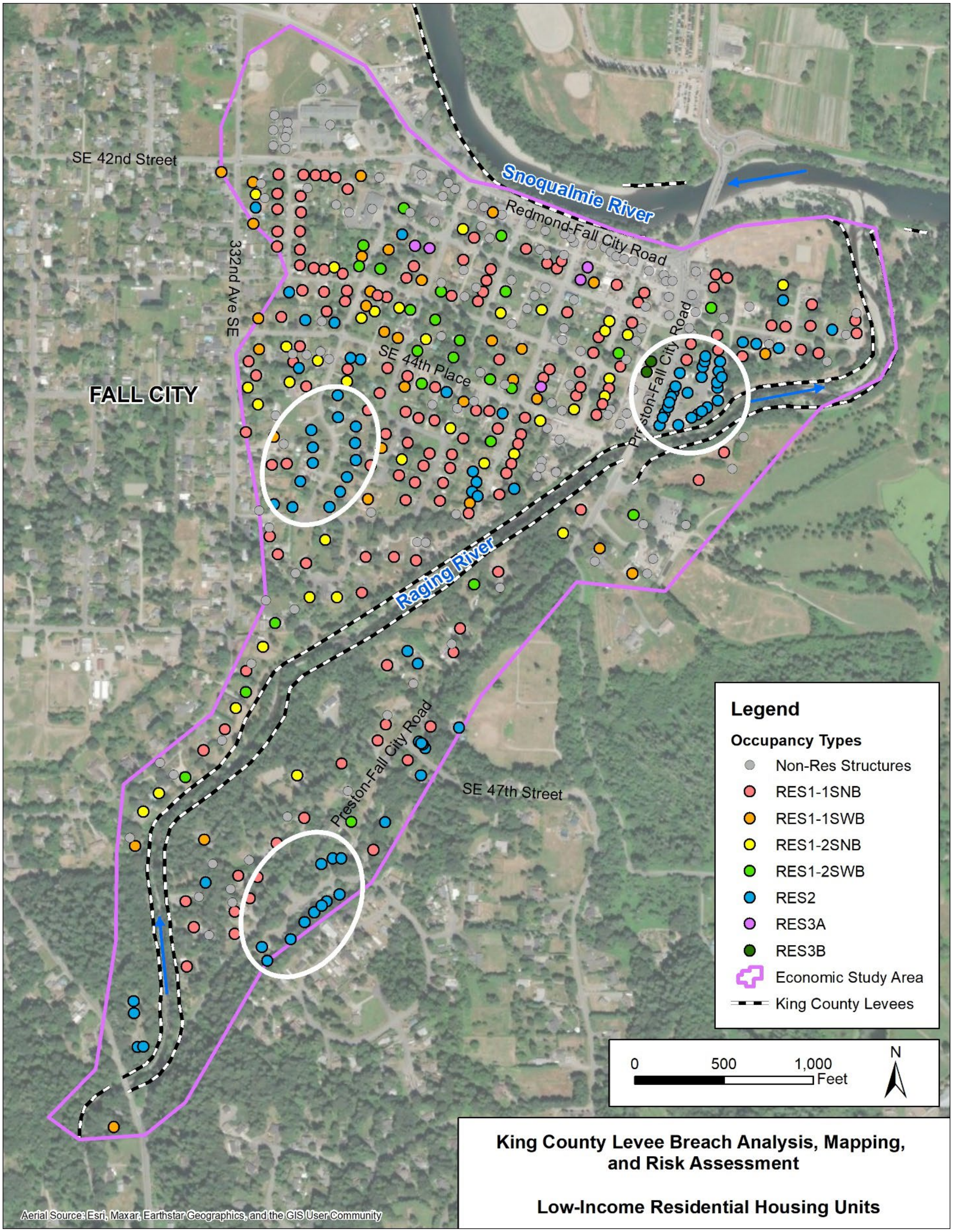


Map 6 – 100-yr Inundation Depths – Breach Location 6 Hydraulic Model

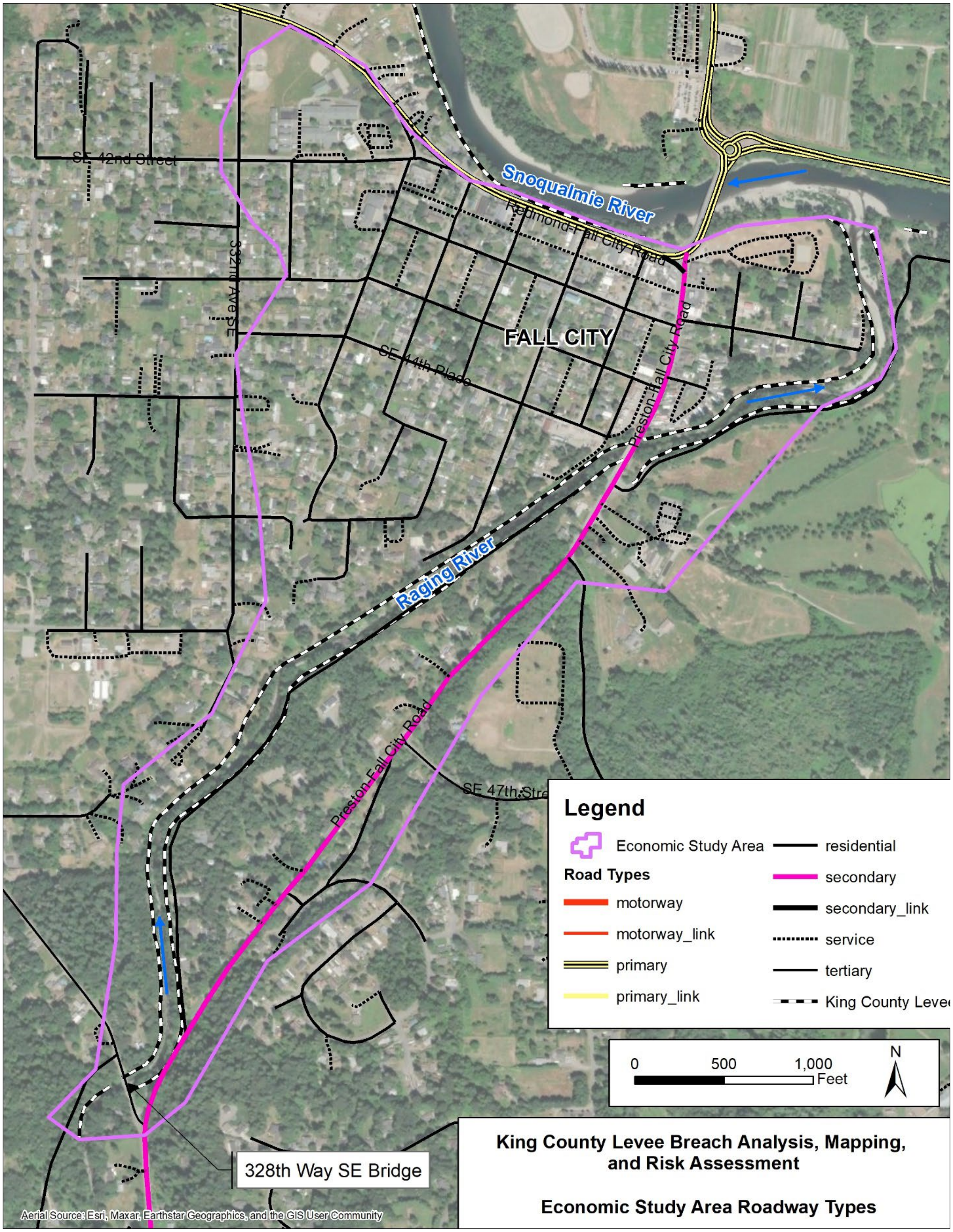
Map 7 – Approximate Low Point of Raging Levee Systems



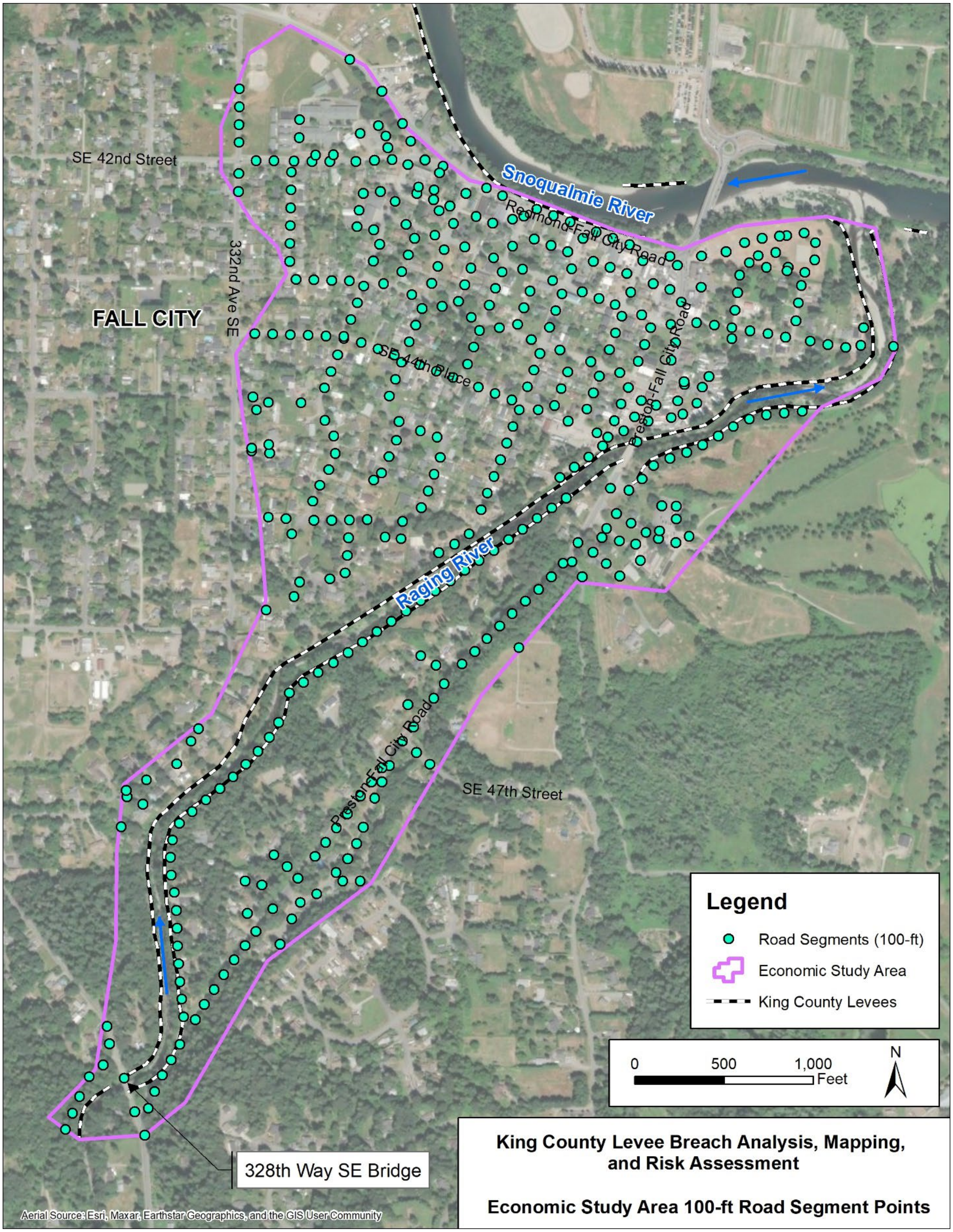
Map 8 – Economic Study Area Reaches



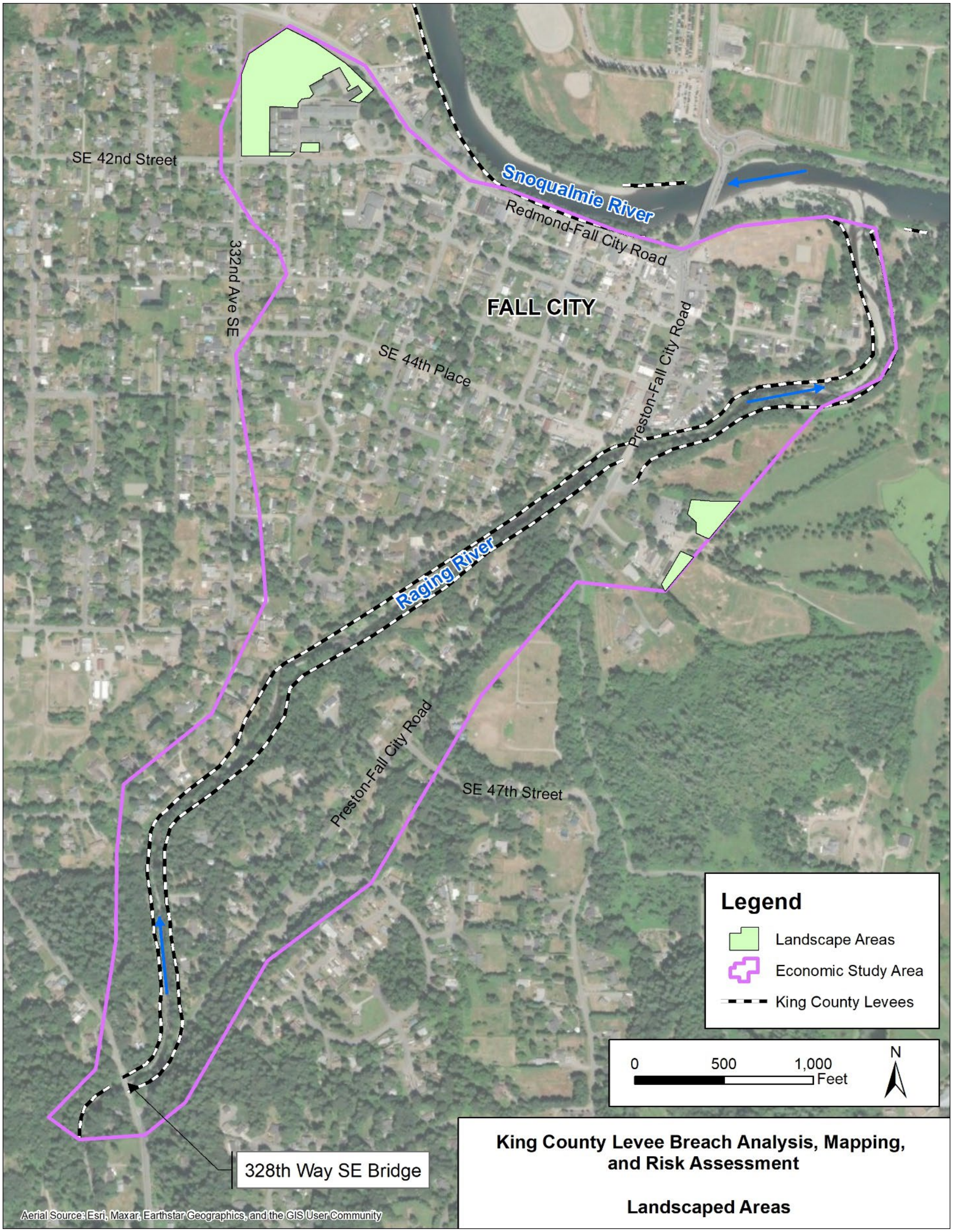
Map 9 – Low-Income Residential Housing Units Circled in White Within the Economic Study Area



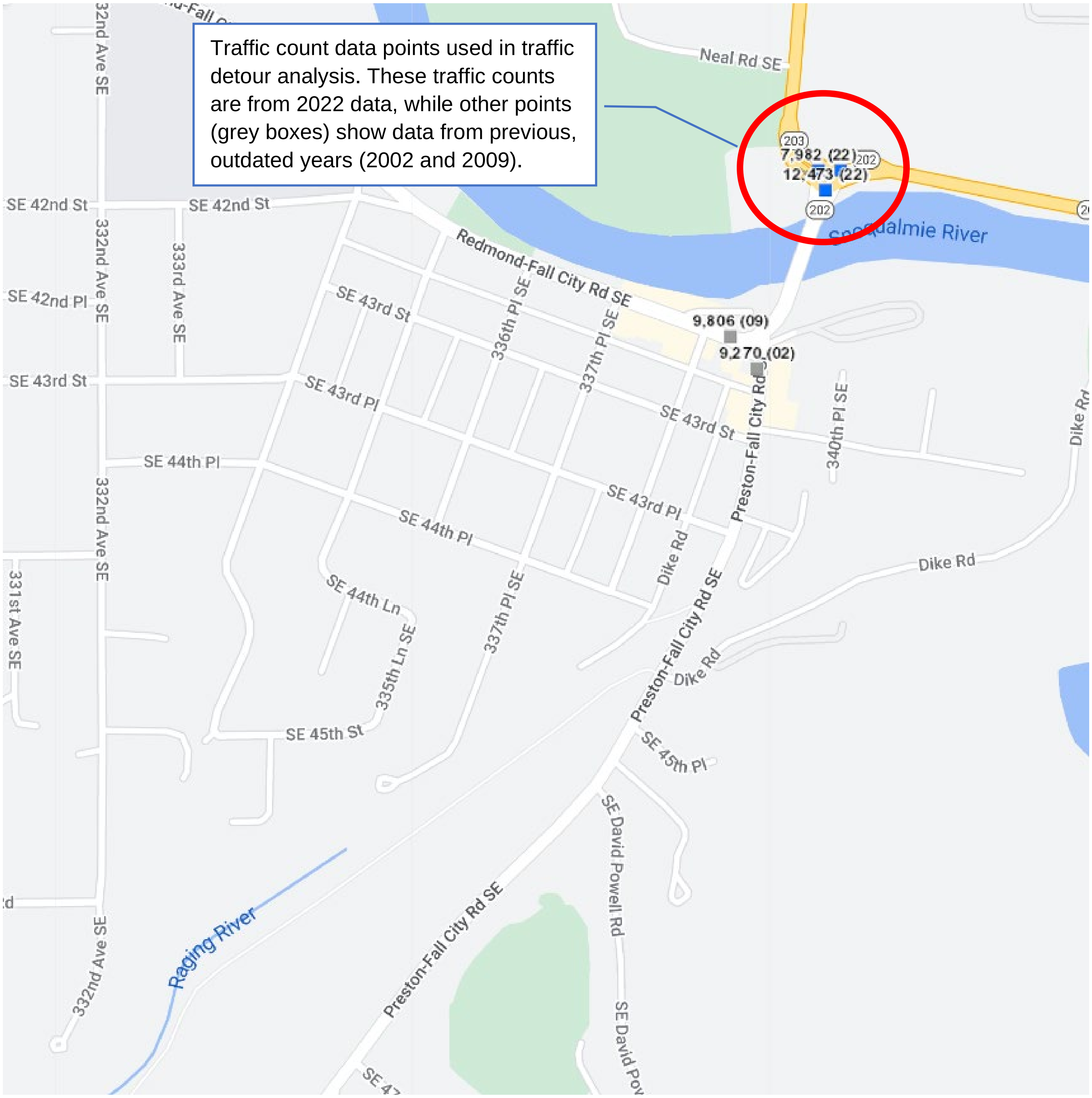
Map 10 – Economic Study Area Roadway Types



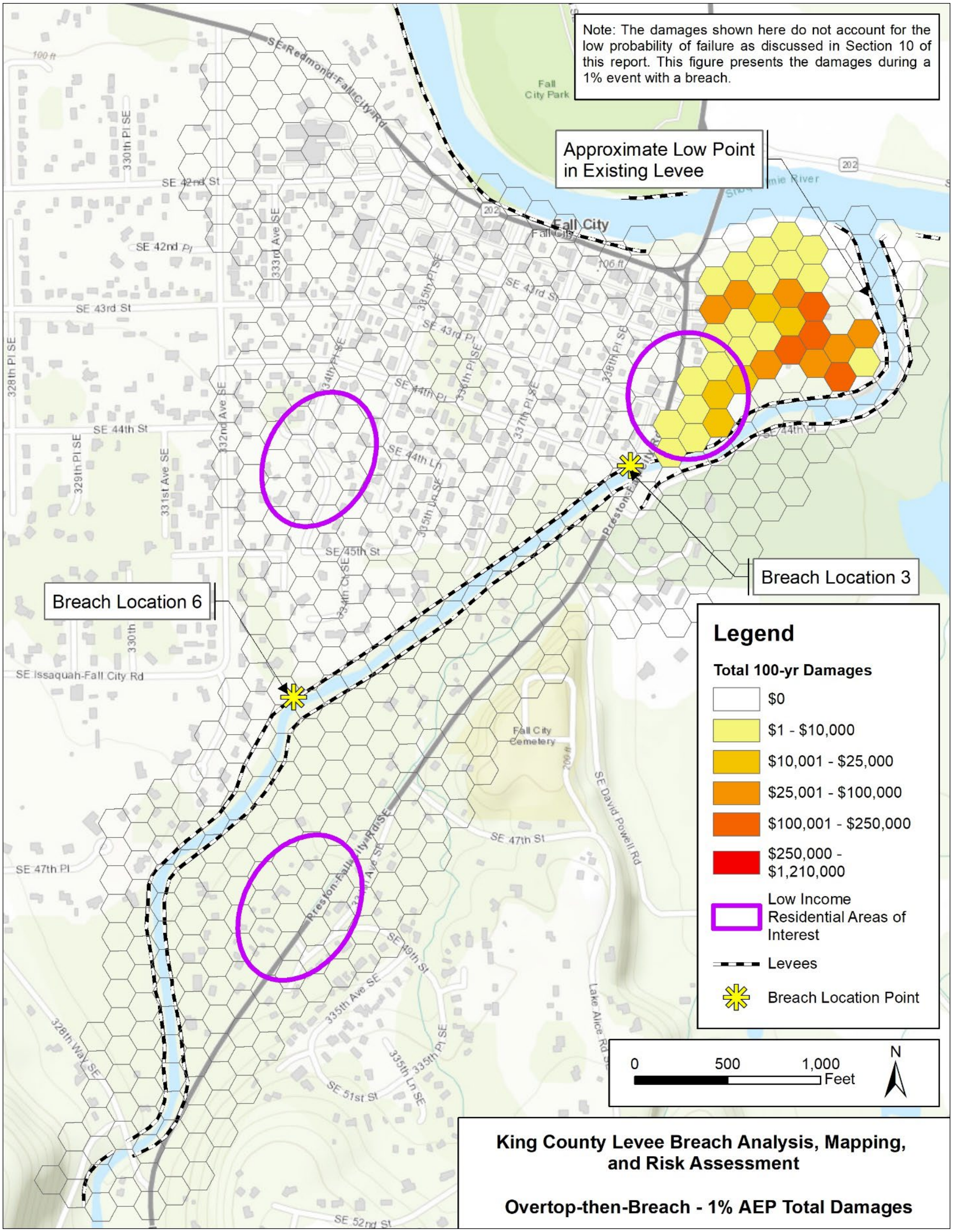
Map 11 – Economic Study Area 100-ft Road Segment Points



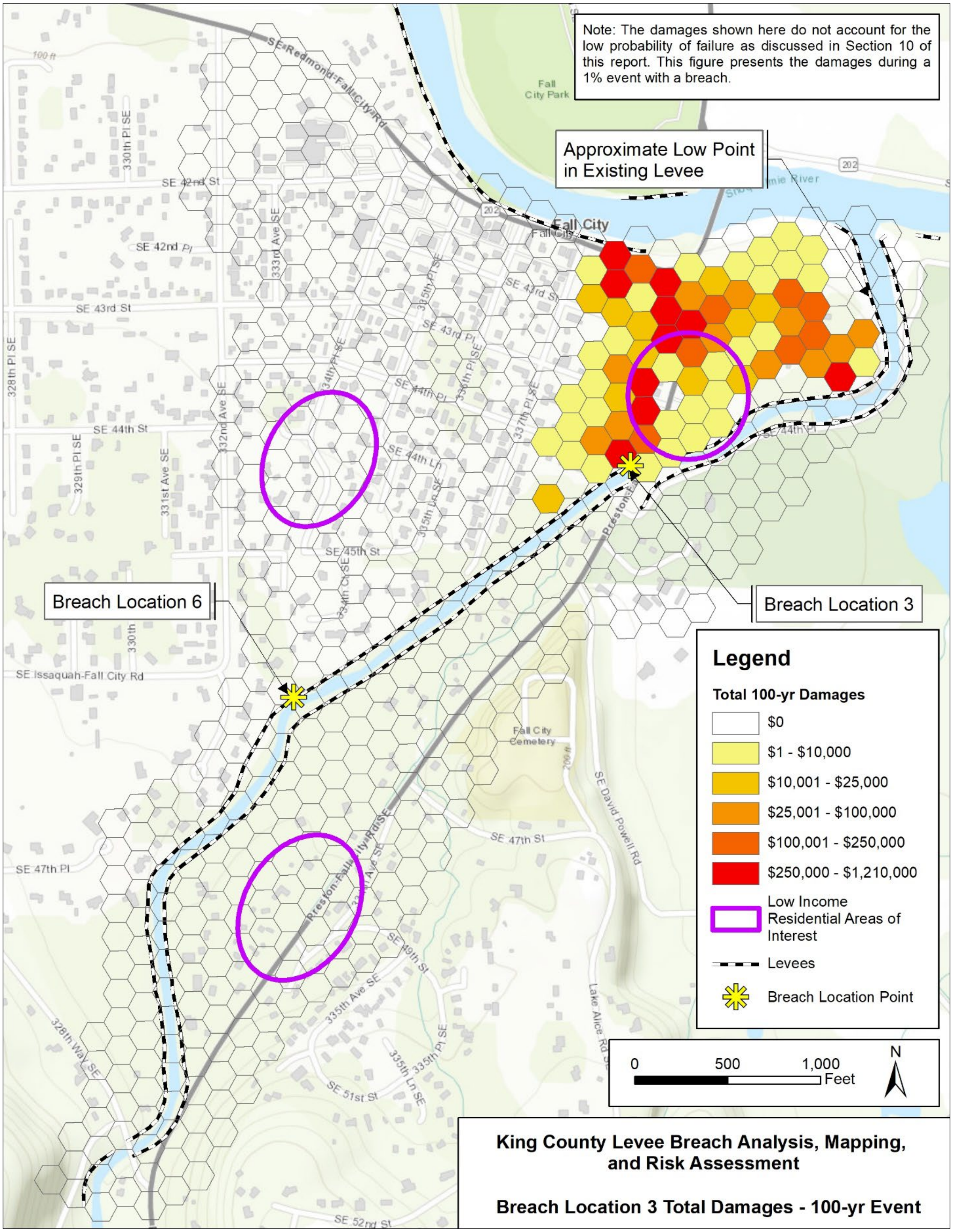
Map 12 – Landscaped Areas



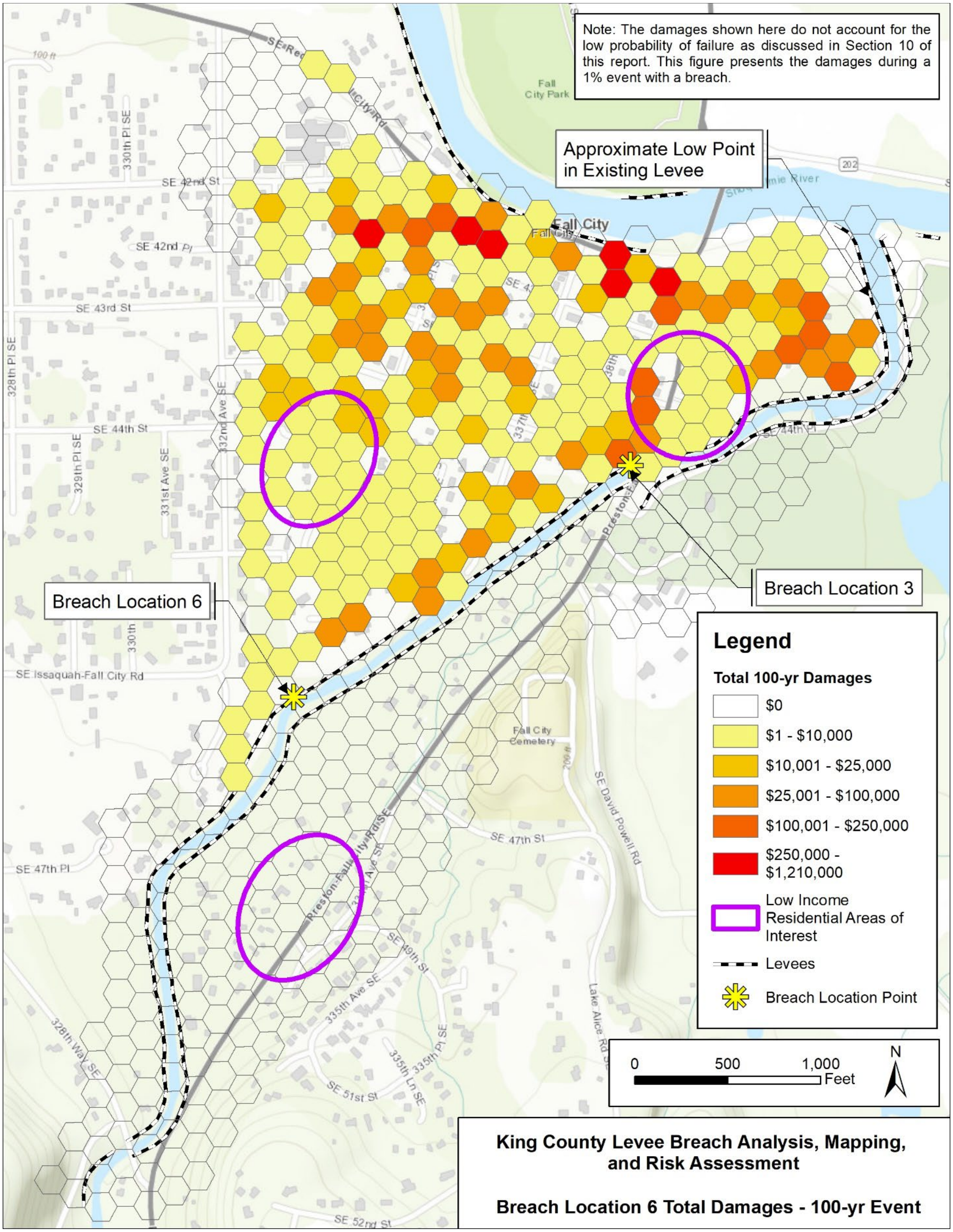
Map 13 – Available Traffic Count Locations
(Source: Washington State Department of Transportation)



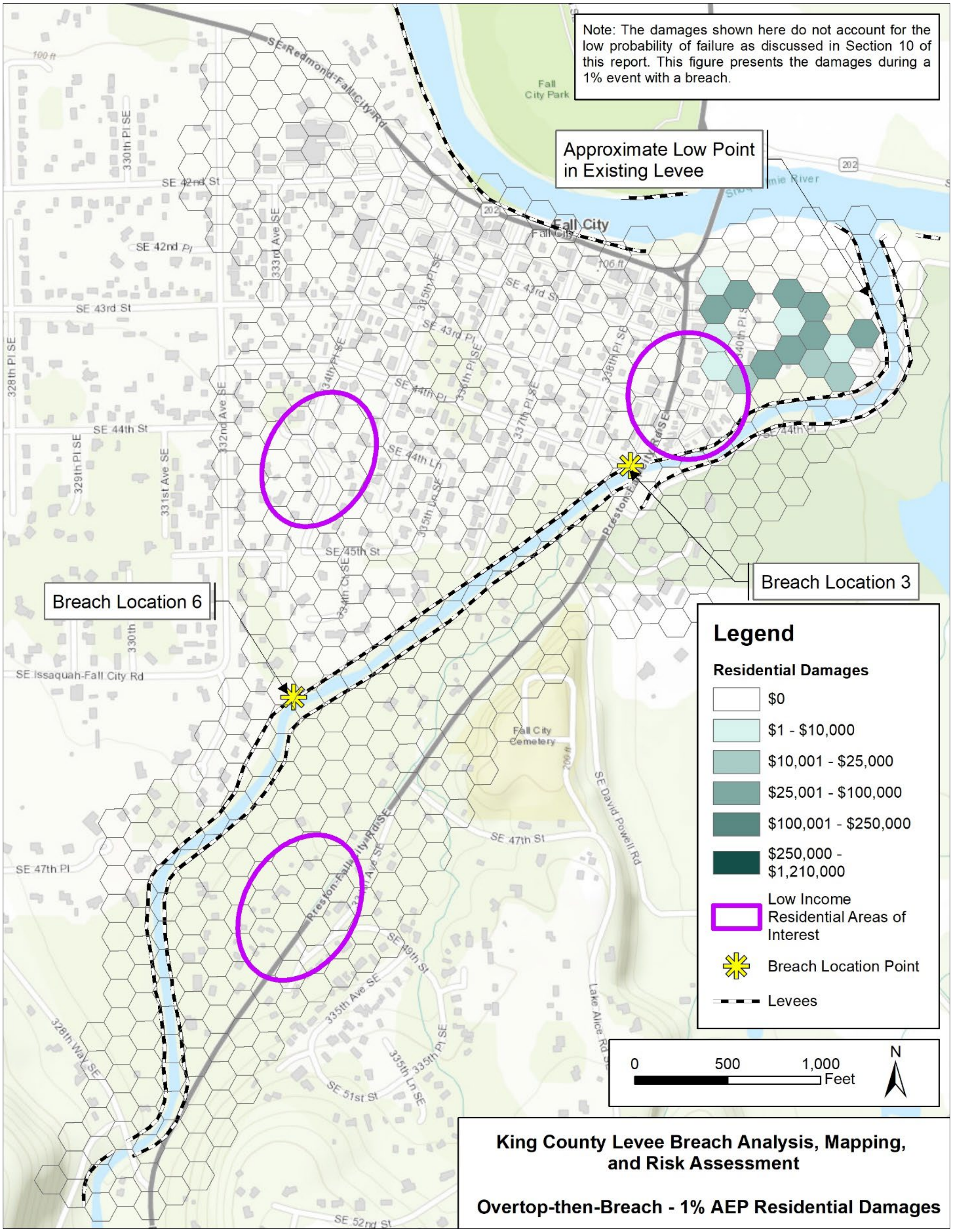
Map 14 – 1% AEP Total Damages by Area for Overtop-then-Breach Scenario



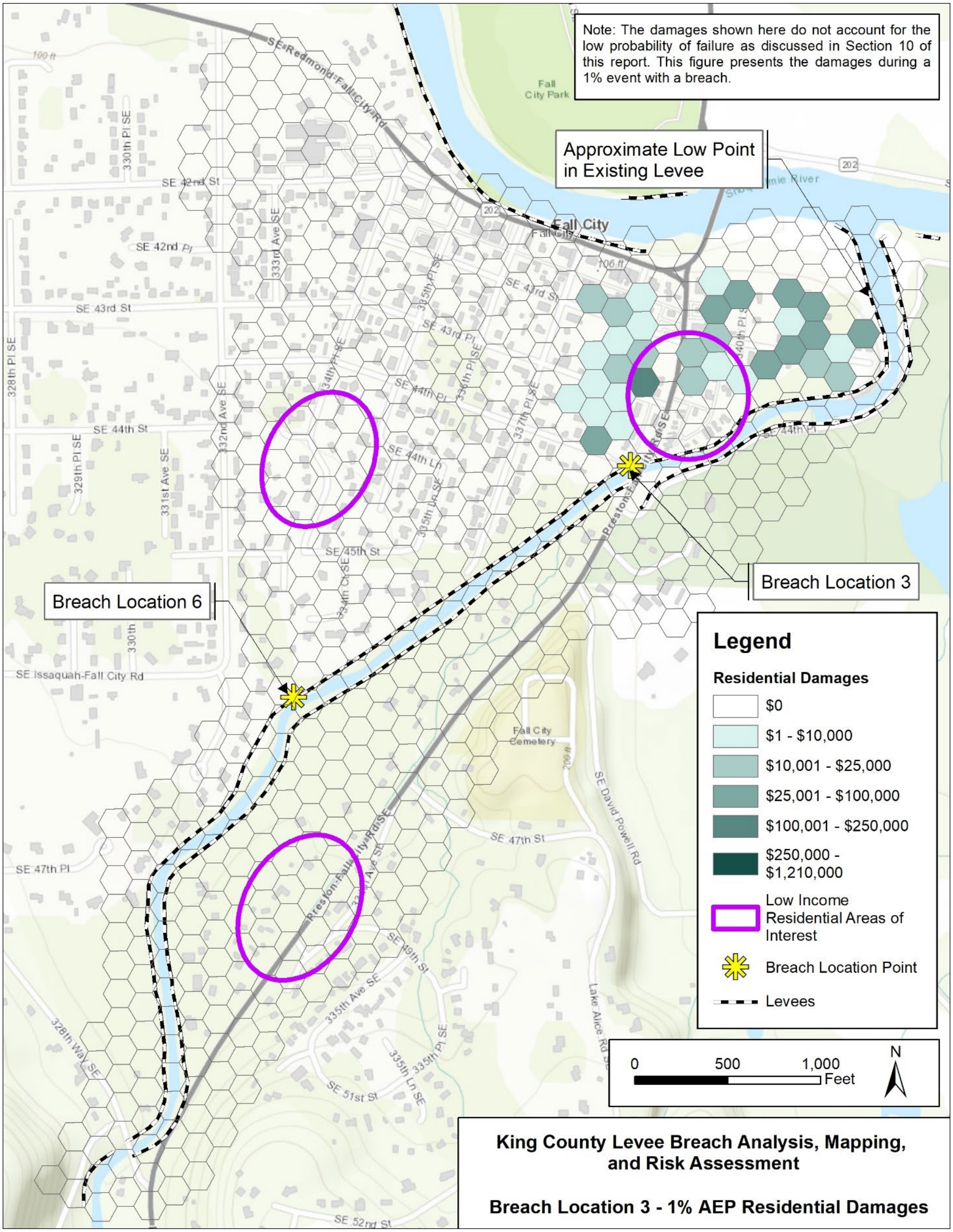
Map 15 – 1% AEP Total Damages by Area for Breach Location 3 Scenario



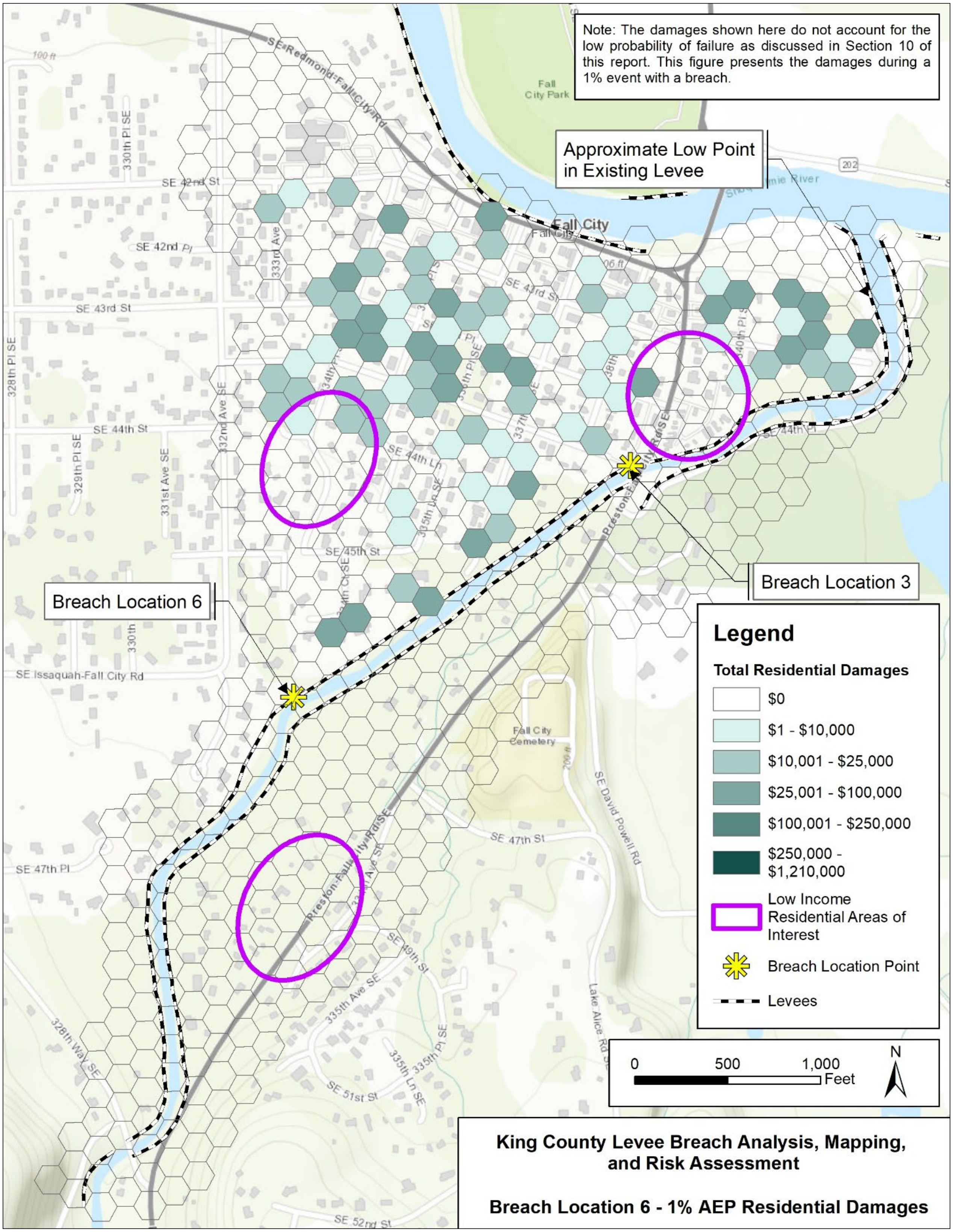
Map 16 – 1% AEP Total Damages by Area for Breach Location 6 Scenario



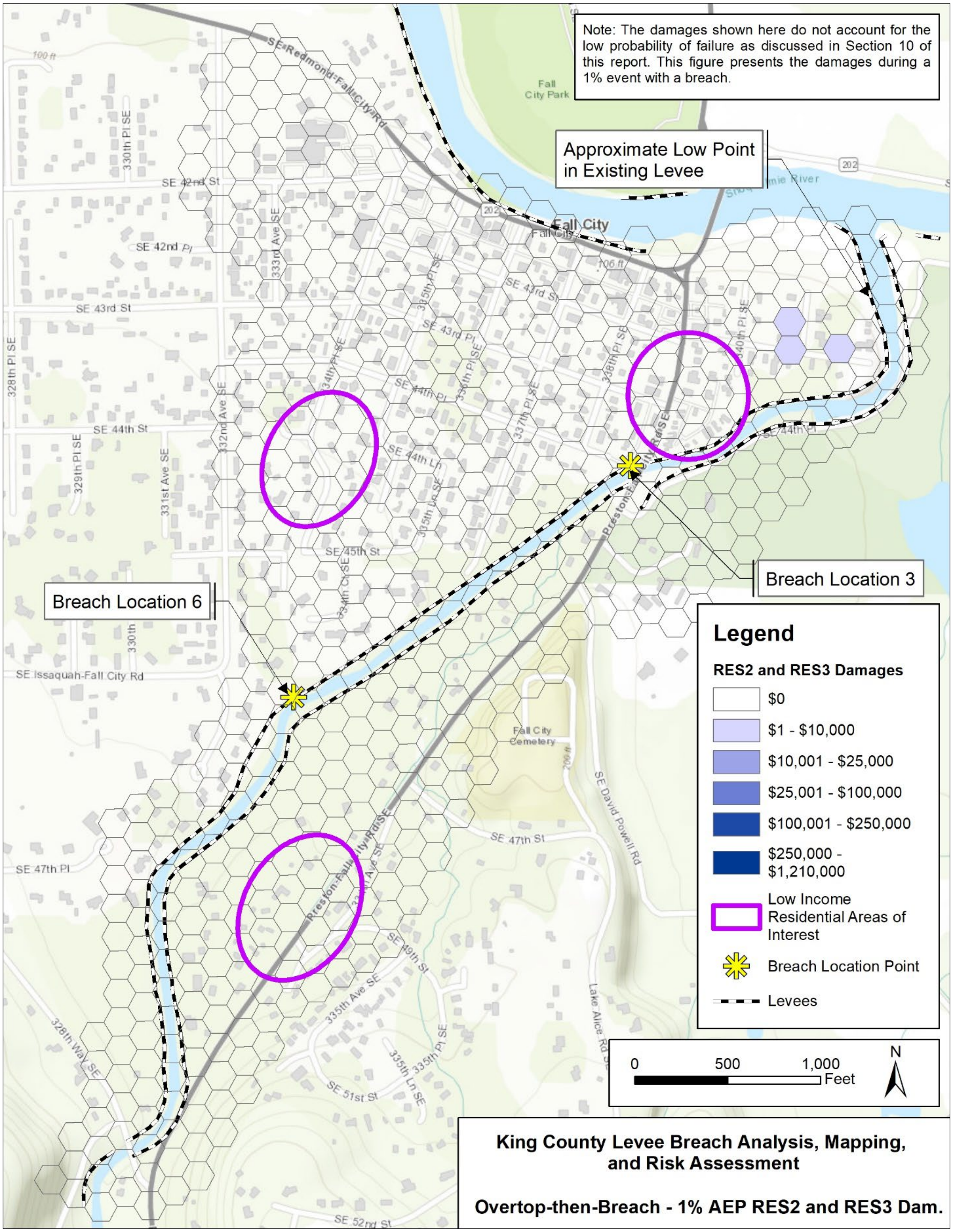
Map 17 – Overtop-then-Breach – 1% AEP Residential Damages



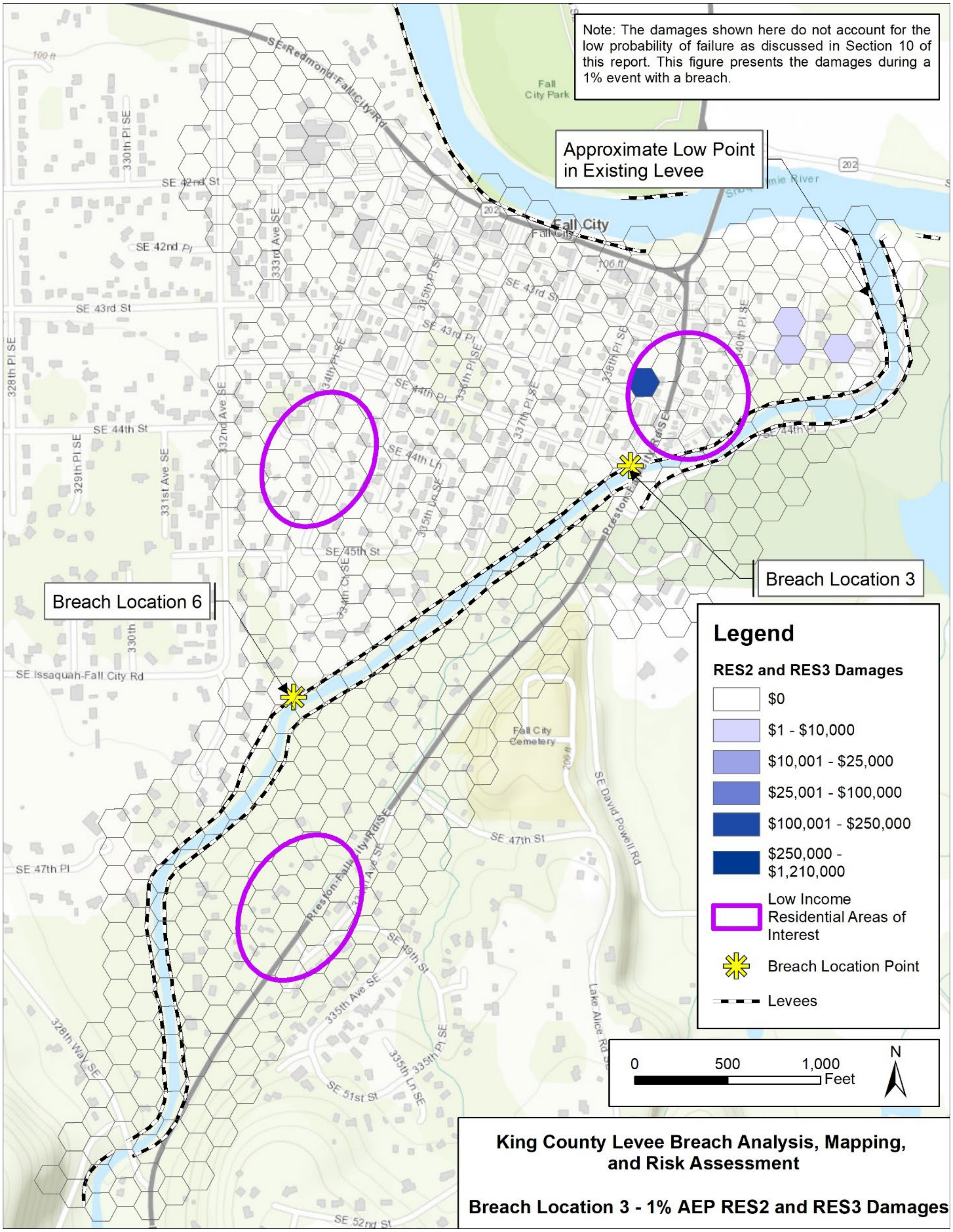
Map 18 – Breach Location 3 – 1% AEP Residential Damages



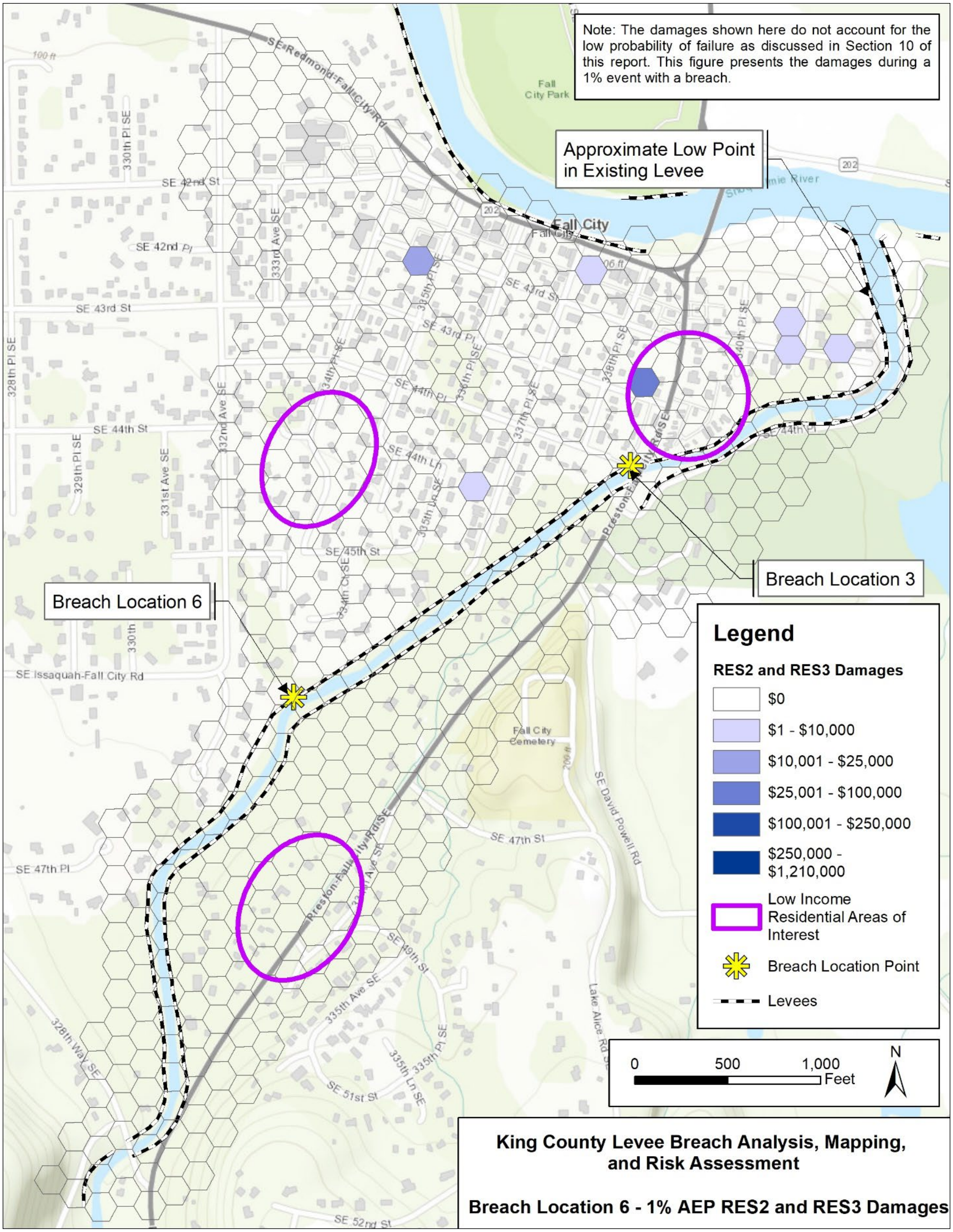
Map 19 – Breach Location 6 – 1% AEP Residential Damages



Map 20 – Overtop-then-Breach – 1% AEP RES2 and RES3 Damages



Map 21 – Breach Location 3 – 1% AEP RES2 and RES3 Damages



Map 22 – Breach Location 6 – 1% AEP RES2 and RES3 Damages

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ATTACHMENT 1 – Depth Damage Functions for Structures and Contents

Depth-Damage Functions for Structures and Contents

Occupancy	Description	Category	Depth Damage Percentages																				
			Depth	-1	-0.5	0	0.5	1	1.5	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AGR1	gen purp barn	Commercial	Structure Damage	0	3	6	8.5	11	13	15	19	25	30	35	41	46	51	57	63	70	75	79	82
			Content Damage	0	3	6	10	20	31.5	43	58	65	66	66	67	70	75	76	76	76	77	77	77
COM1	retail, groc, conv	Commercial	Structure Damage	0	0.5	1	5	9	12	14	16	18	20	23	26	30	34	38	42	47	51	55	58
			Content Damage	0	1	2	14	26	34	42	56	68	78	83	85	87	88	89	90	91	92	92	93
COM2	storage, auto, warehouse	Commercial	Structure Damage	0	0	0	3	5	7	8	11	13	16	19	22	25	29	32	37	41	45	49	52
			Content Damage	0	1.5	3	9.5	16	21.5	27	36	49	57	63	69	72	76	80	82	84	86	87	87
COM3	auto service	Commercial	Structure Damage	0	0	0	4.5	9	10.5	12	13	16	19	22	25	28	32	35	39	43	47	50	54
			Content Damage	0	2	4	16.5	29	37.5	46	67	79	85	91	92	92	93	94	96	96	97	97	98
COM4	office	Commercial	Structure Damage	0	1	2	6.5	11	13.5	16	22	28	35	38	41	44	47	50	54	57	59	62	66
			Content Damage	0	1	2	10	18	21.5	25	35	43	49	52	55	57	58	60	65	67	68	69	70
COM5	bank	Commercial	Structure Damage	0	0	0	5.5	11	11	11	12	13	15	17	19	22	24	28	31	34	37	40	44
			Content Damage	0	0	0	25	50	62	74	100	100	100	100	100	100	100	100	100	100	100	100	100
COM7	medical, dental	Commercial	Structure Damage	0	1	2	6.5	11	11.5	12	13	14	16	17	18	20	22	24	27	30	34	37	41
			Content Damage	0	0	0	14	28	39.5	51	60	63	67	71	72	74	77	81	86	92	94	97	100
COM8	restaur and rec	Commercial	Structure Damage	0	0.5	1	5	9	10	11	12	14	16	18	20	22	26	29	33	37	41	45	50
			Content Damage	0	6.5	13	29	45	50	55	64	73	77	80	82	83	85	87	89	90	91	92	93
COM9	theaters	Commercial	Structure Damage	0	0	0	1	2	3	4	5	5	5	6	8	10	12	15	20	24	29	35	42
			Content Damage	0	0	0	2	4	5	6	8	9	10	12	17	22	30	41	57	66	73	79	84
COM10	parking garage	Commercial	Structure Damage	0	0	0	1.5	3	4.5	5	6	7	8	10	13	17	21	25	30	35	41	47	52
			Content Damage	0	0	0	5.5	11	14	17	20	23	25	29	35	42	51	63	77	93	100	100	100
EDU1	elementary school	Public	Structure Damage	0	0	0	2.5	5	6	7	9	9	10	11	13	15	17	20	24	28	33	39	45
			Content Damage	0	0	0	13.5	27	32.5	38	53	64	68	70	72	75	79	83	88	94	100	100	100
GOV1	gov serv, library	Public	Structure Damage	0	0	0	2.5	5	6.5	8	13	14	14	15	17	19	22	26	31	37	44	51	59
			Content Damage	0	0	0	15	30	44.5	59	74	83	90	100	100	100	100	100	100	100	100	100	100
GOV2	fire station	Public	Structure Damage	0	0	0	3.5	7	8.5	10	11	12	15	17	20	23	27	31	35	40	44	48	52
			Content Damage	0	0	0	4	8	14	20	38	55	70	81	89	98	100	100	100	100	100	100	100
IND1	heavy industrial	Industrial	Structure Damage	0	0.5	1	5.5	10	11	12	15	19	22	26	30	35	39	42	48	50	51	53	54
			Content Damage	0	0	0	7.5	15	19.5	24	34	41	47	52	57	60	63	64	66	68	69	72	73
IND2	light industrial	Industrial	Structure Damage	0	0.5	1	5	9	11.5	14	17	22	26	30	32	35	37	39	43	46	48	50	51
			Content Damage	0	0	0	4.5	9	16	23	35	44	52	58	62	65	68	70	73	74	77	78	78
OUT1-SB	out building - shed/office	Out Building	Structure Damage	0	0.5	1	5	9	11.5	14	17	22	26	30	32	35	37	39	43	46	48	50	51
			Content Damage	0	0	0	4.5	9	16	23	35	44	52	58	62	65	68	70	73	74	77	78	78
OUT2-SH	out building - tool shed	Out Building	Structure Damage	0	0.5	1	5	9	11.5	14	17	22	26	30	32	35	37	39	43	46	48	50	51
			Content Damage	0	0	0	4.5	9	16	23	35	44	52	58	62	65	68	70	73	74	77	78	78
OUT3-DG	out building - detached garage	Out Building	Structure Damage	0	0.5	1	5	9	11.5	14	17	22	26	30	32	35	37	39	43	46	48	50	51
			Content Damage	0	0	0	4.5	9	16	23	35	44	52	58	62	65	68	70	73	74	77	78	78
REL1	church	Public	Structure Damage	0	0	0	5	10	10.5	11	11	12	12	13	14	14	15	17	19	24	30	38	45
			Content Damage	0	5	10	31	52	62	72	85	92	95	98	99	100	100	100	100	100	100	100	100
RES1-1SNB	1-story single family res	Residential	Structure Damage	2.5	8	13.4	18.4	23.3	27.7	32.1	40.1	47.1	53.2	58.6	63.2	67.2	70.5	73.2	75.4	77.2	78.5	79.5	80.2
			Content Damage	2.4	5.3	8.1	10.7	13.3	15.6	17.9	22	25.7	28.8	31.5	33.8	35.7	37.2	38.4	39.2	39.7	40	40	40
RES1-1SWB	1-story w/ basement	Residential	Structure Damage	19.4	22.5	25.5	28.8	32	35.4	38.7	45.5	52.2	58.6	64.5	69.8	74.2	77.7	80.1	81.1	81.2	81.3	81.4	81.5
			Content Damage	13.2	14.6	16	17.5	18.9	20.4	21.8	24.7	27.4	30	32.4	34.5	36.3	37.7	38.6	39.1	39.2	39.3	39.4	39.5
RES1-2SNB	2-story single family res	Residential	Structure Damage	3	6.2	9.3	12.6	15.2	18	20.9	26.3	31.4	36.2	40.7	44.9	48.8	52.4	55.7	58.7	61.4	63.8	65.9	67.7
			Content Damage	1	3	5	6.8	8.7	10.6	12.2	15.5	18.5	21.3	23.9	26.3	28.4	30.3	32	33.4	34.7	35.6	36.4	36.9
RES1-2SWB	2-storyw/ basement	Residential	Structure Damage	13.9	15.9	17.9	20.1	22.3	25.1	27	31.9	36.9	41.9	46.9	51.8	56.4	60.8	64.8	68.4	71.4	73.7	75.4	76.4
			Content Damage	10.1	11	11.9	12.9	13.8	14.8	15.7	17.7	19.8	22	24.3	26.7	29.1	31.7	34.4	37.2	40	43	46.1	49.3
RES2	manufactured homes	Residential	Structure Damage	0	5.5	11	26.5	44	53.5	63	73	78	79	81	82	83	84	85	86	88	89	90	91
			Content Damage	0	1.5	3	15	27	38	49	64	70	76	78	79	81	83	83	83	83	83	83	83
RES3A	duplex	Residential	Structure Damage	0	2.5	5	16.5	28	28.5	29	31	36	37	39	40	41	42	44	46	48	52	55	58
			Content Damage	0	2	4	14	24	29	34	40	47	53	56	58	58	58	61	66	68	76	81	86
RES3B	Multi Family - 3 to 4 units	Residential	Structure Damage	0	2.5	5	16.5	28	28.5	29	31	36	37	39	40	41	42	44	46	48	52	55	58
			Content Damage	0	2	4	14	24	29	34	40	47	53	56	58	58	58	61	66	68	76	81	86
RES4	hotel	Residential	Structure Damage	0	0	0	1.5	3	4	5	6	7	9	12	14	18	21	26	31	36	41	46	50
			Content Damage	0	0	0	5.5	11	15	19	25	29	34	39	44	49	56	65	74	82	88	98	98
RES6	nursing home	Residential	Structure Damage	0	0	0	3.5	7	8.5	10	14	15	15	16	18	20	23	26	30	34	38	42	47
			Content Damage	0	0	0	19	38	49	60	73	81	88	94	100	100	100	100	100	100	100	100	100

Source: HEC-LifeSim depth-damage functions

ATTACHMENT 2 – 1% AEP Structure and Content Damages by Structure Occupancy

1% AEP Structure and Content Damages by Structure Occupancy

Scenario	Structure Occupancy	Left Bank		Left Bank mix		Total	
		Count	Total Damage	Count	Total Damage	Count	Total Damage
Overtop-then-Breach	COM1	0	$0	0	$0	0	$0
	COM2	0	$0	0	$0	0	$0
	COM3	0	$0	0	$0	0	$0
	COM4	0	$0	0	$0	0	$0
	COM7	0	$0	0	$0	0	$0
	COM8	0	$0	1	$11,539	1	$11,539
	EDU1	0	$0	0	$0	0	$0
	GOV1	0	$0	0	$0	0	$0
	GOV2	0	$0	0	$0	0	$0
	IND2	0	$0	0	$0	0	$0
	OUT1-SB	0	$0	1	$12,981	1	$12,981
	OUT2-SH	0	$0	0	$0	0	$0
	OUT3-DG	0	$0	4	$31,013	4	$31,013
	REL1	0	$0	0	$0	0	$0
	RES1-1SNB	0	$0	14	$298,539	14	$298,539
	RES1-1SWB	0	$0	1	$25,643	1	$25,643
	RES1-2SNB	0	$0	1	$37,386	1	$37,386
	RES1-2SWB	0	$0	0	$0	0	$0
	RES2	0	$0	3	$4,895	3	$4,895
	RES3A	0	$0	0	$0	0	$0
	RES3B	0	$0	0	$0	0	$0
	Total	**0**	**$0**	**25**	**$421,996**	**25**	**$421,996**
Breach Location 3	COM1	2	$29,299	1	$3,580	3	$32,879
	COM2	0	$0	0	$0	0	$0
	COM3	4	$93,692	2	$130,928	6	$224,620
	COM4	1	$2,646	0	$0	1	$2,646
	COM7	0	$0	0	$0	0	$0
	COM8	3	$46,802	1	$11,920	4	$58,721
	EDU1	0	$0	0	$0	0	$0
	GOV1	4	$28,804	0	$0	4	$28,804
	GOV2	0	$0	0	$0	0	$0
	IND2	0	$0	0	$0	0	$0
	OUT1-SB	0	$0	1	$16,095	1	$16,095
	OUT2-SH	3	$6,322	0	$0	3	$6,322
	OUT3-DG	6	$59,070	5	$40,408	11	$99,478
	REL1	0	$0	0	$0	0	$0
	RES1-1SNB	12	$83,447	16	$377,876	28	$461,323
	RES1-1SWB	1	$21,776	1	$26,654	2	$48,429
	RES1-2SNB	3	$17,896	1	$39,774	4	$57,670
	RES1-2SWB	1	$23,775	1	$22,059	2	$45,834
	RES2	0	$0	3	$6,572	3	$6,572
	RES3A	0	$0	0	$0	0	$0
	RES3B	2	$117,573	0	$0	2	$117,573
	Total	**42**	**$531,102**	**32**	**$675,865**	**74**	**$1,206,967**
Breach Location 6	COM1	4	$77,857	1	$220	5	$78,077
	COM2	2	$4,953	0	$0	2	$4,953
	COM3	4	$54,891	0	$0	4	$54,891
	COM4	4	$55,383	0	$0	4	$55,383
	COM7	0	$0	0	$0	0	$0
	COM8	3	$27,062	1	$11,397	4	$38,459
	EDU1	1	$1,391	0	$0	1	$1,391
	GOV1	5	$95,197	0	$0	5	$95,197
	GOV2	2	$333,086	0	$0	2	$333,086
	IND2	1	$251	0	$0	1	$251
	OUT1-SB	3	$13,562	1	$12,226	4	$25,787
	OUT2-SH	3	$8,053	0	$0	3	$8,053
	OUT3-DG	18	$103,110	5	$29,955	23	$133,065
	REL1	0	$0	0	$0	0	$0
	RES1-1SNB	39	$395,383	13	$285,422	52	$680,805
	RES1-1SWB	12	$338,120	1	$24,628	13	$362,748
	RES1-2SNB	17	$181,354	1	$36,660	18	$218,015
	RES1-2SWB	9	$260,472	0	$0	9	$260,472
	RES2	1	$350	3	$4,358	4	$4,708
	RES3A	3	$20,348	0	$0	3	$20,348
	RES3B	2	$69,625	0	$0	2	$69,625
	Total	**133**	**$2,040,448**	**26**	**$404,867**	**159**	**$2,445,315**