CHAPTER 6.
ECONOMIC ANALYSIS

This chapter documents the analysis of flood damage in the Lower Puyallup River floodplain that could be expected without implementing any new flood damage reduction measures (without-project conditions). It summarizes the methodology applied, the characteristics of the floodplain in the study area, expected flood damage under existing and future conditions, and project performance statistics for the existing flood control system in the study area.

METHODOLOGY

The economic analysis was conducted in accordance with standards, procedures, and guidance of the U.S. Army Corps of Engineers, in order to facilitate incorporation of the analysis by the Corps if a federal flood damage reduction project for the Lower Puyallup is pursued in the future. The key guidance document for Corps water resources planning studies is the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (USWRC, 1983). This document specifies that the federal objective of water resources planning is to contribute to national economic development (NED), consistent with national environmental statues, applicable executive orders, and other federal planning requirements.

According to the Corps' *National Economic Development Procedures Manual – Urban Flood Damage* (USACE, 1988), most NED benefits addressed by flood damage reduction studies come from reducing costs associated with inundation damage. These include physical costs such as those associated with inundation damage, as well as non-physical costs associated with flood cleanup, flood-fighting, evacuation and traffic/transportation rerouting. This economic analysis estimates costs associated with the following:

- Inundation damage to structures and contents
- Inundation damage to agriculture
- Inundation damage to railway infrastructure
- Traffic delays/rerouting
- Flood cleanup
- Post-flood temporary relocation assistance
- Other public assistance for disaster recovery.

Corps guidance states that flood damage reduction studies are to be conducted using a risk-based analytical framework. This approach improves decision-making by quantifying flood risk while addressing the impact of uncertainty in project planning data and parameters. For this study, the effects of uncertainty in project planning data were evaluated for the following:

- Economic parameters (variations in observed first floor elevations, content values, and structure values associated with the stage-damage function were evaluated)
- Hydrologic parameters (variations in discharge associated with the exceedance-frequency function were evaluated)
- Hydraulic parameters (variations in conveyance roughness and cross-section geometry were evaluated).

Guidance for risk-based analysis was obtained from the Corps' Engineer Manual EM-1110-2-1619, *Engineering and Design – Risk-Based Analysis for Flood Damage Reduction Studies* (August 1996) and Engineer Regulation ER-1105-2-101, *Planning Risk-Based Analysis for Flood Damage Reduction Studies* (USACE, 2000; revised January 2006). Project performance statistics identified in these regulations are presented in this chapter for the existing levee system in the study area.

The Corps' ER-1105-2-100, *Guidance for Conducting Civil Works Planning Studies* (April 2000; with emphasis on Appendix D, Economic and Social Considerations, Amendment #1, June 2004) serves as the primary source for Corps evaluation methods of flood damage reduction studies and was used as guidance for this economic analysis. It includes the following steps for evaluating without-project flood damage:

- Delineate the study area
- Determine existing floodplain characteristics (floodplain inventory and flooding characteristics)
- Estimate existing flood damage
- Estimate future flood damage.

The Corps' flood damage analysis software program HEC-FDA was applied for modeling expected flood damage, based on the results of the geotechnical, hydrologic, and hydraulic studies described in earlier chapters of this report. Hydrologic, hydraulic, geotechnical and economic input data used in the model are presented in Appendix G.

The study area for economic analysis of flood damage costs is the same as the study area for the overall without-project analysis: the 500-year Puyallup River floodplain downstream of the Meridian Street Bridge in Puyallup, as designated in the FEMA 2007 flood insurance study. Existing and future conditions referred to in this chapter are the existing and future river bed levels calculated in the sediment analysis presented in Chapter 4. No changes were included in the economic inventory for the future conditions because, in accordance with federal policy, future development is assumed to be constructed above the 100-year regulatory floodplain and not included in future damage estimates.

All monetary values are expressed in October 2007 prices. Damage costs are projected over a 50-year period, and costs projected to occur in future years are converted to their present value by application of the federal discount rate for fiscal year 2008 (4.875 percent) as specified in Corps' Economic Guidance Memorandum EGM-08-01.

Corps regulations for defining without-project conditions require that existing and likely future conditions be incorporated into models for estimating flood damage. In the case of the Puyallup River system, this involved an assessment of existing levee conditions, including estimation of probable failure/probable non-failure points on the left and right bank levees. This analysis is documented in Chapter 3 of this report. Corps regulations require that the levees be included in floodplain modeling to provide a realistic assessment of expected floodplains and depths for various frequency hydrologic events. This policy differs from that of FEMA, which was applied in the FEMA 2007 flood insurance study, requiring that the Lower Puyallup River's non-certified levees be excluded from modeling of regulatory floodplains. The FEMA procedures reflect current policies related to administration of the National Flood Insurance Program. These different approaches to floodplain development result in different floodplains and depths. The analysis documented in this report is consistent with the Corps of Engineers approach.

EXISTING FLOODPLAIN CHARACTERISTICS

Inventory of Study Area Structures

Land use and development were reviewed to determine existing floodplain characteristics within the study area. A primary element of this characterization was an inventory of study area structures to be incorporated into a database for use in modeling flood damage. The initial inventory included all structures in the study area. Data for each structure were collected and added to the database using GIS-based Pierce County tax parcel data, including structure use (residential, commercial, industrial, public or farm), construction type, number of stories, square footage and condition and quality.

Over 3,200 parcels with structures were identified and incorporated into the database. Figure 6-1 shows the breakdown of all structures in the database as either residential or non-residential. Figure 6-2 shows the breakdown of all non-residential structures by subcategory (commercial, farm use, industrial and public).

Elevation data developed for the hydraulic modeling was used to associate a ground elevation with each structure in the database. A field inventory was conducted to spot check the existing data and to supplement Pierce County tax parcel data in three ways:

- Collecting structure attributes required for flood damage analysis that were not provided in the tax parcel database (for example, foundation height)
- Adding any new development that was not included in tax parcel database
- Collecting data for all non-residential structures, as required by Corps planning regulations.

Field data was collected for 100 percent of non-residential structures and a sample of residential structures (a 20-percent sample distributed throughout the study area). Figure 6-3 shows the locations of all residential structures with an overlay of those structures that were included in the residential sample.

Pierce County tax parcel data identified approximately 1,300 acres of farm use lands in the study area, as shown in Figure 6-4. Subsequent field observations and coordination with the Washington agricultural extension identified the following crops in the study area: hay, cucumber, rhubarb, corn, and berries.

The field work was completed in 2007 and the collected data was entered into the structures database. This database served as the base economic inventory for determining flood inundation. The study schedule dictated that the database be developed prior to completion of the hydraulic modeling, so the FEMA 500-year floodplain boundaries were used for the database development effort. The FEMA 500-year floodplain is conservative because it does not include any flood-reduction function of the existing Puyallup River levees.

Structure Valuation for Study Area

Under Corps planning regulations, structure valuation for estimating flood damage costs is based on depreciated replacement value. Depreciated replacement value is used in the analysis to reflect the actual value subject to damage as opposed to full replacement cost which would reflect a betterment relative to the actual condition. Depreciated replacement values of structures for this study were determined based on parcel attribute data, field observations, and regional building cost data from the Marshall and Swift, Inc. Real Estate Valuation Databases.

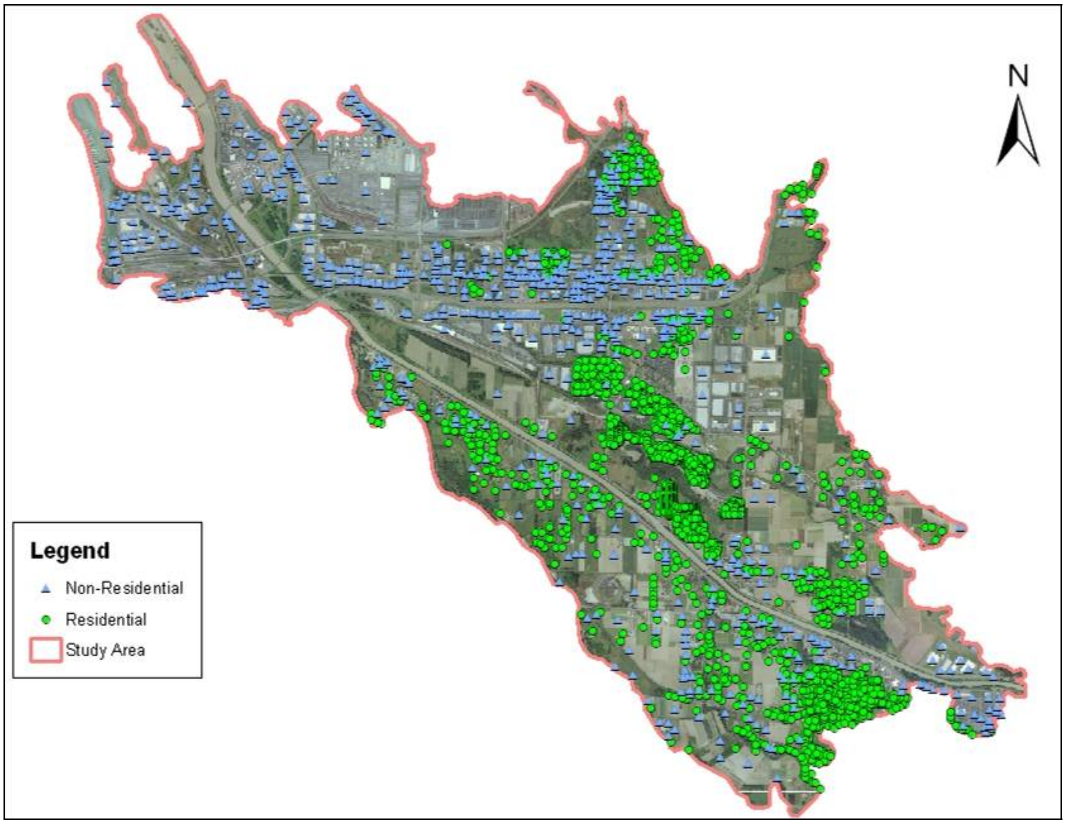

Figure 6-1. Structures in Study Area

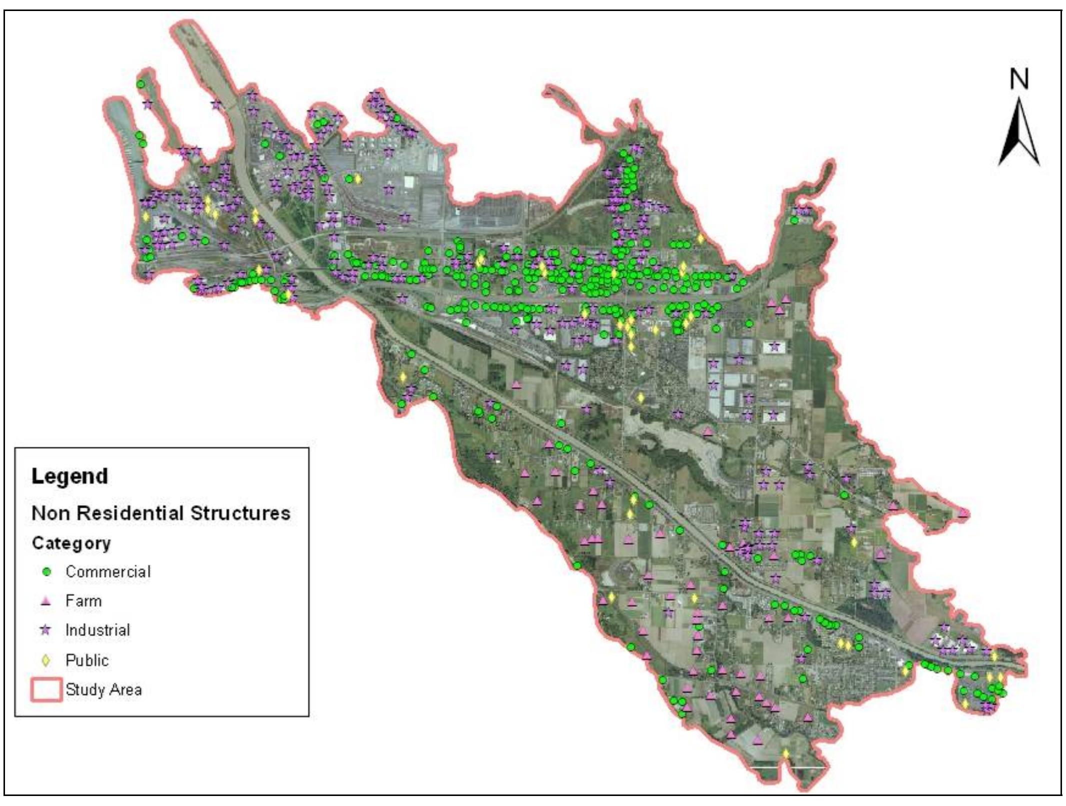

Figure 6-2. Classification of Non-Residential Structures in Study Area

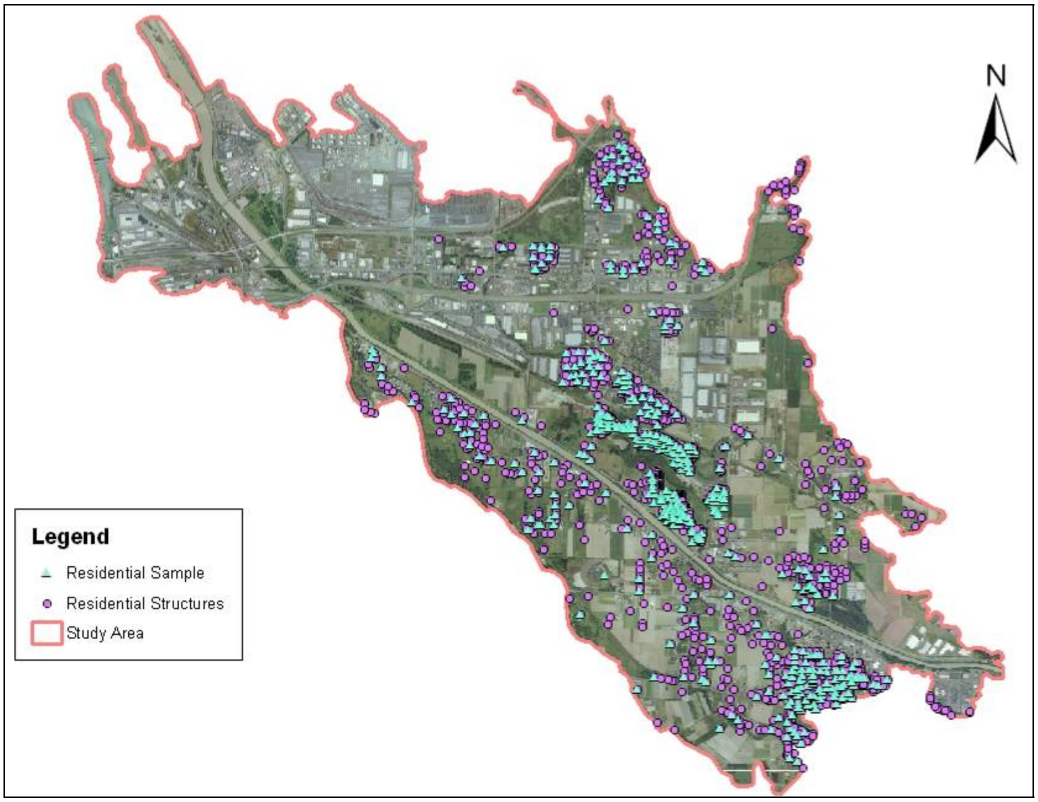

Figure 6-3. Residential Structures Sampled

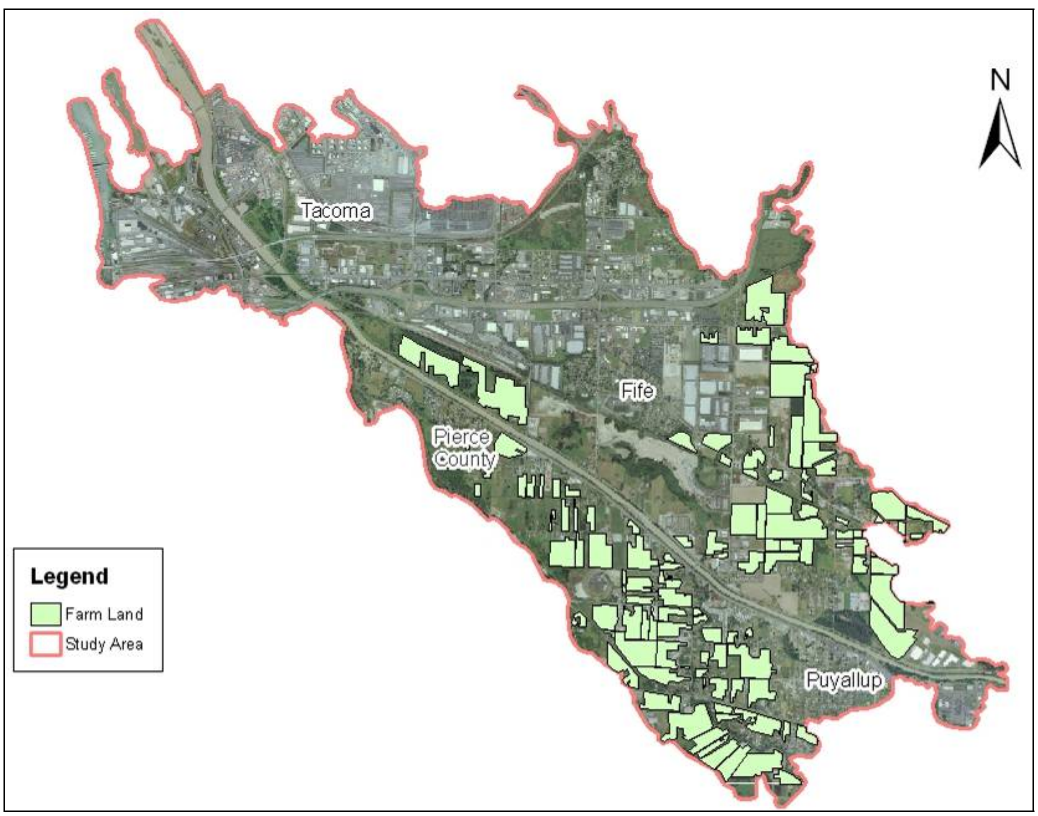

Figure 6-4. Designated Farm Land

The replacement value per square foot for each structure was determined by the Marshall & Swift cost data, based on attributes in the structures database (building use, class, type). Building square footage was developed from the Pierce County parcel database and GIS measurement. Depreciation was estimated based on field observations by category and condition. For residential structures, average values from the 20-percent sample were applied to non-sampled structures. The preliminary valuation of all 3,200 parcels with structures in the database identified over 16 million square feet of structures, with an estimated depreciated replacement value of $1.2 billion. Figure 6-5 shows the breakdown by structure category.

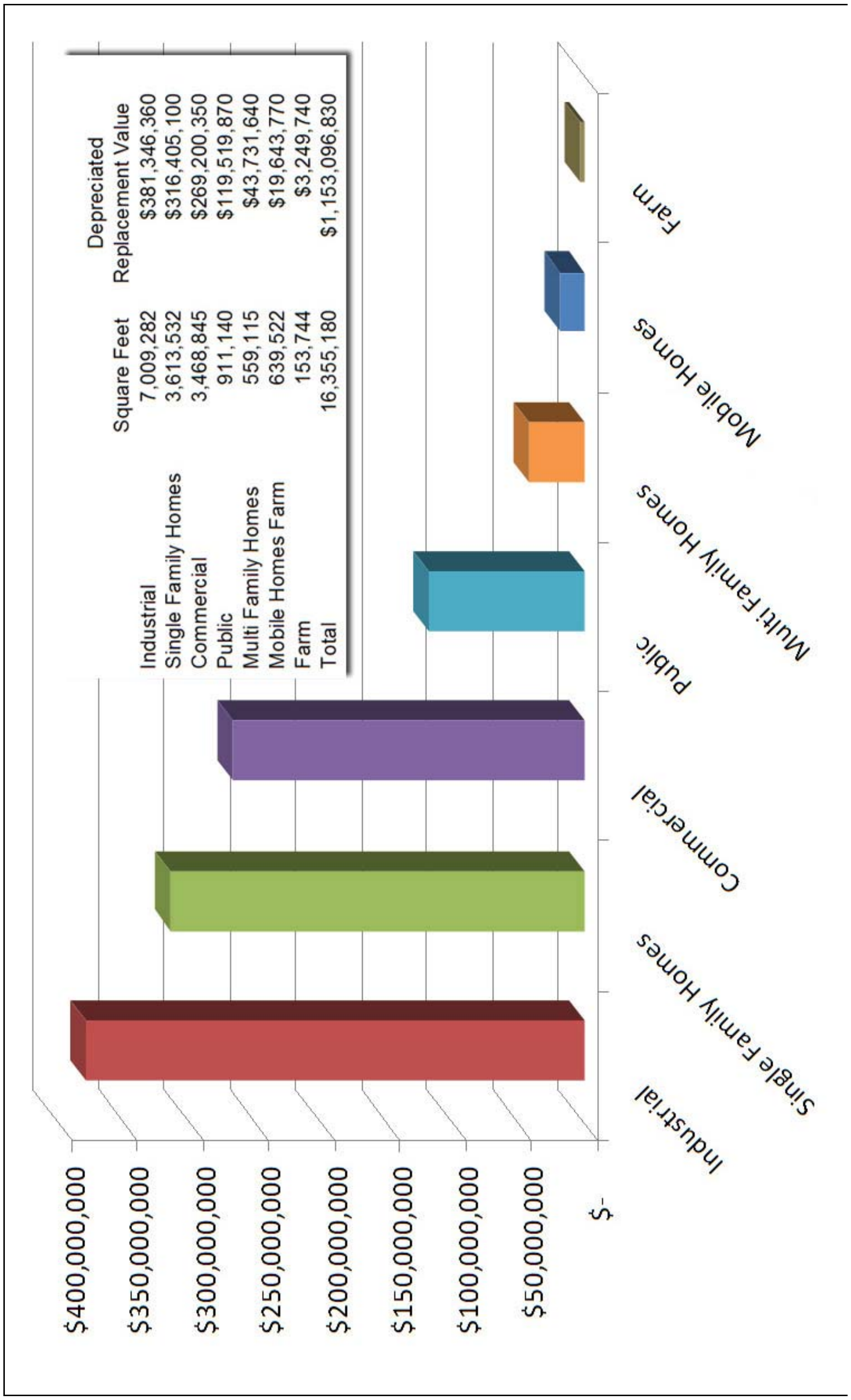

Figure 6-5. Estimated Depreciated Replacement Value of All Structures in Study Area Database

Structures Inundated with Updated Floodplain

Once the analyses to incorporate the existing levees into floodplain models were completed, new without-project floodplains were used to determine how many of the structures in the study area would be subject to flood damage, based on modeled water surface elevations and first floor elevations of structures. Figure 6-6 shows the limits of the new floodplains used for this analysis. For floods of lesser magnitude than the 100-year flood, the river would not overtop the levees on the right bank, but the floodplains shown assume a right-bank levee failure for these floods.

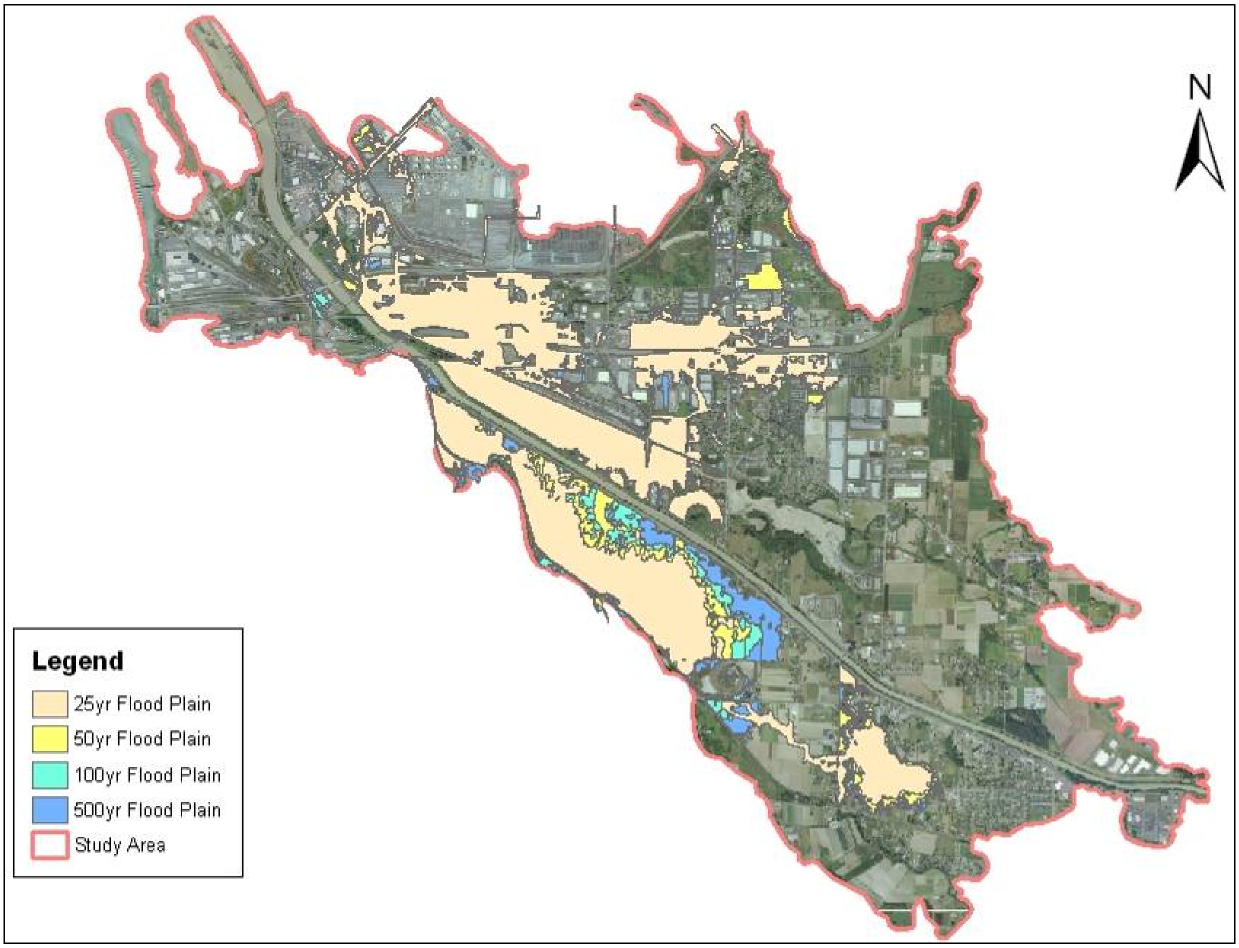

Figure 6-6. Updated Without-Project Floodplains with Right-Bank Levee Breach

Number of Structures Inundated

The number of structures inundated was determined by category and hydrologic event for existing conditions. The structure counts by event are shown in Tables 6-1 and 6-2 and Figures 6-7 and 6-8. Of the 3,200 structured parcels evaluated, only 214 are within the existing-conditions without-project 500-year floodplain as modeled.

All of the structures at risk within the 5-year floodplain are in the left bank area. This area is subject to flooding from local drainage and will continue to be inundated even if improvements are constructed on the Puyallup River. For the right bank, inundation of structures for the 10- to 50-year flood events assumes that the levees would be breached; otherwise, flooding would not occur until the levees are overtopped at the 100-year flood stage.

TABLE 6-1.
NUMBER OF RIGHT-BANK STRUCTURES INUNDATED, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Number of Structures Inundated					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	0	0	0	0	0	**0**
10-Year	7	24	7	0	1	**39**
25-Year	13	29	10	0	1	**53**
50-Year	19	31	11	0	1	**62**
100-Year	21	31	13	0	1	**66**
500-Year	24	34	15	0	1	**74**

TABLE 6-2.
NUMBER OF LEFT-BANK STRUCTURES INUNDATED, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Number of Structures Inundated					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	2	0	1	0	0	**3**
10-Year	28	1	1	1	1	**32**
25-Year	55	3	1	1	3	**63**
50-Year	76	4	2	1	8	**91**
100-Year	96	4	2	1	8	**111**
500-Year	116	8	2	2	12	**140**

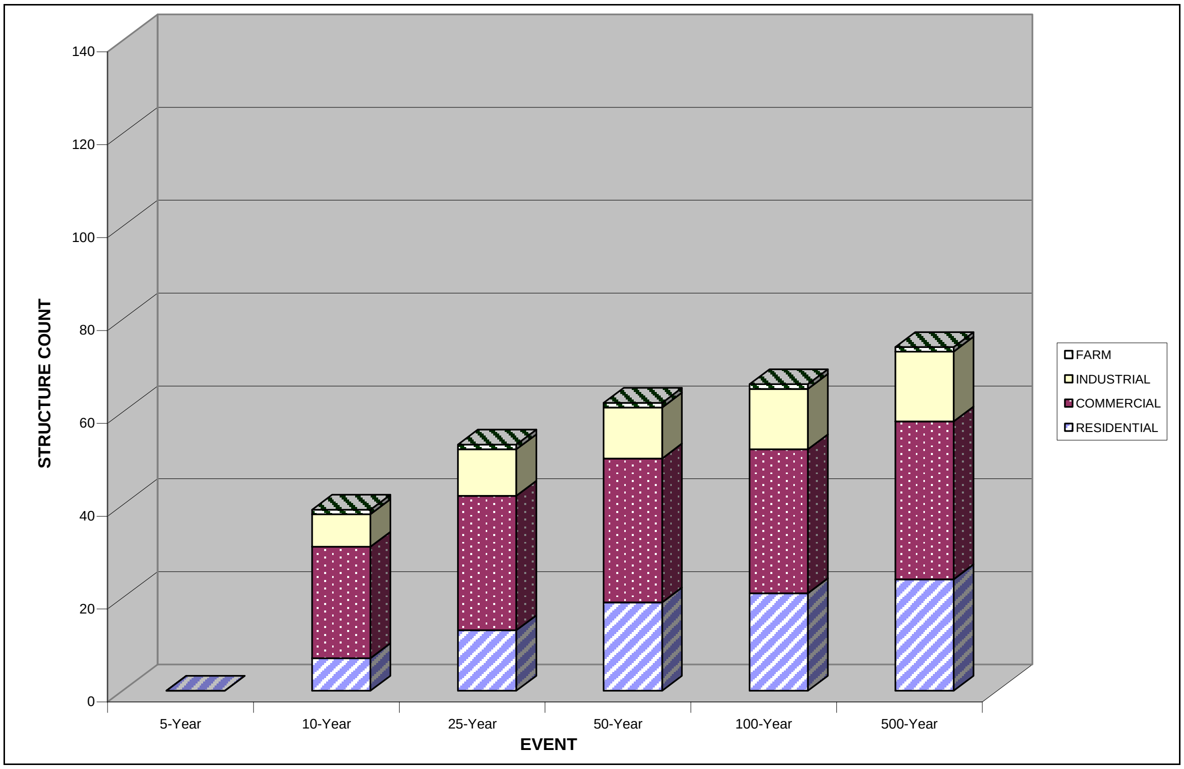

Figure 6-7. Number of Right-Bank Structures Inundated; Existing Conditions

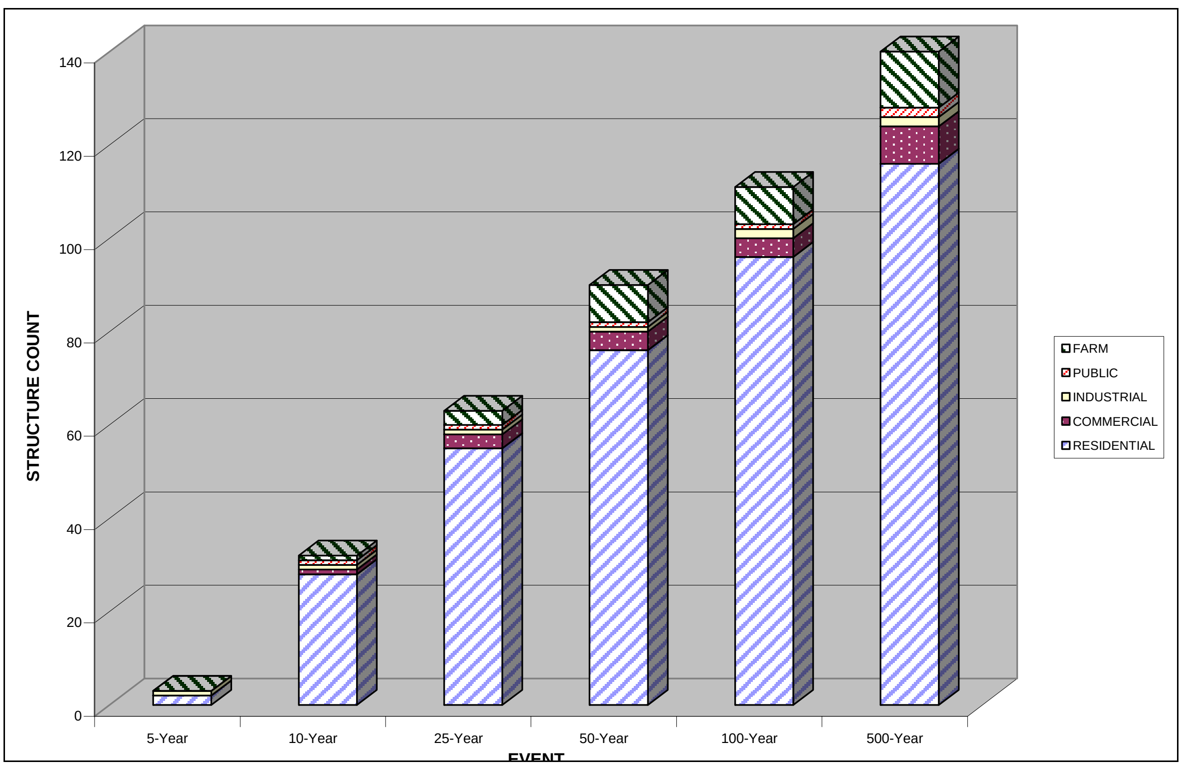

Figure 6-8. Number of Left-Bank Structures Inundated; Existing Conditions

Depreciated Replacement Value of Structures Inundated

Tables 6-3 and 6-4 and Figures 6-9 and 6-10 show the depreciated replacement value of the structural inventory within the floodplain for various frequency events by structure use category. Note this is not an estimate of damage costs but rather of the total depreciated replacement value of property that could be damaged by modeled hydrologic events. Damage cost estimates, presented later in this chapter, are determined as a percentage of value based on depth of flooding. The total structure value within the newly modeled 500-year floodplain is about $126 million.

TABLE 6-3.
DEPRECIATED REPLACEMENT VALUE OF INUNDATED RIGHT-BANK STRUCTURES, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Depreciated Replacement Value of Structures Inundated ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	0	0	0	0	0	**0**
10-Year	22,076	29,791	29,662	0	102	**81,631**
25-Year	22,598	40,707	33,629	0	102	**97,036**
50-Year	22,933	44,450	33,642	0	102	**101,127**
100-Year	23,072	44,450	36,471	0	102	**104,095**
500-Year	23,333	47,555	37,029	0	102	**108,019**

TABLE 6-4.
DEPRECIATED REPLACEMENT VALUE OF INUNDATED LEFT-BANK STRUCTURES, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Depreciated Replacement Value of Structures Inundated ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	221	0	60	0	0	**281**
10-Year	2,954	52	60	386	21	**3,473**
25-Year	6,945	162	60	386	175	**7,728**
50-Year	9,073	219	97	386	584	**10,359**
100-Year	10,924	219	97	386	584	**12,210**
500-Year	12,894	674	97	3,003	848	**17,516**

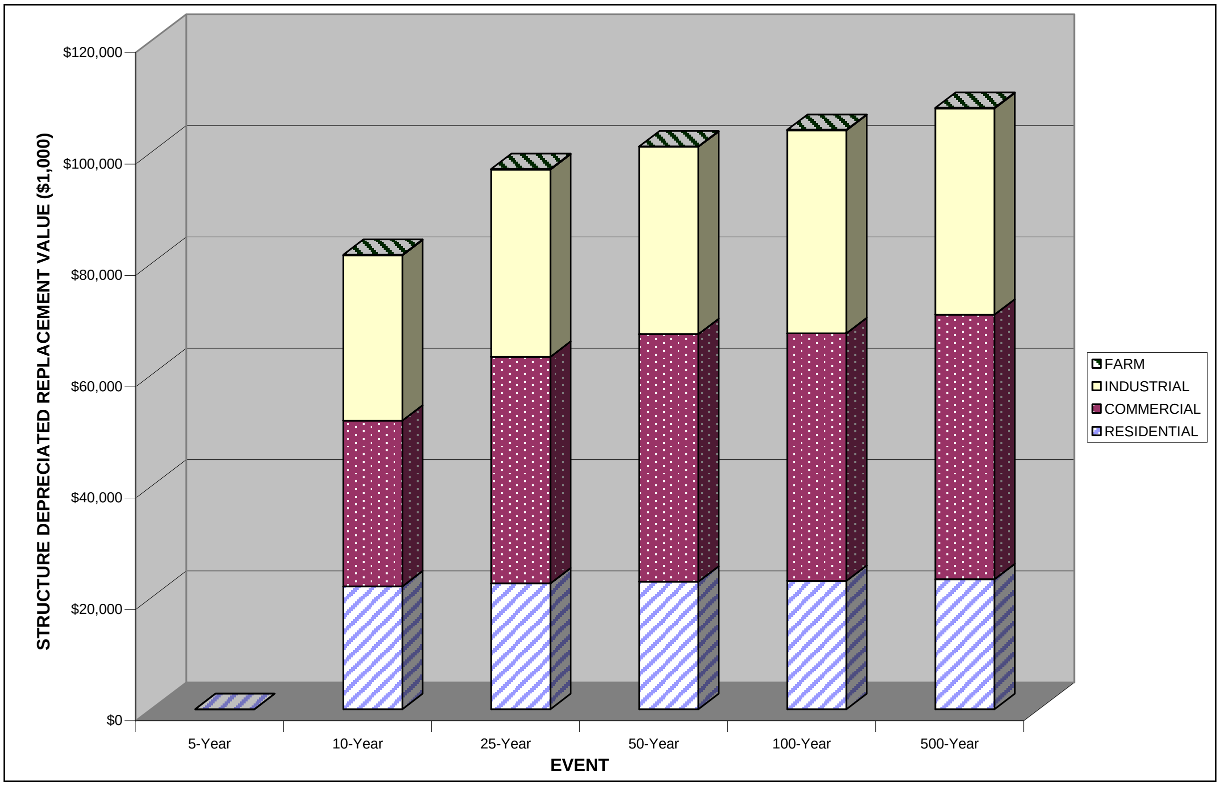

Figure 6-9. Depreciated Replacement Value of Inundated Right-Bank Structures; Existing Conditions

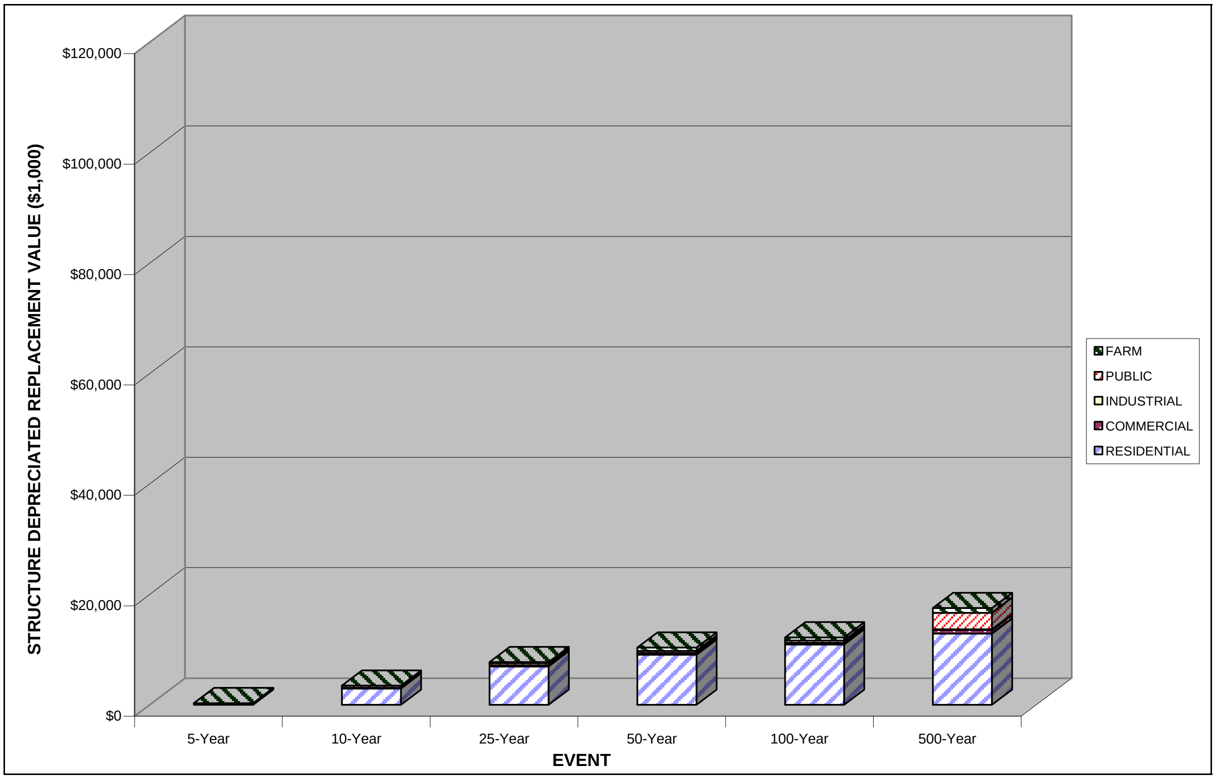

Figure 6-10. Depreciated Replacement Value of Inundated Left-Bank Structures; Existing Conditions

Content Value in Structures Inundated

The value of contents was determined as a percentage of depreciated structure value by category. These percentages, taken from *Centralia Flood Damage Reduction Project - Chehalis River, Washington - Final General Reevaluation Report* (USACE, June 2003), range from 50 percent for residential structures to 113 percent for retail commercial. The resultant value of contents by category and event is presented in Tables 6-5 and 6-6 and Figures 6-11 and 6-12. The average content value was around 91 percent, adding $110 million of value to the depreciated replacement value of the structures for the 500-year event, for a total of $236 million in damageable property at risk.

TABLE 6-5.
VALUE OF CONTENTS IN INUNDATED RIGHT-BANK STRUCTURES, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Estimated Value of Contents ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	0	0	0	0	0	**0**
10-Year	11,038	31,431	28,774	0	111	**71,354**
25-Year	11,299	43,289	32,630	0	111	**87,329**
50-Year	11,467	47,347	32,642	0	111	**91,567**
100-Year	11,536	47,347	35,396	0	111	**94,390**
500-Year	11,666	50,855	35,937	0	111	**98,569**

TABLE 6-6.
VALUE OF CONTENTS IN INUNDATED LEFT-BANK STRUCTURES, BY EVENT AND CATEGORY; EXISTING CONDITIONS

	Estimated Value of Contents ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	110	0	59	0	0	**169**
10-Year	1,477	59	59	436	23	**2.054**
25-Year	3,473	169	59	436	190	**4,327**
50-Year	4,536	234	94	436	637	**5,937**
100-Year	5,462	234	94	436	637	**6,863**
500-Year	6,447	748	94	3,393	924	**11,606**

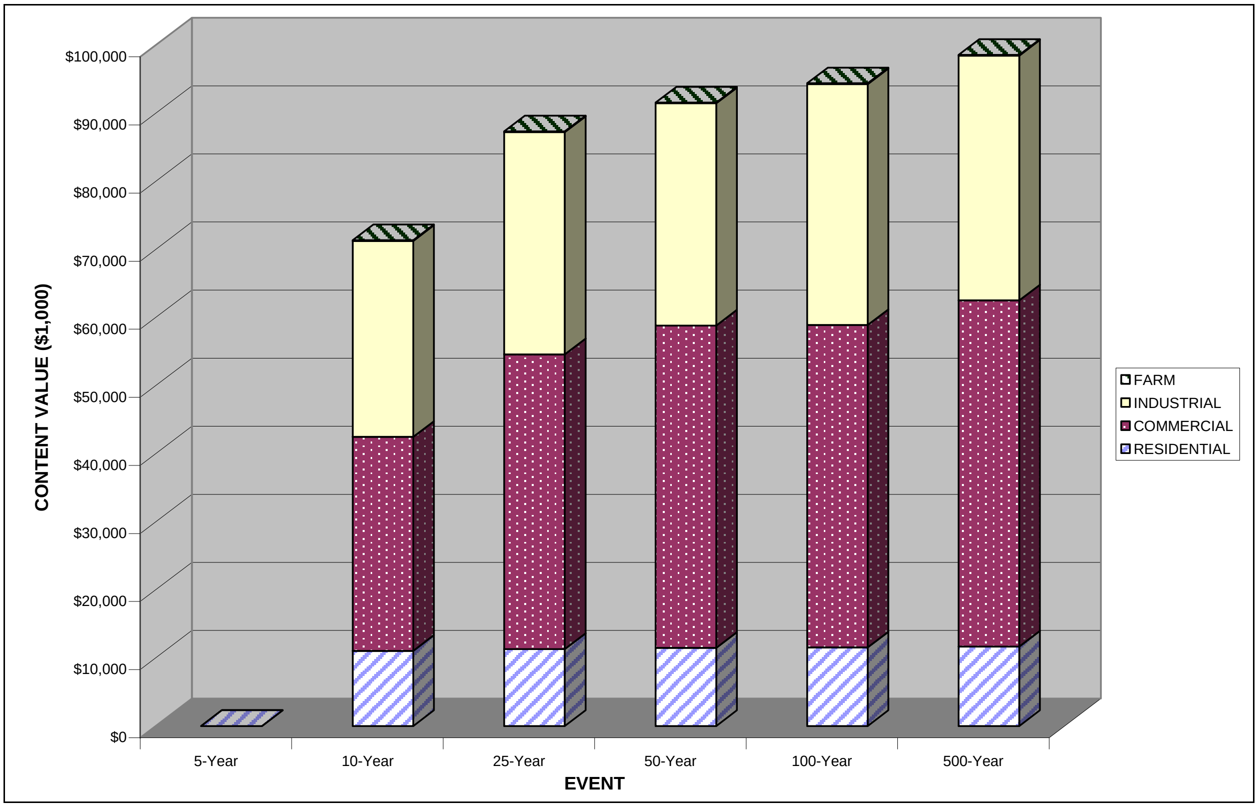

Figure 6-11. Value of Content in Inundated Right-Bank Structures; Existing Conditions

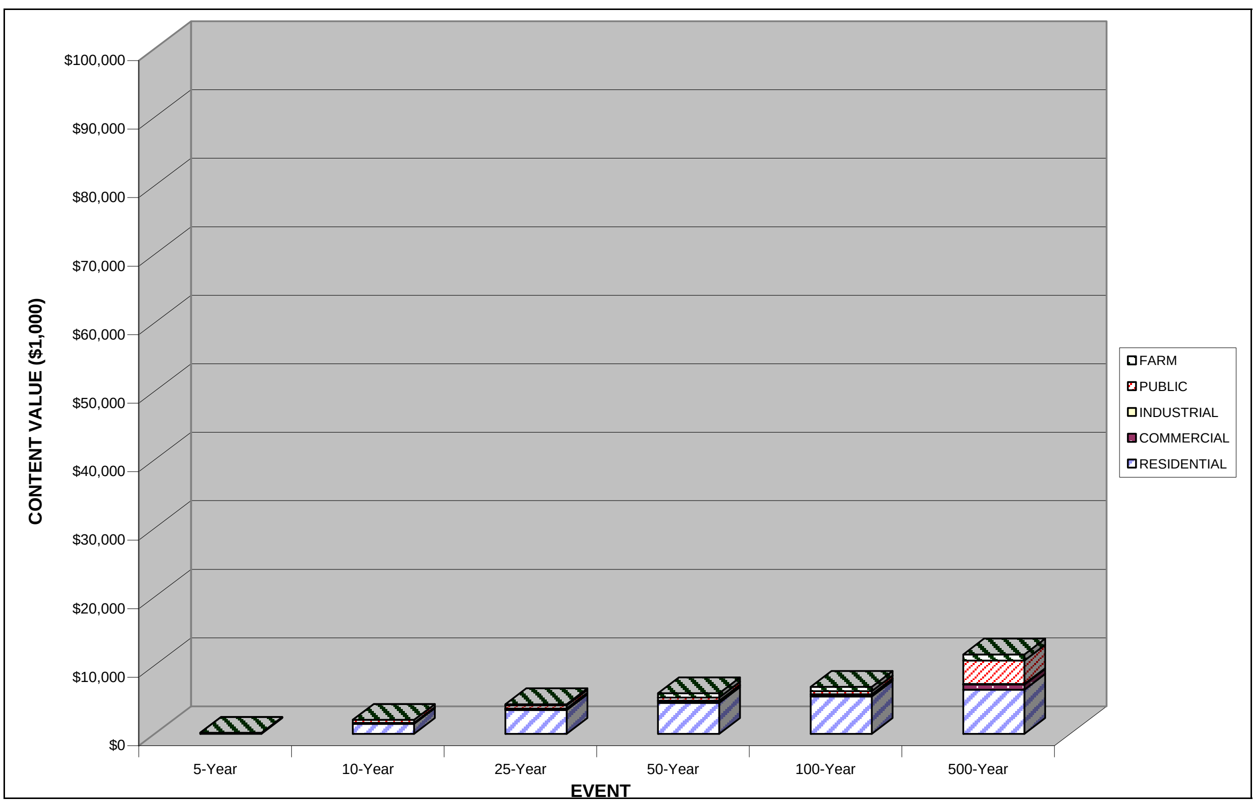

Figure 6-12. Value of Content in Inundated Left-Bank Structures; Existing Conditions

ESTIMATED DAMAGE COSTS

Economic Uncertainty

Flood inundation damage costs are estimated as a percentage of value based on depth of flooding by applying stage-damage functions. Sources of uncertainty involved in developing a stage-damage function include structure foundation height, structure depreciated replacement value, structure depth-damage function, content depreciated replacement value, and content depth-damage function. In accordance with EM 1110-2-1619, each of these sources of uncertainty was addressed in this analysis.

Uncertainty in the valuation of structures and contents was addressed by considering three variables to have a possible range of values: value per square foot, building square footage, and percent of estimated depreciation. Using a triangular distribution to describe the range of these three variables, a Monte Carlo simulation was run on typical structures by category and the mean and standard deviations were compared to derive coefficients of variation for structure values by category. These uncertainty parameters for valuation were imported into the HEC-FDA program.

Uncertainty was also incorporated into the estimated first floor elevations and percent damage per depth. Additional economic uncertainty in automobile losses (based on ranges of values, evacuation rates), traffic delays (routing miles, velocity, duration, wage rate), clean-up (cost per square foot and square footage), post-flood temporary relocation assistance (TRA) parameters, and other public assistance for disaster recovery (PA) parameters were used in estimating losses.

Existing Conditions

Costs for Damage to Structures and Contents

Damage to structures and contents is determined based on flood depth relative to the first-floor height of the building. Average depths by hydraulic storage area for each flood event were compared with estimated foundation heights to determine the depth of flooding for each structure. Damage costs were then estimated as a percentage of value using depth-damage functions. For residential damage costs, these functions were taken from the generic depth-damage curves found in the Corps' Economic Guidance Memorandum 04-01. For non-residential structures, damage functions were from the Corps' Chehalis River, Washington study, which was based on FEMA National Flood Insurance Administration claim data. Mean damage costs are summarized in Tables 6-7 and 6-8 and Figures 6-13 and 6-14. Based on averages, a 100-year flood event could cause losses to structures and contents of about $79 million.

Other Damage Costs

Auto Damage Costs

Auto damage costs were computed within HEC-FDA based on flooding depths, estimated auto counts (based on number of residential units), and values for each residential parcel within the floodplain.

Clean-Up Costs

Flooding leads to significant clean-up costs to remove debris and sediment that floodwaters leave in structures. The Chehalis River report estimated mean costs of clean-up for residential structures of around $4 per square foot. Clean-up costs per event were calculated based on this average value and first-floor building square footage.

TABLE 6-7.
RIGHT-BANK STRUCTURE AND CONTENT DAMAGE COSTS BY FLOOD EVENT; EXISTING CONDITIONS

	Estimated Value of Flood Damage to Structures and Contents ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	0	0	0	0	0	**0**
10-Year	5,857	16,993	35,671	0	97	**58,618**
25-Year	6,245	20,424	37,207	0	112	**63,987**
50-Year	6,427	26,726	37,745	0	120	**71,018**
100-Year	6,504	27,704	37,978	0	125	**72,311**
500-Year	6,747	37,298	38,179	0	135	**82,358**

TABLE 6-8.
LEFT-BANK STRUCTURE AND CONTENT DAMAGE COSTS BY FLOOD EVENT; EXISTING CONDITIONS

	Estimated Value of Flood Damage to Structures and Contents ($1,000s; October 2007)					
Event	Residential	Commercial	Industrial	Public	Farm	**Total**
5-Year	23	0	4	0	0	**27**
10-Year	688	7	78	550	28	**1,351**
25-Year	1,674	89	78	559	75	**2,475**
50-Year	3,176	185	115	562	248	**4,286**
100-Year	4,885	264	135	593	570	**6,447**
500-Year	7,079	497	139	1,991	920	**10,625**

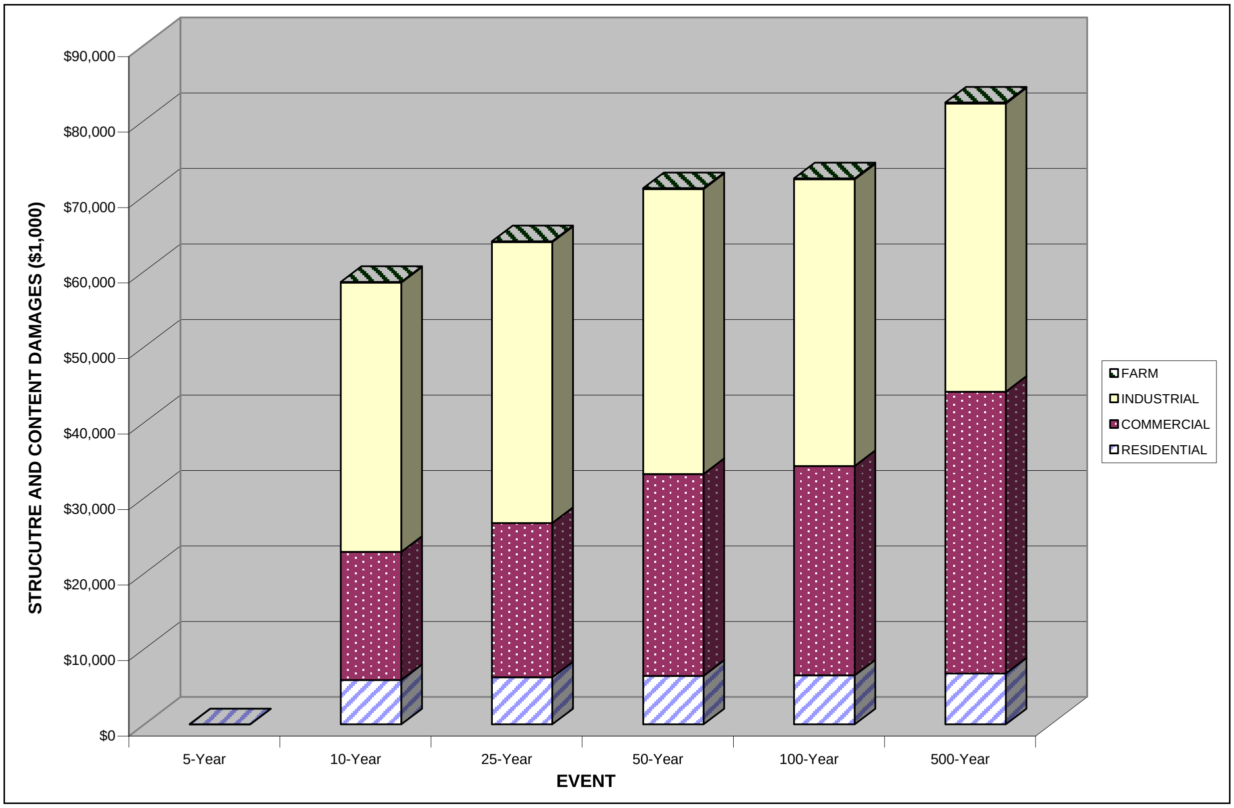

Figure 6-13. Right-Bank Structure and Content Damage Costs; Existing Conditions

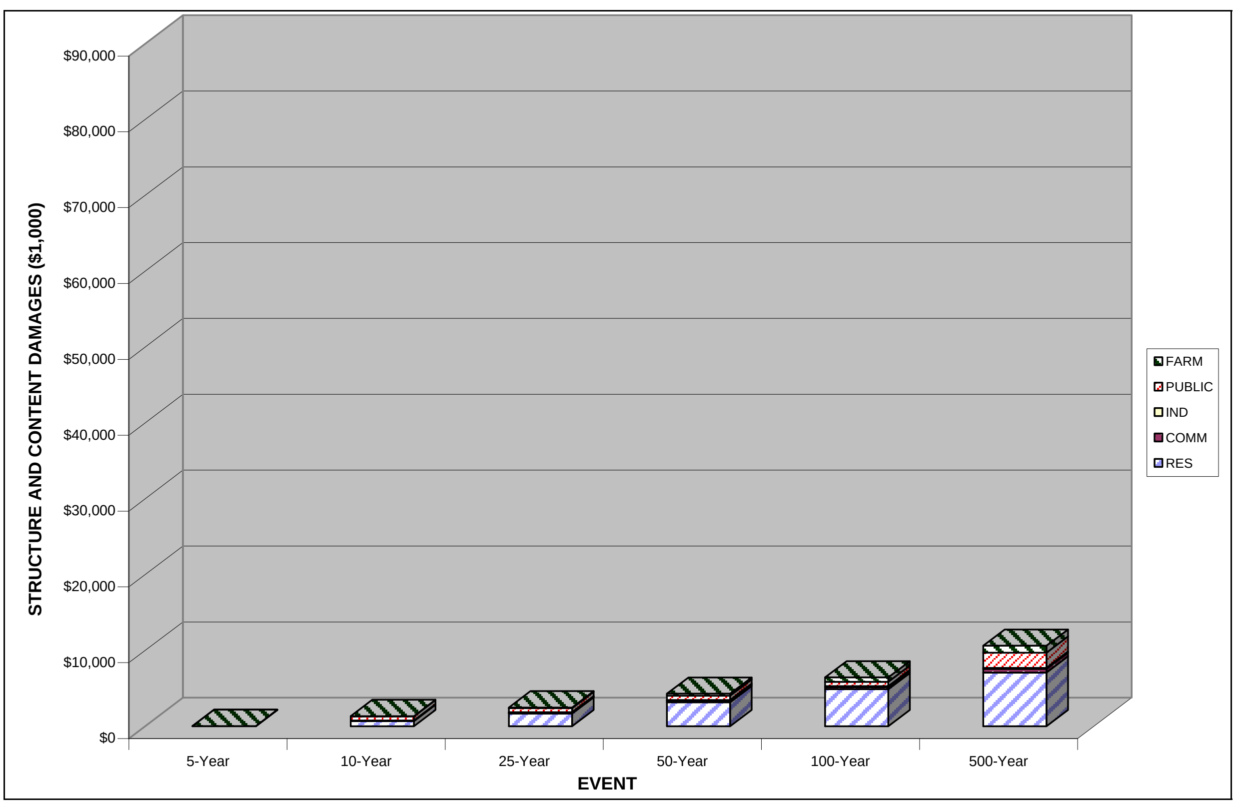

Figure 6-14. Left-Bank Structure and Content Damage Costs; Existing Conditions

Temporary Relocation Assistance

FEMA grants to help individuals and families find suitable housing when they are displaced by federally declared disasters are counted as flood damage costs. Based on information in the Chehalis River report, temporary relocation assistance (TRA) costs are around $1,600 per family inundated. TRA losses were computed based on this average and the number of residential structures inundated.

Public Assistance

FEMA reimburses local and state governments a portion of eligible disaster response costs through its public assistance (PA) program. These costs as well as any local contributions are counted as flood damage costs. PA costs for this evaluation were calculated as three times the TRA costs, based on ratios presented in the Chehalis River report.

Crop Losses

Crop losses were estimated based on average losses for hay, corn and berries. Direct losses were determined as a function of percent crop loss multiplied by acres multiplied by average loss per acre. The time of year is the primary factor in crop losses. Due to the seasonality of flooding, most of the losses were based on land preparation and clean-up costs rather than cultivation costs. On average, losses were around $330 per acre and damage costs per event were estimated based on the number of active agricultural acres inundated. Because so few acres in the floodplain are in production (less than 400 acres), crop losses make up less than 1 percent of total damage costs.

Traffic Delays

The duration of the flood event is the key factor in traffic disruption. Inundation of I-5 will require major rerouting of the Pacific Northwest’s primary north-south corridor (Figure 6-15 shows I-5 in relationship to the 500-year floodplain).

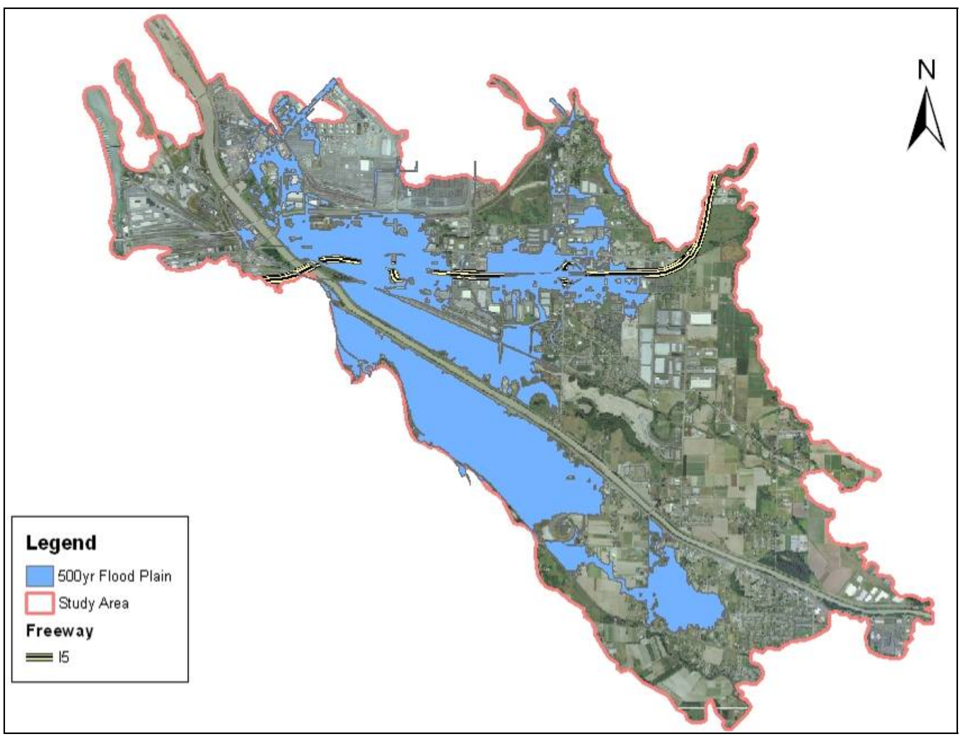

Figure 6-15. Inundation of I-5 by 500-Year Flood Event

Traffic disruptions include time loss as well as traffic costs associated with additional miles covered and the reduction in average speed. Three alternative routes were determined and I-5 traffic was distributed between these routes. These diversions added anywhere from 4.5 to 9 miles for Tacoma through traffic. Losses were based on average daily volumes, additional miles per trip, variable costs per mile, addition time per trip, average hourly wage rates, and the duration of I-5 disruption. Based on these inputs, delays along the I-5 route would lead to $1.2 million in time and variable costs per day. Duration varied by event from 3 to 6 days. Costs associated with increased congestion along the detour routes were not modeled, as they are expected to be too low to warrant the additional traffic modeling that would be required to establish accurate estimates for them.

Railroad Losses

The railroad system that travels through Fife (see Figure 6-16) carries 50 trains per day on average. This railroad line is subjected to inundation that could range from minor disruption to failure of the embankment, depending on flood event. The line is owned by Union Pacific Railroad and is used by Union Pacific, BNSF Railway, Tacoma Rail and Amtrak. Both passenger trains and freight trains could be disrupted. Rerouted freight deliveries would add additional miles to deliveries. Rerouting could add from 90 to 270 miles to destinations, depending on route. Additional costs per mile were based on values from the Association of American Railroads Policy and Economics Department for National Averages US Class I Railroads. Freight revenue per ton-mile and average tons per train from the 2004 to 2006 statistics were use to estimate costs per mile and the additional miles and trips per day were used to determine that losses per day could be about $875,000.

Passenger losses assumed that an alternate form of transportation would be required for the duration. Station on-off counts for the Amtrak Cascades route for travel to Seattle and Portland through Tacoma were used to estimate the number of riders impacted. Computed costs of private automobile travel as a temporary substitute were used to estimate additional travel costs.

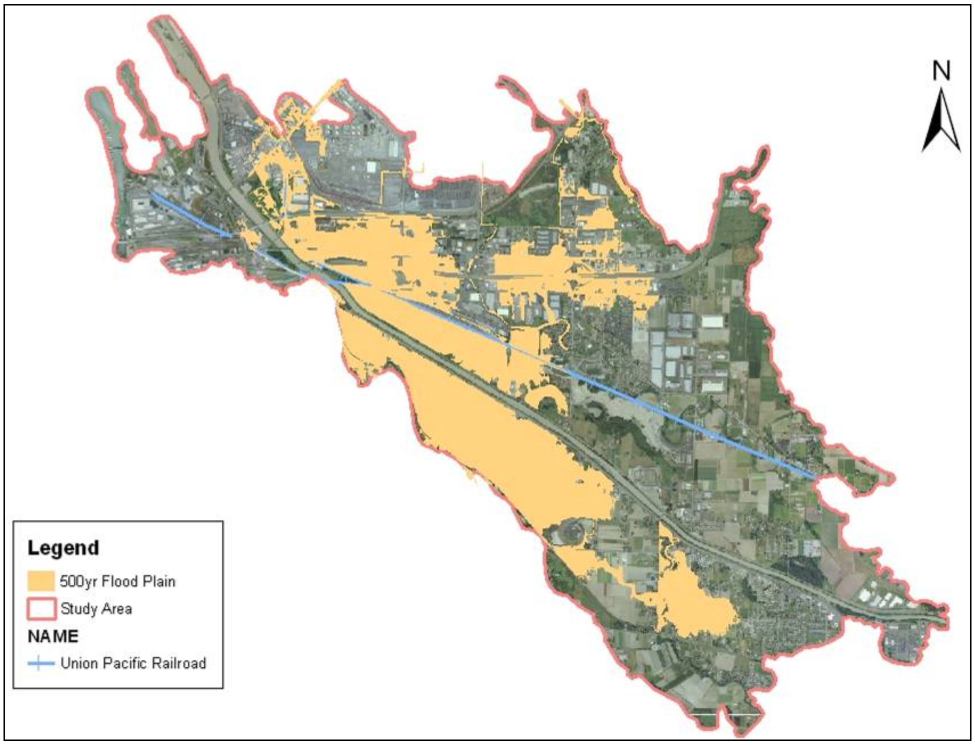

Figure 6-16. Inundation of Union Pacific Railroad by 500-Year Flood Event

As this alternative would also be impacted by the delays of I-5 rerouting, both additional time and out-of-pocket expenses were compared to the standard ticket rate and schedule. The computed losses are based only on the additional time and operating costs and do not consider the quality of commute time or that for many travelers, private automobile may not be practical or available. With these limitations, the increased cost per day was around $70,000.

The duration of railroad disruption varied in the model, based on flood event and on length of time for temporary repair of the line. With a week allocated to complete basic repairs, durations ranged from 7 to 14 days. Note that under existing conditions, only rare events such as the 500-year event would be severe enough to cause either I-5 traffic delays or railroad disruptions.

Total Damage Costs

Tables 6-9 and 6-10 and Figures 6-17 and 6-18 show total damage costs by event. Losses other than those associated with damage to structures and contents add $14 million for a 100-year event, for a total loss of around $93 million, and $21 million for a 500-year event, for a total of $114 million.

TABLE 6-9.
TOTAL RIGHT-BANK DAMAGE COST BY FLOOD EVENT; EXISTING CONDITIONS

	Estimated Value of Flood Damage ($1,000s; October 2007)								
Event	Structure & Content	Auto Losses	Clean Up	TRA	PA	Crop Loss	Traffic Delay	Railroad Loss	**Total**
5-Year	0	0	0	0	0	0	0	0	**0**
10-Year	58,618	2,782	862	325	975	32	0	0	**63,594**
25-Year	63,987	3,019	875	331	991	32	0	6,611	**75,843**
50-Year	71,018	3,123	896	335	1,000	32	0	6,611	**83,015**
100-Year	72,311	3,168	900	336	1,009	32	0	6,611	**84,367**
500-Year	82,358	3,326	923	344	1,040	33	4,030	8,315	**100,369**

TABLE 6-10.
TOTAL LEFT-BANK DAMAGE COST BY FLOOD EVENT; EXISTING CONDITIONS

	Estimated Value of Flood Damage ($1,000s; October 2007)						
Event	Structure & Content	Auto Losses	Clean Up	TRA	PA	Crop Loss	**Total**
5-Year	27	0	0	0	0	1	**28**
10-Year	1,351	66	104	26	77	13	**1,637**
25-Year	2,475	177	226	53	158	47	**3,136**
50-Year	4,286	324	560	138	414	59	**5,781**
100-Year	6,447	605	726	180	542	70	**8,570**
500-Year	10,625	1,018	810	205	614	82	**13,354**

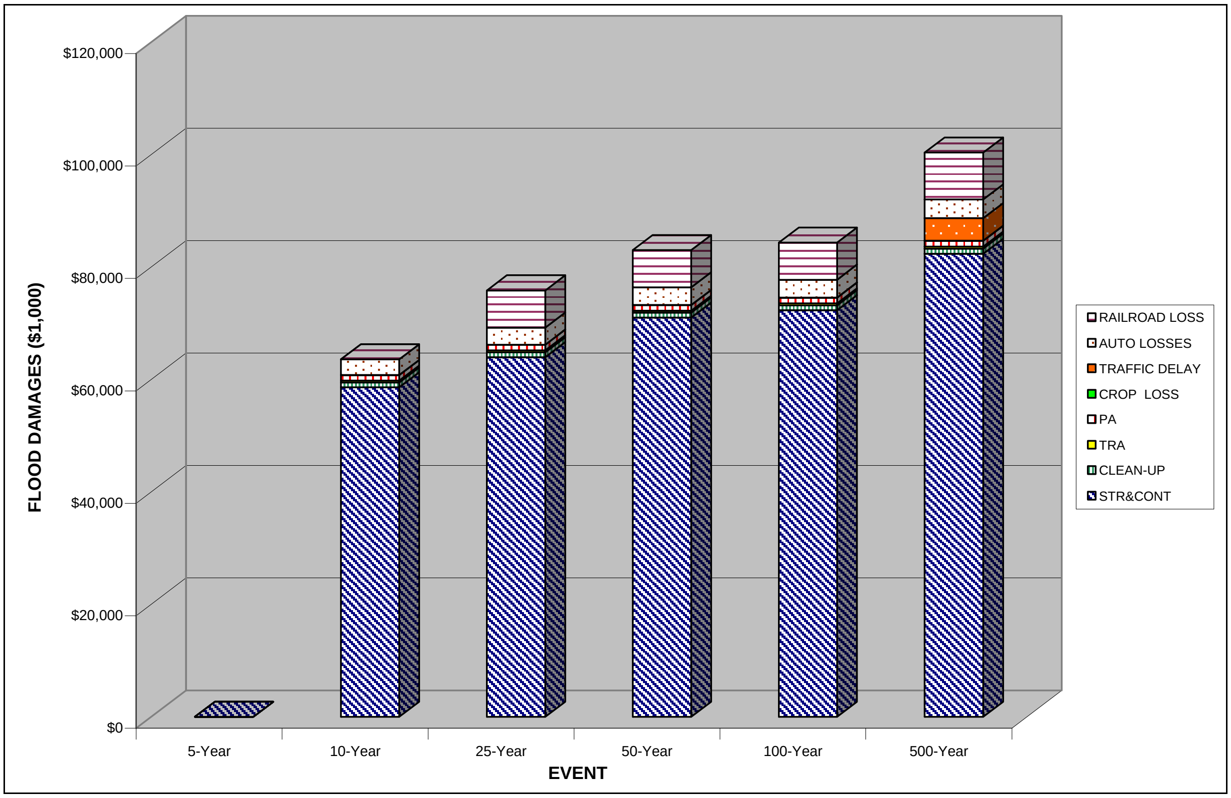

Figure 6-17. Total Right-Bank Damage Cost; Existing Conditions

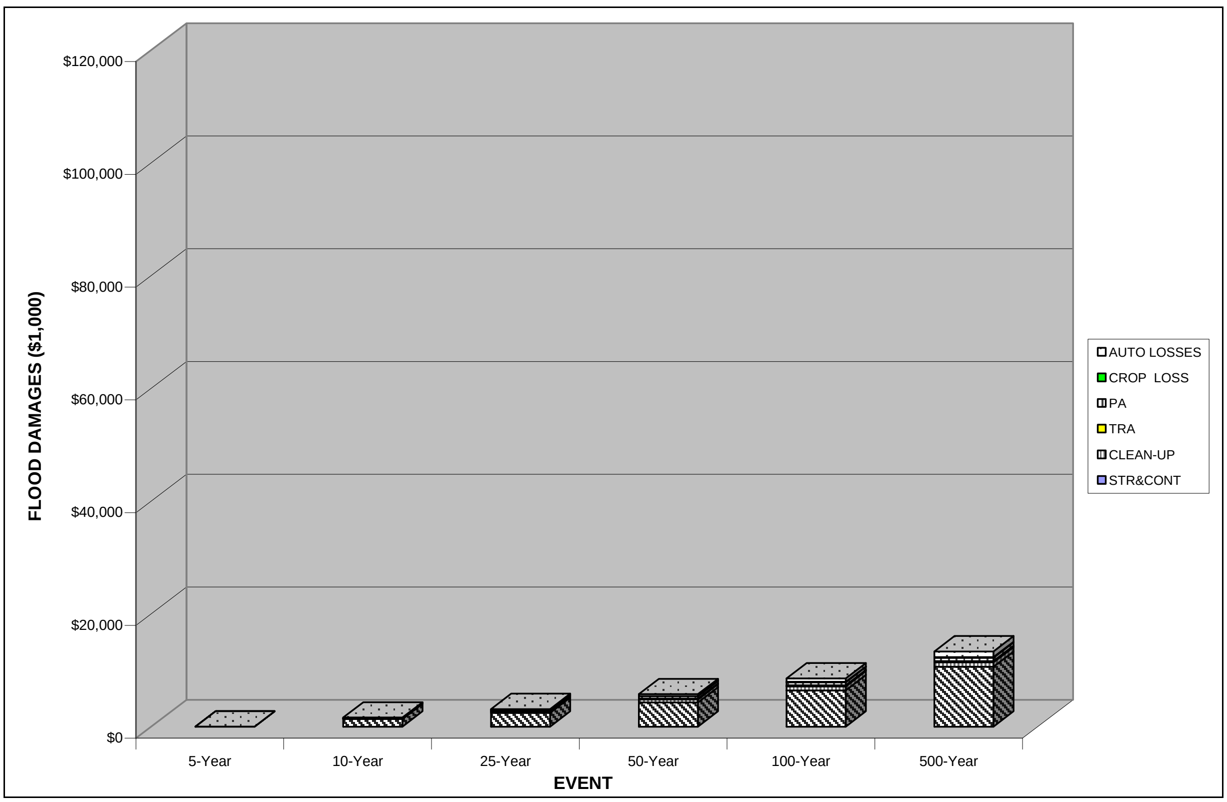

Figure 6-18. Total Left-Bank Damage Cost; Existing Conditions

Future Conditions

For modeling of the future conditions, the only change from existing conditions that was analyzed for this evaluation was the rise in water surface elevation due to channel sedimentation. New development was not addressed because it is assumed that any such development within the floodplain will be raised or constructed on fill so that the first floor will be above the 100-year water surface elevation.

Damage costs were estimated using the stage-discharge relationships and water surface elevations for projected 2017 and 2057 river bed levels. Tables 6-11 and 6-12 and Figures 6-19 and 6-20 show the change in the number of structures within the 100-year and 500-year floodplains as the river bed rises with sediment deposition. In general, the 100- and 500-year floodplains will be larger under future conditions, exposing more existing structures to potential flood damage. The changes in estimated flood damage costs are shown in Tables 6-13 and 6-14 and Figures 6-21 and 6-22. Under future conditions, traffic delays and railroad losses will occur for events more frequent than the 100-year flood.

TABLE 6-11.
NUMBER OF RIGHT-BANK STRUCTURES INUNDATED, BY EVENT AND CATEGORY; EXISTING AND FUTURE CONDITIONS

	Number of Structures Inundated					
	100-Year Event			500-Year Event		
	2007	2017	2057	2007	2017	2057
Residential	21	24	24	24	26	26
Commercial	31	34	34	34	38	38
Industrial	13	12	13	15	16	17
Public	0	0	0	0	0	0
Farm	1	1	1	1	1	1
Total	**66**	**71**	**72**	**74**	**81**	**82**

TABLE 6-12.
NUMBER OF LEFT-BANK STRUCTURES INUNDATED, BY EVENT AND CATEGORY; EXISTING AND FUTURE CONDITIONS

	Number of Structures Inundated					
	100-Year Event			500-Year Event		
	2007	2017	2057	2007	2017	2057
Residential	96	103	108	116	126	129
Commercial	4	5	6	8	8	8
Industrial	2	2	2	2	2	2
Public	1	1	2	2	2	2
Farm	8	10	10	12	13	14
Total	**111**	**121**	**128**	**140**	**151**	**155**

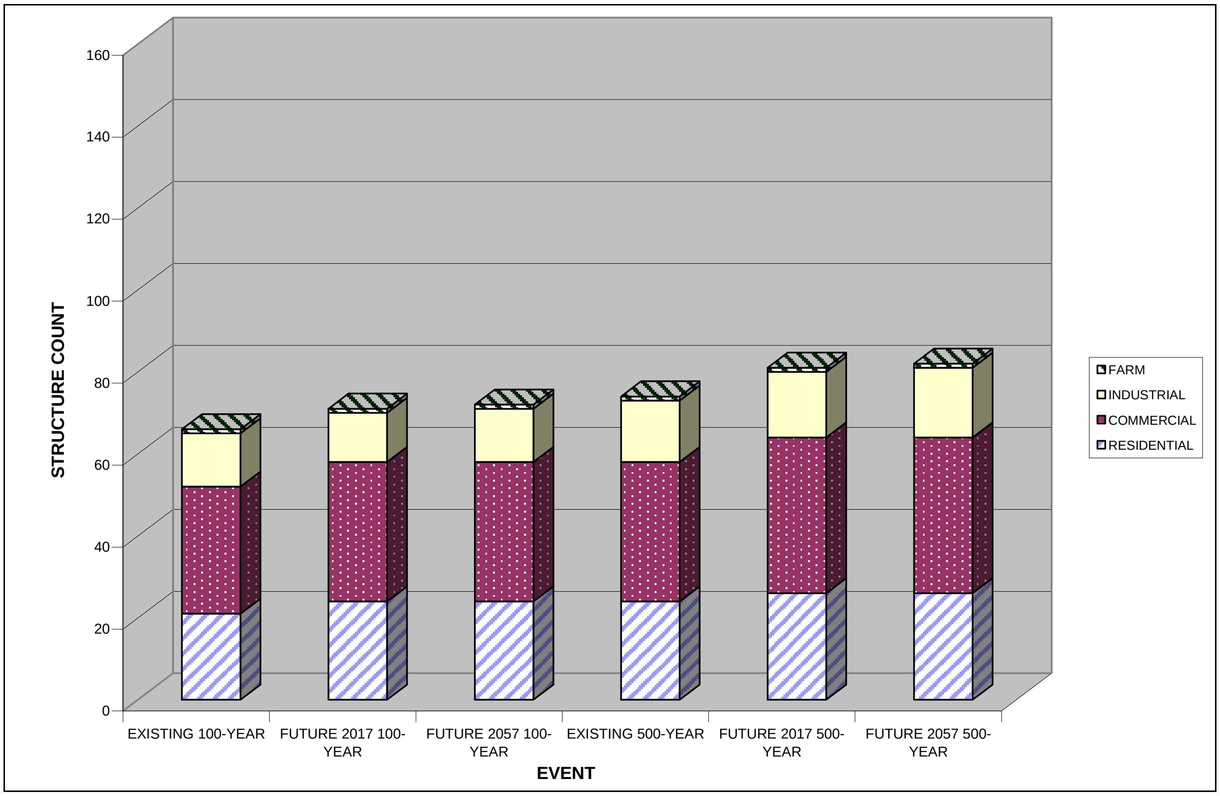

Figure 6-19. Number of Right-Bank Structures Inundated; Existing and Future Conditions

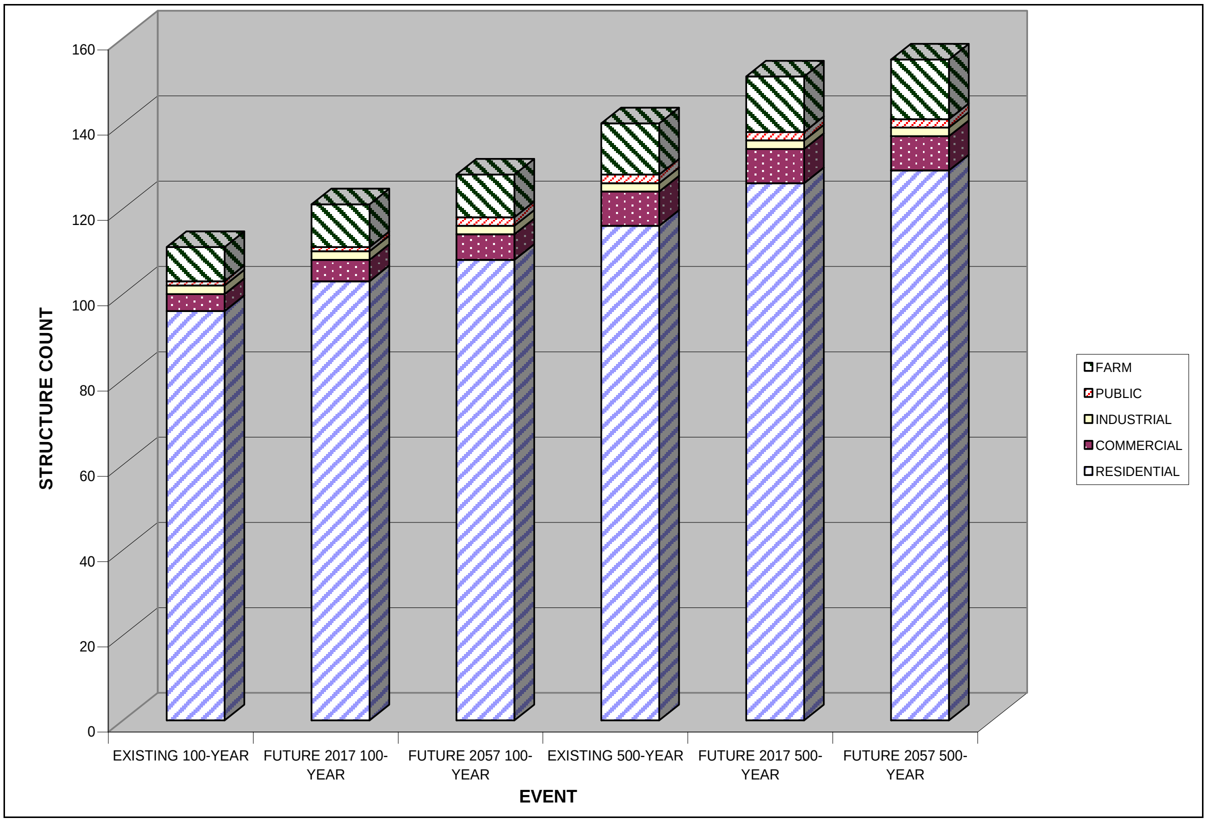

Figure 6-20. Number of Left-Bank Structures Inundated; Existing and Future Conditions

**TABLE 6-13.
TOTAL RIGHT-BANK DAMAGE COSTS BY EVENT AND CATEGORY;
EXISTING AND FUTURE CONDITIONS**

	Estimated Value of Flood Damage ($1,000s; October 2007)					
	100-Year Event			500-Year Event		
	2007	2017	2057	2007	2017	2057
Structure & Contents–Residential	6,504	6,656	6,659	6,747	6,847	6,843
Structure & Contents–Commercial	27,704	33,694	34,194	37,298	41,807	40,928
Structure & Contents–Industrial	37,978	38,079	38,092	38,179	38,297	38,268
Structure & Contents–Public	0	0	0	0	0	0
Structure & Contents–Farm	125	134	134	135	136	136
Autos	3,168	3,236	3,237	3,326	3,429	3,421
Clean Up	900	917	916	923	932	934
TRA	336	342	343	344	347	347
PA	1,009	1,028	1,028	1,040	1,044	1,049
Crop Loss	32	33	33	33	33	33
Traffic Delay	0	4,284	4,880	4,030	4,391	5,130
Railroad Loss	6,611	7,845	12,285	8,315	9,360	12,298
Total	**84,367**	**96,248**	**101,801**	**100,379**	**106,623**	**109,387**

**TABLE 6-14.
TOTAL LEFT-BANK DAMAGE COSTS BY EVENT AND CATEGORY;
EXISTING AND FUTURE CONDITIONS**

	Estimated Value of Flood Damage ($1,000s; October 2007)					
	100-Year Event			500-Year Event		
	2007	2017	2057	2007	2017	2057
Structure & Contents–Residential	4,885	5,914	6,445	7,079	7,659	8,011
Structure & Contents–Commercial	264	304	360	497	646	765
Structure & Contents–Industrial	135	137	138	139	140	143
Structure & Contents–Public	593	602	730	1,991	3,595	4,080
Structure & Contents–Farm	570	729	823	920	1,001	1,034
Autos	605	784	879	1,018	1,128	1,194
Clean Up	726	746	781	810	864	882
TRA	180	187	197	205	219	224
PA	542	561	590	614	657	671
Crop Loss	70	74	74	82	87	96
Total	**8,570**	**10,338**	**11,017**	**13,355**	**15,996**	**17,100**

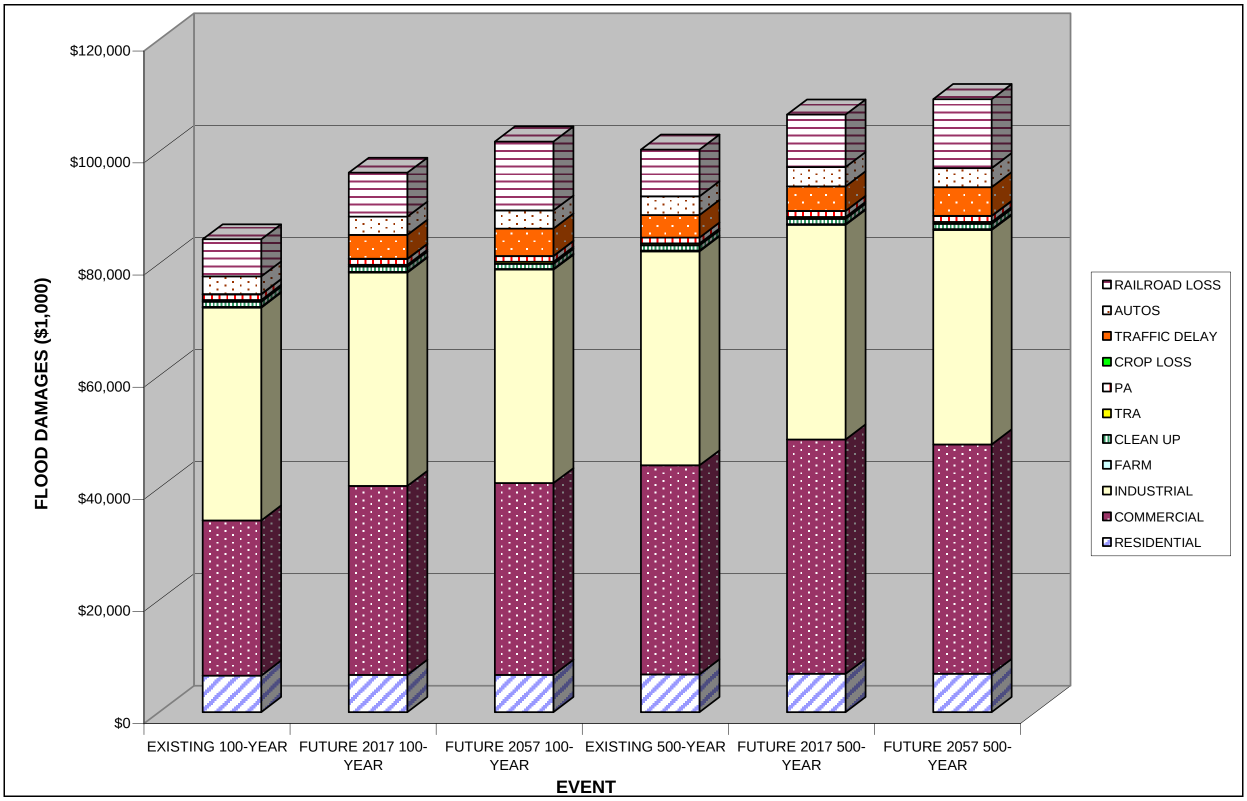

Figure 6-21. Right-Bank Damage Costs; Existing and Future Conditions

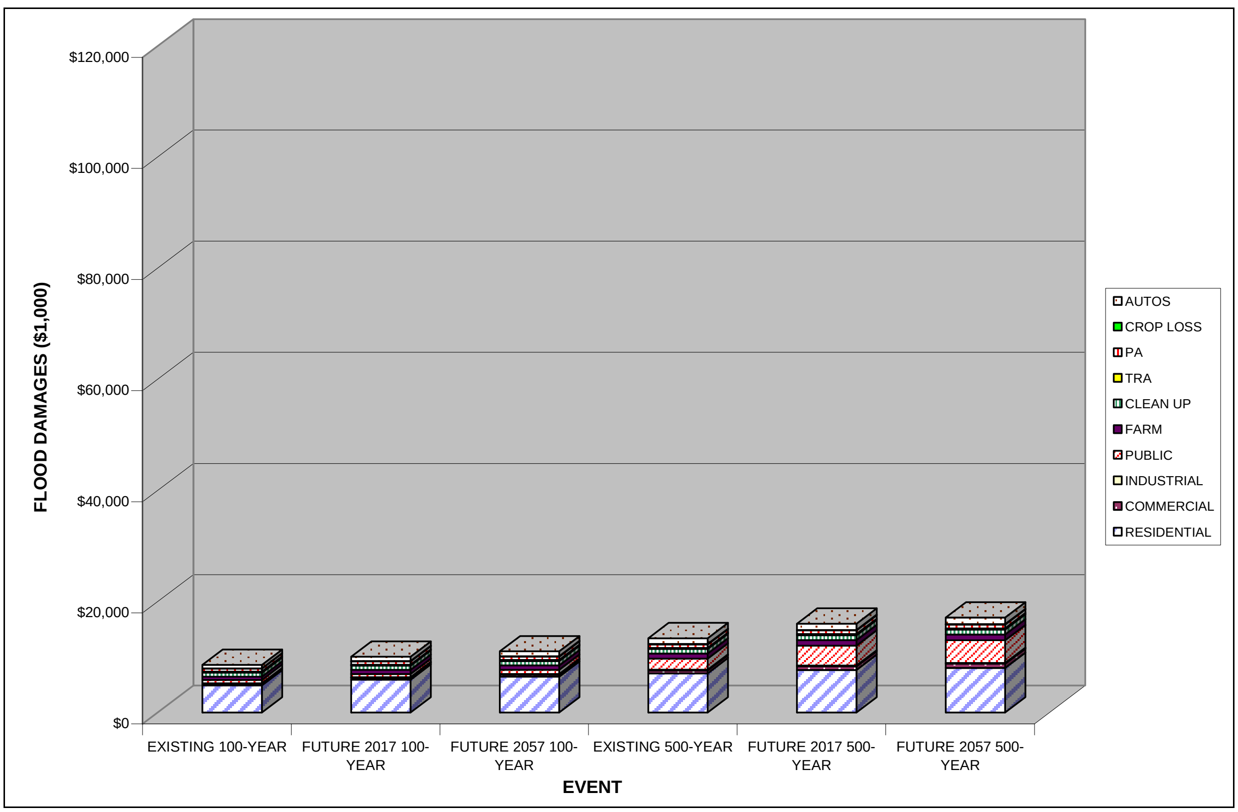

Figure 6-22. Left-Bank Damage Costs; Existing and Future Conditions

Average Annual Equivalent Damage

The HEC-FDA program integrates hydrologic, hydraulic, geotechnical and economic relationships using Monte Carlo simulation to estimate expected annual damage (EAD). The model analyzes these relationships with uncertainty and derives a frequency-damage function to compute EAD. The EAD calculation measures the area under the damage-probability curve (see Figure 6-23). It is a single number representing the present value of the potential damage costs of all possible storms on an annual basis. EAD was calculated independently for the left and right banks of the Lower Puyallup River.

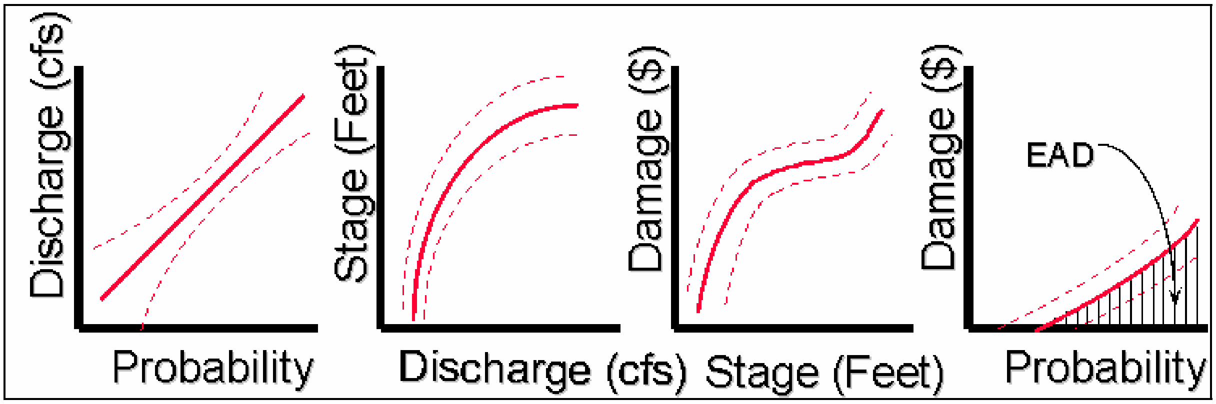

Figure 6-23. Uncertainty in Discharge, Stage and Damage in Determining Expected Annual Damage

Average annual equivalent damage (AAED) evaluates EAD over the full 50-year period of analysis using the 4.875-percent discount rate. Table 6-15 and Figure 6-24 show the AAED results by category for each reach. Tables 6-16 and 6-17 and Figures 6-25 and 6-26 show the breakout of EAD by category for each reach and each time period, as well as the AAED for each reach over the entire period of analysis.

**TABLE 6-15.
AVERAGE ANNUAL EQUIVALENT DAMAGE**

	Average Annual Equivalent Damage ($1,000s; October 2007)	
	Right Bank	Left Bank
Structure & Contents–Residential	539	503
Structure & Contents–Commercial	2,037	21
Structure & Contents–Industrial	2,501	32
Structure & Contents–Public	18	142
Auto	232	47
Clean Up	118	225
TRA	44	56
PA	133	167
Crop Losses	5	33
Traffic Delays	103	0
Railroad	652	0
Total	**6,382**	**1,227**

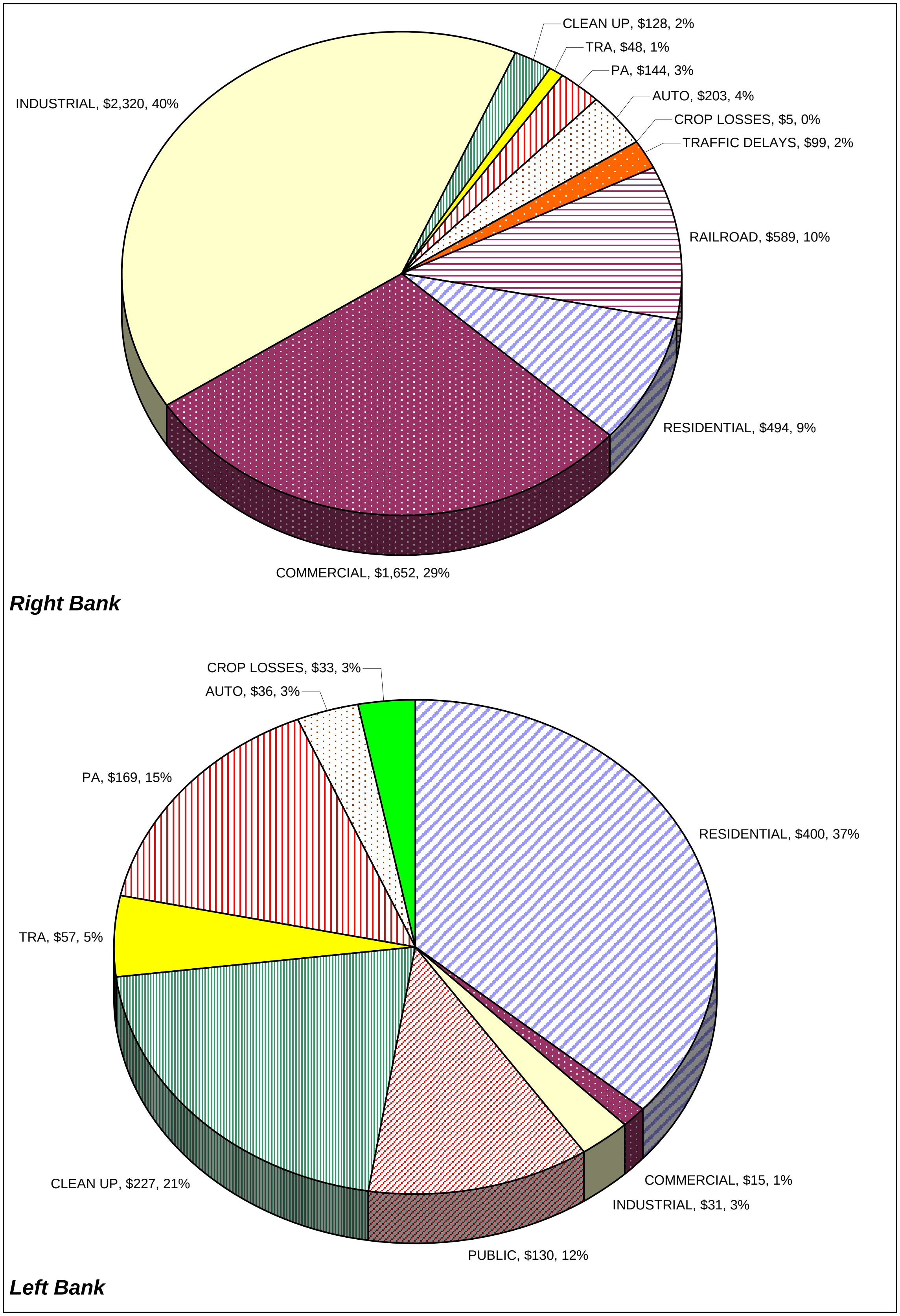

Figure 6-24. Average Annual Equivalent Damage Costs

TABLE 6-16.
EXISTING AND FUTURE RIGHT-BANK EXPECTED ANNUAL DAMAGE AND 50-YEAR AVERAGE ANNUAL EQUIVALENT DAMAGE

	EAD ($1,000s; October 2007)			AAED
	Existing 2007	Future 2017	Future 2057	($1,000s; October 2007)
Structure & Contents–Residential	494	541	590	539
Structure & Contents–Commercial	1,652	2,118	2,288	2,037
Structure & Contents–Industrial	2,320	2,500	2,732	2,501
Structure & Contents–Public	10	20	22	18
Auto	203	238	250	232
Clean Up	83	128	133	118
TRA	31	48	50	44
PA	94	144	150	133
Crop Losses	3	5	5	5
Traffic Delays	32	99	174	103
Railroad	589	662	703	652
Total	**5,572**	**6,503**	**7,105**	**6,382**

TABLE 6-17.
EXISTING AND FUTURE LEFT-BANK EXPECTED ANNUAL DAMAGE AND 50-YEAR AVERAGE ANNUAL EQUIVALENT DAMAGE

	EAD ($1,000s; October 2007)			AAED
	Existing 2007	Future 2017	Future 2057	($1,000s; October 2007)
Structure & Contents–Residential	400	524	574	503
Structure & Contents–Commercial	15	22	25	21
Structure & Contents–Industrial	31	32	33	32
Structure & Contents–Public	130	145	149	142
Auto	36	49	54	47
Clean Up	217	227	231	225
TRA	53	57	57	56
PA	159	169	170	167
Crop Losses	31	33	37	33
Total	**1,075**	**1,257**	**1,330**	**1,227**

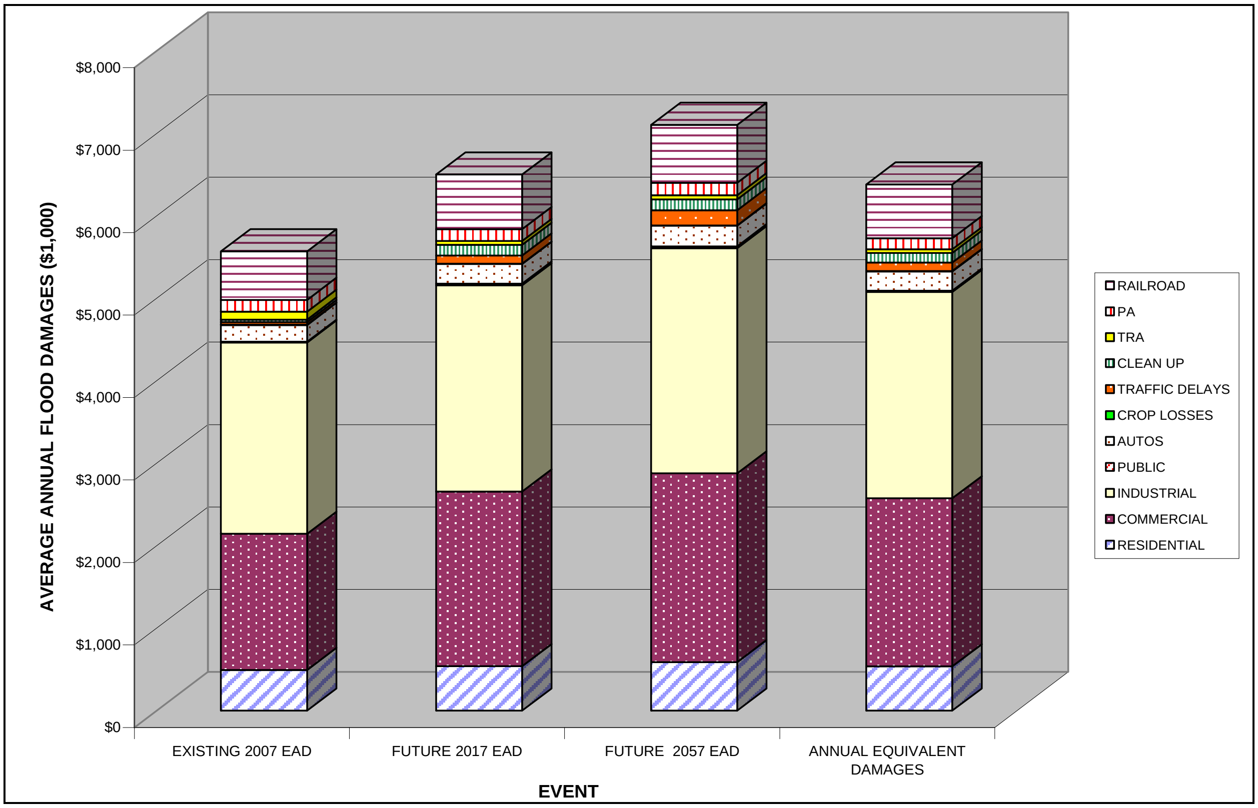

Figure 6-25. Existing and Future Right-Bank EAD and 50-Year AAED

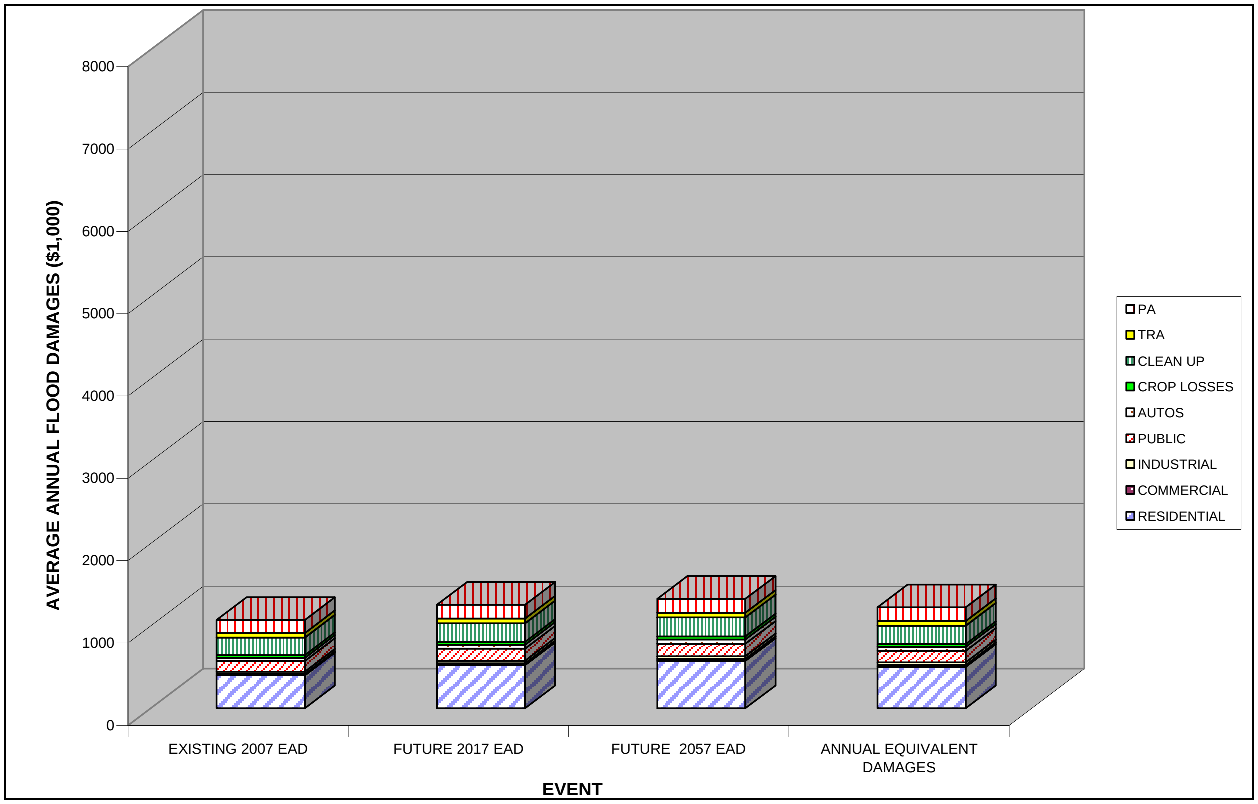

Figure 6-26. Existing and Future Left-Bank EAD and 50-Year AAED

Effect of Levee Failure

For the right bank, damage costs are very sensitive to levee failure assumptions. The probable non-failure point (PNP) and probable failure point (PFP) flood levels, as described in Chapter 5, were included in the HEC-FDA model (the flood levels with a 15-percent and 85-percent chance of levee failure, respectively). The PNP was set 3 feet below the top of levee and the PFP just below the top. Tables 6-16 and 6-17 show the annual damage costs under existing and future conditions based on these probabilities of levee failure for the right bank and left bank, respectively. The average annual equivalent damage costs would be approximately $6.4 million to the right bank, with commercial and industrial damage making up about 70 percent of the total, and approximately $1.2 million to the left bank.

As a sensitivity analysis, a second set of HEC-FDA runs were made assuming no levee failures. In this scenario, the only flooding would be due to overtopping of the levees. Figure 6-27 compares the extent of the 100-year floodplain with a levee failure to the extent with overtopping only; Figure 6-28 shows the same relationship for the 500-year floodplain. The difference for the right bank is dramatic for both events. The changes between existing and future conditions are much greater for the overtopping only scenario. Figure 6-29 compares the 100-year overtopping event for the existing, 2017, and 2057 conditions.

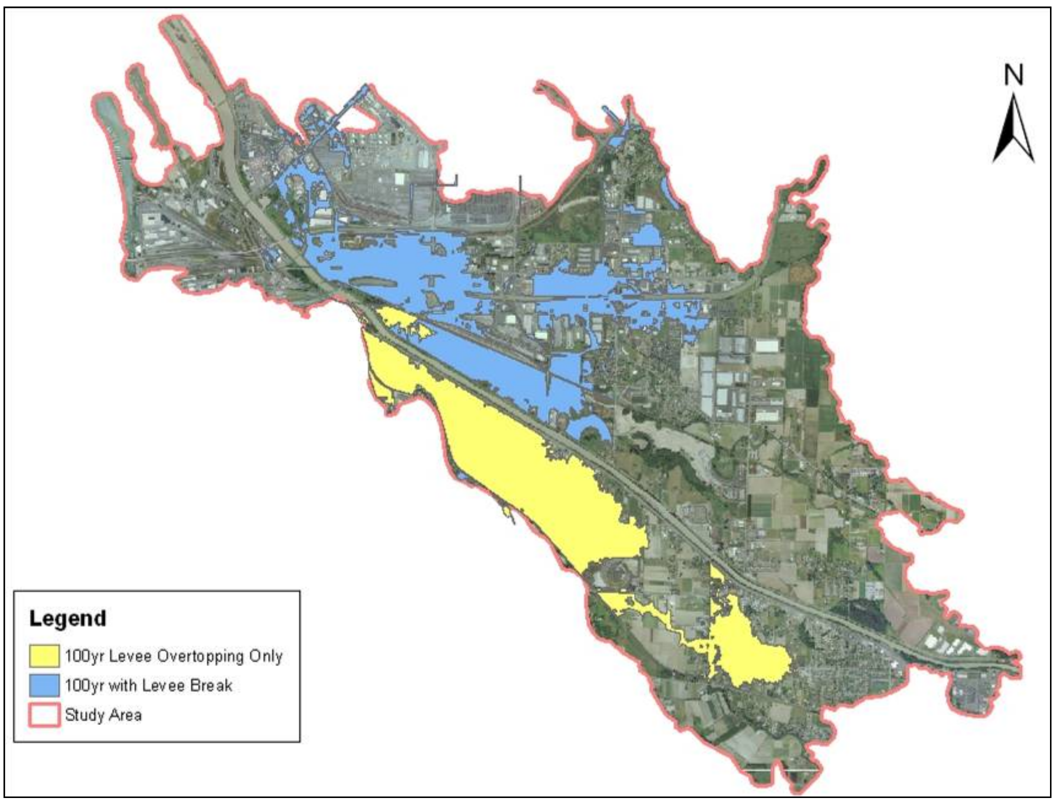

Figure 6-27. 100-Year Floodplain with Levee Breach and with Levee Overtopping Only

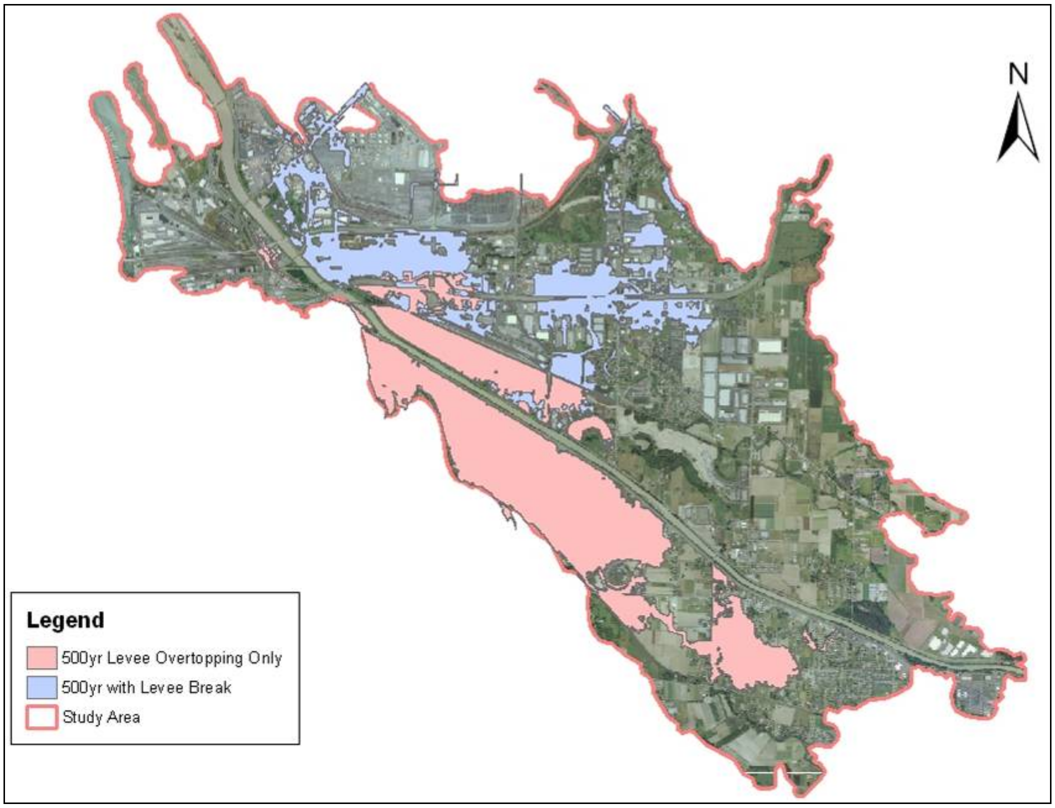

Figure 6-28. 500-Year Floodplain with Levee Breach and with Levee Overtopping Only

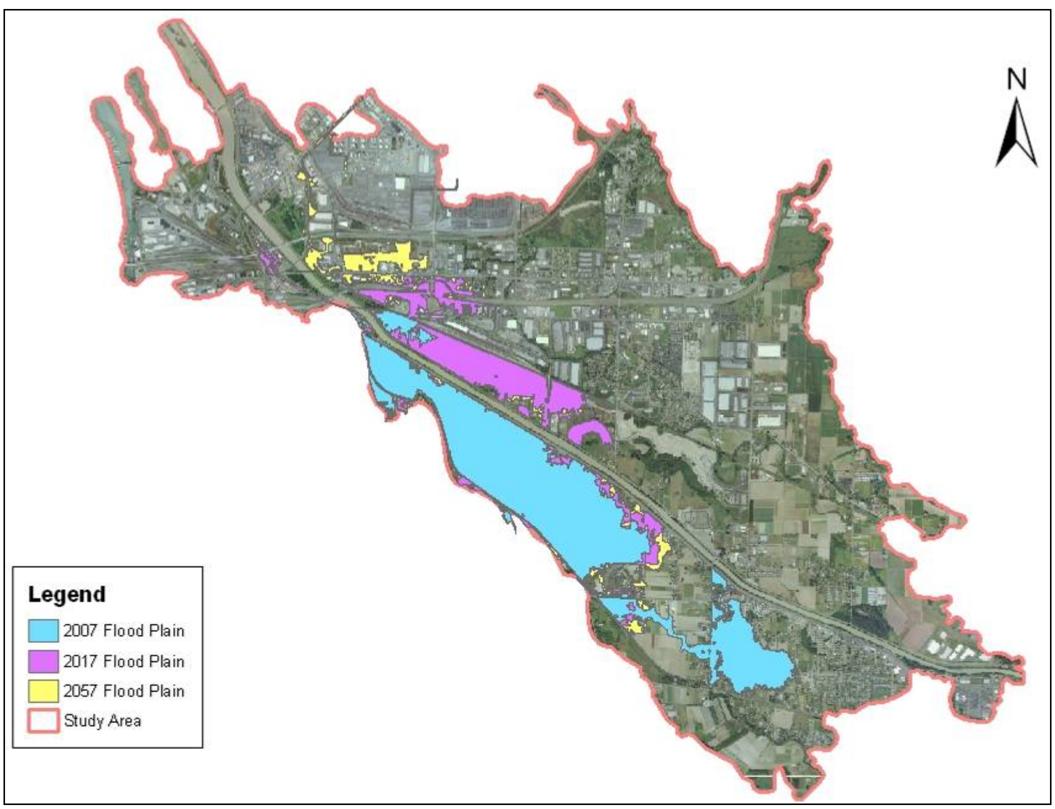

Figure 6-29. Existing and Future Conditions 100-Year Floodplain with Levee Overtopping Only

Tables 6-18 and 6-19 and Figures 6-30 and 6-31 show economic analysis results based on overtopping only. For the right bank, average annual equivalent damage costs based on overtopping are only 7 percent as much as those with levee failure, dropping from $6.4 million to $463,000. In contrast, AAED for the left bank (which is not expected to have any levee failures) would increase by approximately 3 percent. This is because the lack of a right-bank levee failure leaves more water in the river to overtop the left bank.

TABLE 6-18.
EXISTING AND FUTURE RIGHT-BANK EXPECTED ANNUAL DAMAGE AND 50-YEAR AVERAGE ANNUAL EQUIVALENT DAMAGE; LEVEE OVERTOPPING ONLY

	EAD ($1,000s; October 2007)			AAED
	Existing 2007	Future 2017	Future 2057	($1,000s; October 2007)
Structure & Contents–Residential	0	0	0	0
Structure & Contents–Commercial	0	78	118	67
Structure & Contents–Industrial	0	85	114	70
Structure & Contents–Public	0	0	0	0
Autos	0	0	0	0
Clean Up	0	0	0	0
TRA	0	0	0	0
PA	0	0	0	0
Crop Losses	0	1	1	1
Traffic Delays	56	75	69	69
Railroad	94	286	375	256
Total	**150**	**525**	**677**	**463**

TABLE 6-19.
EXISTING AND FUTURE LEFT-BANK EXPECTED ANNUAL DAMAGE AND 50-YEAR AVERAGE ANNUAL EQUIVALENT DAMAGE; LEVEE OVERTOPPING ONLY

	EAD ($1,000s; October 2007)			AAED
	Existing 2007	Future 2017	Future 2057	($1,000s; October 2007)
Structure & Contents–Residential	444	547	539	520
Structure & Contents–Commercial	18	23	23	22
Structure & Contents–Industrial	31	32	32	32
Structure & Contents–Public	143	152	348	188
Autos	40	53	52	50
Clean Up	223	229	228	227
TRA	55	57	57	57
PA	165	170	169	169
Crop Losses	31	31	32	31
Total	**1,150**	**1,294**	**1,480**	**1,296**

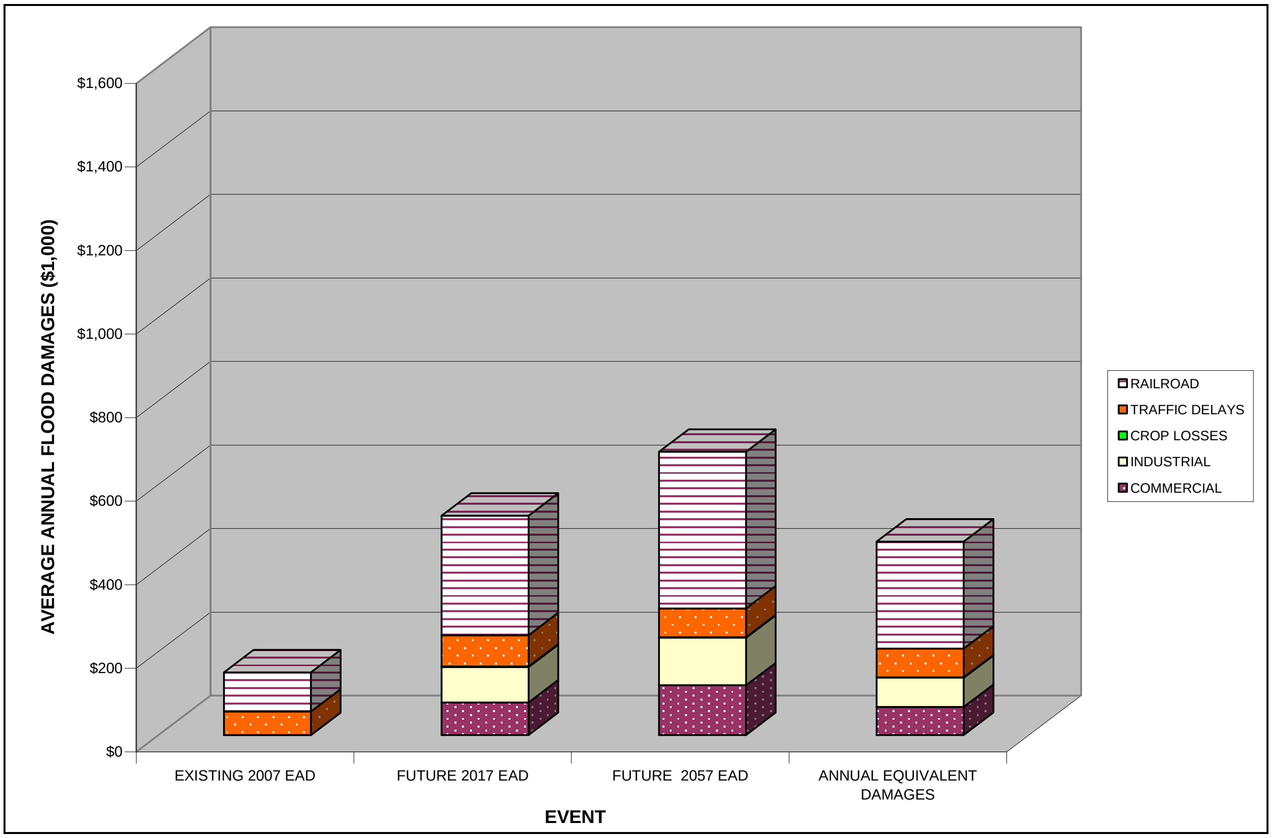

Figure 6-30. Existing and Future Right-Bank EAD and 50-Year AAED, Levee Overtopping Only

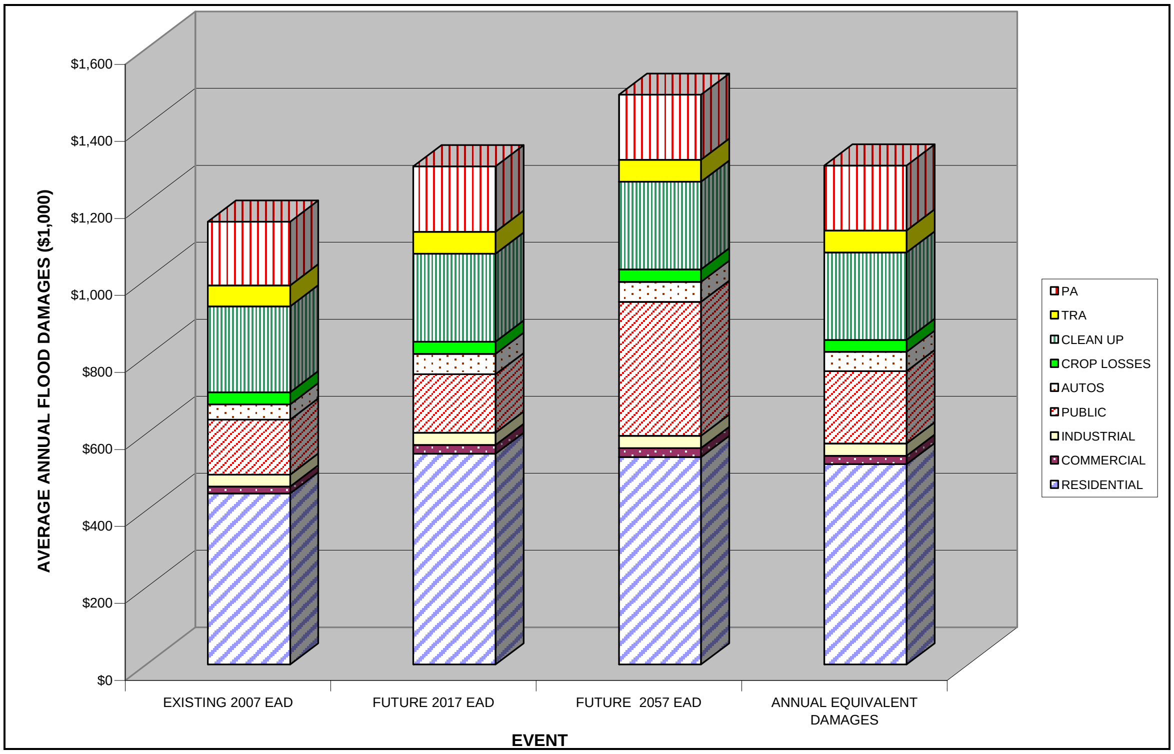

Figure 6-31. Existing and Future Left-Bank EAD and 50-Year AAED, Levee Overtopping Only

PROJECT PERFORMANCE

In addition to damage estimates, HEC-FDA reports flood risk in terms of project performance. ER 1105-2-101 outlines three statistical measures to describe performance risk in probabilistic terms:

- **Annual exceedance probability (AEP)**—The chance of a damaging flood in any given year. The results for AEP (Table 6-20) indicate that, for example, under existing conditions in any given year there is about a 25-percent chance of left-bank flood damage with a levee failure, a 21-percent chance of left-bank flood damage with overtopping only, a 9-percent chance of right-bank flood damage with overtopping only, and a 2-percent chance of right-bank flood damage with a levee failure. The AEP for the left bank may decrease with future sediment levels, as increased right-bank overtopping and levee failure lead to less water in the river to overtop the left bank levees.
- **Long-term risk—**The chance of one or more damaging floods over a period of time. The results for long-term risk (Table 6-20) indicate that, for example, over a 10-year period under existing conditions, there is about a 94-percent chance of left-bank flood damage with a levee failure, about a 91-percent chance of left-bank flood damage with overtopping only, a 61-percent chance of right-bank flood damage with a levee failure, and a 19-percent chance of right-bank flood damage with overtopping only.
- **Conditional non-exceedance probability (CNP)—**The chance of not having a damaging flood given a specific magnitude event. Table 6-21 shows the CNP, which indicates the probability of the levee containing a given frequency event without any damage. Due to the frequent flooding that occurs on the left bank, there is zero probability of avoiding flood damage for any event greater than 25-year. For the right bank, the probability of containing a 25-year event ranges from 9 percent (2057 conditions with levee failure) to 85 percent (existing conditions with overtopping only).

TABLE 6-20.
ANNUAL EXCEEDANCE PROBABILITY AND LONG-TERM RISK

	Annual Exceedance Probability	Long-Term Risk 10 Years	Long-Term Risk 30 Years	Long-Term Risk 50 Years
Left Bank				
Levee Failure (PNP & PFP) on Right Bank				
Existing	0.251	94%	100%	100%
2017	0.248	94%	100%	100%
2057	0.220	92%	100%	100%
Overtopping Only				
Existing	0.211	91%	100%	100%
2017	0.232	93%	100%	100%
2057	0.212	91%	100%	100%
Right Bank				
Levee Failure (PNP & PFP)				
Existing	0.091	61%	94%	99%
2017	0.150	80%	99%	100%
2057	0.157	82%	99%	100%
Overtopping Only				
Existing	0.021	19%	48%	66%
2017	0.063	48%	86%	96%
2057	0.070	51%	89%	97%

TABLE 6-21.
CONDITIONAL NON-EXCEEDANCE PROBABILITY

	Conditional Non-Exceedance Probability 25-Year Event	50-Year Event	100-Year Event	250-Year Event
Left Bank				
Levee Failure (PNP & PFP) on Right Bank				
Existing	0%	0%	0%	0%
2017	0%	0%	0%	0%
2057	0%	0%	0%	0%
Overtopping Only				
Existing	0%	0%	0%	0%
2017	0%	0%	0%	0%
2057	0%	0%	0%	0%
Right Bank				
Levee Failure (PNP & PFP)				
Existing	42%	30%	17%	2%
2017	12%	4%	1%	0%
2057	9%	2%	1%	0%
Overtopping Only				
Existing	85%	62%	36%	4%
2017	25%	8%	2%	0%
2057	18%	5%	1%	0%