HAZUS Analysis for the Green River Valley

Prepared by: FEMA Region X Mitigation
October 6, 2009

HAZUS Disclaimer

The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

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Table of Contents

Executive Summary

- Howard Hanson Dam, which provides flood control for the Green River, was affected by floods from January 2009, resulting in two depressions at the dam. The dam may have to operate under below normal pool restrictions, which could yield to increased flooding in the Green River valley
- King County Emergency Management asked FEMA to conduct a HAZUS analysis to determine economic losses, potential shelter requirements and debris generated from a flooding disaster
- HAZUS used King County GIS data to update building replacement value and square footage. Depth grids provided by USACE, King County, and FEMA were used in HAZUS to calculate losses due to flooding. HAZUS is a modeling tool to estimate losses and could differ greatly from the losses in an actual event.
- United States Army Corp of Engineers (USACE) created various depth grids resulting from various discharges at the Auburn stream gage, including 13,900, 17,600, 19,000, and 25,000 cfs.
- The report presented here used the 17,600 cfs depth grid created by USACE.
- King County also conducted a 100 Year FEMA Flood Study to be included in the preliminary Digital Flood Insurance Rate Map (DFIRM) using a 100 year discharge of 12,800 cfs. The 100 Year flood study also incorporated levee removals to simulate levee failure.
- This report details analysis for three scenarios which include: Scenario 1 – USACE 17,600 cfs depth grid, Scenario 2 – King County 100 Year DFRIM with a discharge of 12,800 cfs, and Scenario 3 – the USACE 17,600 cfs discharge, with the levee removal scenarios provided in the King County 100 Year DFIRM
- Results for Scenario 1 include $1.34 billion of economic losses, 35 substantially damage buildings, 15,500 people displaced, and 84,000 tons of debris generated
- Results for Scenario 2 include $1.97 billion of economic losses, 100 substantially damage buildings, 21,000 people displaced, and 208,000 tons of debris generated
- Results for Scenario 3 include $3.75 billion of economic losses, 170 substantially damage buildings, 21,000 people displaced, and 280,000 tons of debris generated
- Levee removal scenarios greatly impact the level of flooding which could be seen. Therefore all levee removals were modeled to simulate levee failure and are used for planning purposes. During the event an individual levee failure could greatly change the flood depth grid.
- FEMA Region X has released this report to all local and State governments affected by this potential disaster with the hope to better mitigate, plan, prepare, and respond to this pending disaster.

Green River and Howard Hanson Dam – Background

The Green River is 65 miles long and is controlled by the Howard Hanson Dam, which is owned by the United States Army Corp of Engineers (USACE). The Green River is located in southern King County and ultimately flows through the cities of Auburn, Kent, Renton and Tukwila (Figure 1).

Following a record high level of water behind Howard Hanson Dam in January 2009, the USACE became concerned after the discovery of two depressions on the right abutment, increased water levels in groundwater monitoring wells, and the appearance of silty water entering the abutment drainage tunnel. The USACE has since installed additional monitoring equipment and continues with tests to determine with more certainty to what elevation the pool can be raised without significant adverse impacts to the abutment. Potential impacts of the restrictions on the flood storage capacity are increased flood risk to the Green River Valley below the dam. (USACE, 2009)

USACE contracted with northwest hydraulic consultants, Inc. (nhc) to develop various flood scenarios for the Green River Valley. Each scenario was based on various reservoir pool levels and inflow/outflow parameters. The scenarios included depth grids (flood depths in feet) for the following discharges at the Auburn gage: 13,900 cfs, 17,600 cfs, 19,500 cfs, and 25,000 cfs (with levee failure at 180th St). All scenarios with the exception of 25,000 cfs scenario assumed all levees were intact, and accounted for overtopping.

In addition to the USACE Study, King County completed a flood hazard study which included revised hydrologic and hydraulic analyses for the Green River to better define the floodplain. This study was submitted to FEMA as an appeal to the initial preliminary digital flood insurance rate map (DFIRM). King County's study followed FEMA Guidelines and Specifications for levee modeling (Appendix H, see links) and reflects a simulated removal of left and right bank levees and combines those results into a single depiction of the base (1% annual chance) floodplain.The overall inundation area is a combination of 1-dimensional modeling (within the channel), and 2-dimensional modeling of the overbank using FLO-2D (numeric model). The basemaps reflect high resolution LIDAR and imagery collected by King County. The King County Green River Maps can be found at http://www.kingcounty.gov/environment/waterandland/flooding/maps.aspx.

In June of 2009, King County Emergency Management requested support from FEMA Region X in assessing risk to communities potentially affected by the Howard Hanson Dam. After a thorough review of available data, it was determined that a risk assessment could be best accomplished through HAZUS modeling that incorporated the USACE and King County developed depth grids, planning and infrastructure data from local communities, and default HAZUS information where more accurate data did not exist.

Study Objectives

- Provide an overview of potential economic and social impacts associated with the current state of the Howard Hanson Dam

- Compare differences of damage between the proposed base (1% flood) of 12,800 cfs and a greater magnitude flood caused by impaired dam operation resulting in 17,600 cfs at Auburn

- Provide the County and affected communities with risk assessment data to be used for future mitigation, response, recovery, and operations efforts

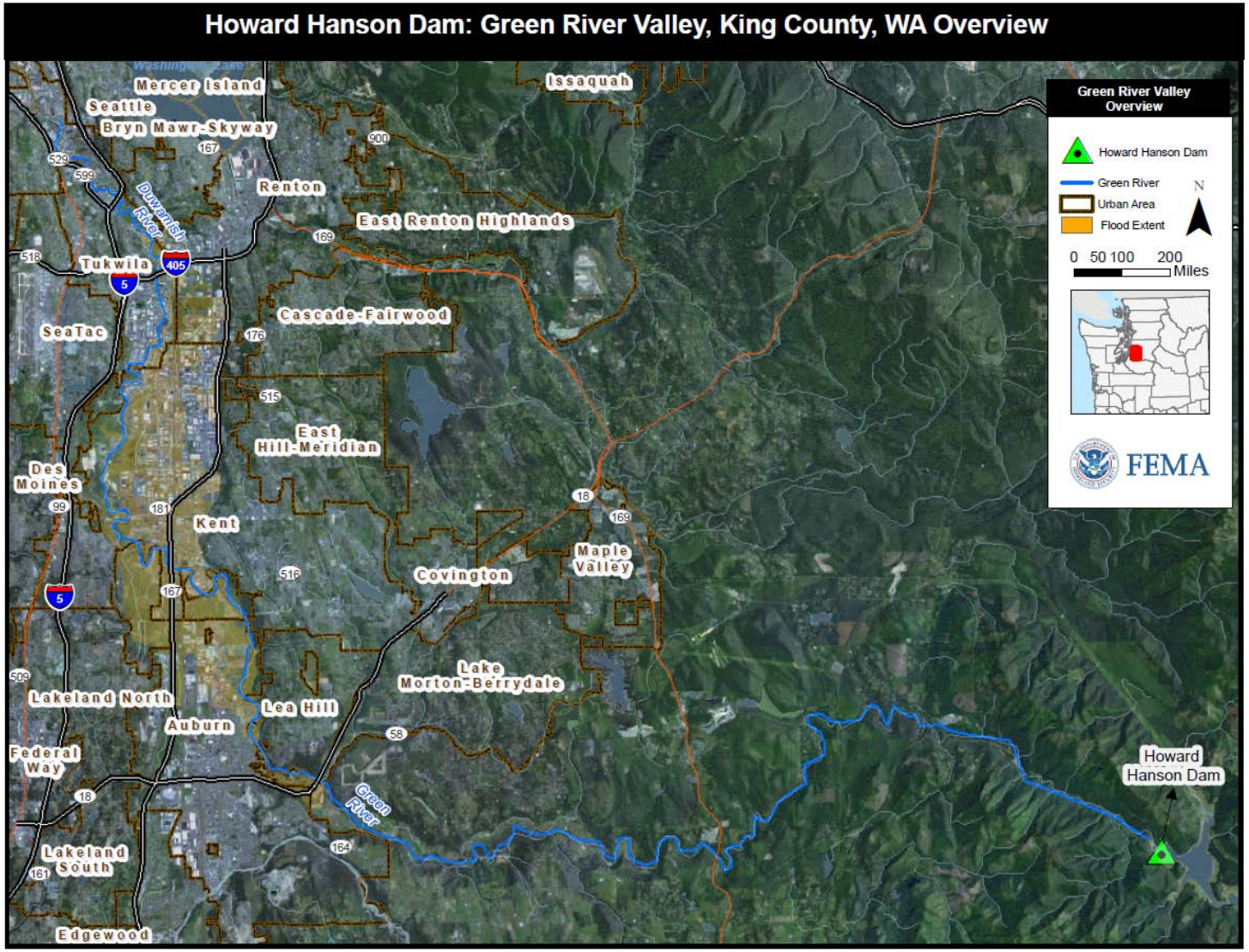

Figure 1. Location map of Howard Hanson Dam, the Green River, and the USACE 17,600 cfs flood extent.

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Methodology

Overview

A level 2 HAZUS MH MR3 study was completed for this project, which incorporated updated building information. In order to calculate loss due to flooding, HAZUS requires the following information about the built environment: structure location, occupancy type, square footage, first floor height above grade, as well as replacement and content values. All but content value and first floor height above grade were available in King County's standard GIS data package. This package dated April 2009, includes parcels, assessment information, and essential facilities. The improvement value from King County's Assessor was used for the replacement value. Content value and first floor height above grade were not available for this study area and were calculated using HAZUS default methodologies (see Links). King County did not include the necessary transportation and utility data required for HAZUS, so the default values were used.

Prior to incorporation into HAZUS, data provided by King County was formatted to work within the Comprehensive Data Management System (CDMS), a tool provided by FEMA to incorporate localized data into HAZUS. Detailed methodologies and assumptions for each of the GIS layers are provided in the sections to follow. Calculations, fields, and tables used are provided in Appendix A.

In addition to local GIS data, HAZUS uses flood depth grids to calculate economic losses. Depth grids are created from hydrologic and hydraulic modeling, which show flood depth in feet. For this study, three depth grids were used including the USACE 17,600 cfs (Scenario 1), the King County 100 year base flood study (Scenario 2), and a combination of both studies with 17,600 cfs with levee removals (Scenario 3). Using the combination of the depth grid and the local data, HAZUS calculates economic losses, shelter requirements, and debris. A comparison was also completed between each flood scenario.

Methods

The database construction was completed using Microsoft Access. The creation of the tables required many queries, calculations, and joining in order for the information to be formatted correctly for HAZUS (see Appendix). Once the data was in the correct format it was imported into CDMS which updates the statewide dataset (originally given with HAZUS). The parcel data was input as aggregated data by census block. Once input into CDMS, fields are chosen to match the HAZUS fields such as replacement value. Once completed, the existing state dataset was updated with the information for the locality given (i.e. King County). The statewide dataset was only updated locally to the user's computer; therefore, the dataset would need to be copied to other computers or a network to be used for future HAZUS analyses. Once this process was completed the updated HAZUS inventory was available in HAZUS.

HAZUS allows the user to input a depth grid which is used to calculate economic losses and damages. A study region was created in HAZUS by census blocks, the smallest unit

of analysis. Census blocks were chosen based on the extent of the Green River Valley. Once HAZUS created the study region, the food hazard type was set to riverine. The depth grid was supplied under User data and a new scenario was created. Once the floodplain was delineated, the analysis was run for general building stock, shelter requirements and debris. HAZUS found no bridge, utility, or agriculture losses using the original HAZUS inventory data. This information could be updated with local data to better determine these losses.

HAZUS then outputs the results in tables or reports, and also maps the data which can then be exported into an ArcGIS format. The data was mapped for total economic loss, substantial damage, shelters, and debris. The maps shown in this report were created from this output.

HAZUS Data Assumptions and Damage Estimates

For residential occupancy, HAZUS calculates the content value to be 50% of the building cost. For all other occupancies the building value could be multiplied by 50-150% to determine content value (see HAZUS Technical Manuals). These estimates could significantly affect the total economic loss, especially since the Green River valley contains large warehousing facilities. To better constrain the content and inventory values, the appropriate data should be supplied and input into HAZUS.

The previous calculations refer only to the inventory base data, not the calculated losses. To calculate losses, HAZUS-MH uses depth damage curves. Depth-damage curves are contained in HAZUS-MH and come from various data sources. For each census block an appropriate damage curve is assigned for each occupancy type and water depths are used to determine the associated percent damage. The percent damage is multiplied by the replacement value (i.e. building value, content value etc.) to determine the full dollar loss. Shelter estimations are determined based on flood depth, individuals or households within a census block, population of a census block, number of census blocks affected, and restricted ingress/egress areas due to flooding. Updated demographic information was not provided by King County; therefore data from the 2000 Census was used. The shelter estimations are believed to be a minimum due to population changes in the area since 2000. Debris is calculated based on flood depth and calculates debris generated from buildings and contents, not roads or utilities. More information on the HAZUS-MH calculations and depth curves can be found in the HAZUS User and Technical Manuals (See Links).

King County GIS Data Assumptions

Aggregate Updates by Occupancy Class

The parcel data provided by King County served as the basis for joining assessor's information regarding commercial, residential and industrial structures to their appropriate geographic location. Updated parcel data attributed with assessor's values and default HAZUS information was then aggregated at the census block level for

incorporation into CDMS. Detailed methodologies for updating each occupancy type are provided in the section below.

Commercial
Both commercial data as well as improvement values were joined to the parcel data based on parcel number (PIN) to produce a single table containing building square footage, improvement value, and building count. Net building square footage was used over gross values to provide an adequate estimate of square footage. Improvement values were obtained from the most recent assessment year provided and was used as the building replacement value in HAZUS. In areas where improvement values were missing, average improvement value per square foot was calculated and was used to calculate an improvement value based on the given square footage. Once every commercial parcel had square footage and improvement values, improvement values were divided by 1000 to format the data for HAZUS.

It is important to note that the King County data classified apartments as commercial, not residential. Due to time constraints, this data was left as is. Consequently, residential economic values may be slightly lower and the commercial values may be slightly higher. This will not affect the overall economic values for the study region.

Residential
Residential data was created using the same methodology that was used for the commercial data. Instead of having a single net square footage field, there were multiple square footage fields for living space, garage, etc. To properly calculate total square footage, square footage of living, finished basement and attached garage were added. Parcels with no improvement value were calculated using the same methods as commercial.

Condominiums
Condominium data was created using the same methodology that was used for the residential and commercial data. Condos included number of units and average unit size, which were multiplied to determine a net square footage per building. Parcels with no improvement value were calculated using the same methods as commercial and residential.

Parcel Zoning/Land Use Classification
Once the commercial, residential, and condo tables were finalized they were joined together. The present use field was used to determine building type. HAZUS has specified zoning/land use codes for each building type which were used to approximate the parcel's present use. The fields used are shown in Appendix A.

Essential Facilities
HAZUS loss calculations for essential facilities are performed at the site level rather than at the census block level. In order to best assess loss to a specific building within HAZUS, it is important to have detailed building specific information such as a building's first floor height above grade and construction type. Because this information

could not be obtained within current time constraints, the essential facilities analysis was conducted outside of HAZUS and was based on general exposure rather than estimated losses.

Essential facilities data were included with the King County Standard Data, which provides information about fire, police, schools, and medical facilities. The essential facilities data did not contain square footage or improvement values. This data was obtained from the parcel number using the same methodology that was used for the parcel data. Essential facilities with no improvement value were calculated using the same methods as commercial and residential. This data was then used to create exposure maps of essential facilities and identified facilities which may be at a higher risk based on flood depth.

Results

Scenario 1: USACE Derived 17,600 cfs Discharge Due to Impaired Dam Operations

The first scenario analyzed used the USACE 17,600 cfs depth grid which produced a total of $1.35 billion in economic losses (Table 1). This scenario was chosen for analysis by King County and represents a plausible flooding scenario based on the operating conditions at the Howard Hanson Dam, but it does not represent the worst possible outcome.

Table 1. Building-Related Economic Loss Estimates (in millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	110.91	53.06	171.66	4.66	340.28
	Content	78.73	125.86	492.71	28.54	725.84
	Inventory	0.00	4.08	253.84	0.07	257.99
	Subtotal	**189.63**	**183.00**	**918.21**	**33.27**	**1,324.11**
Business Interruption						
	Income	0.16	1.71	0.31	0.22	2.39
	Relocation	0.32	0.73	0.48	0.00	1.53
	Rental Income	0.54	0.53	0.15	0.00	1.23
	Wage	0.37	1.46	0.52	14.78	17.13
	Subtotal	**1.39**	**4.43**	**1.46**	**14.99**	**22.28**
ALL	**Total**	**191.03**	**187.43**	**919.66**	**48.27**	**1,346.39**

Economic loss is calculated by census block as shown in Figure 2. Economic loss is calculated by building, content, and inventory (business) loss as well as business interruption costs listed in Table 1. Damage to residential structures is shown in Figure 3. A minimum of 30 residential buildings could be substantially damaged, with approximately 600 residential buildings having at least minimal damage. Substantially damaged buildings can have significant implications in Washington due to RCW 86.16

and the National Flood Insurance Program. In WA, new construction or substantial improvement of residential buildings located within the floodway is prohibited. Ultimately, the determination of "substantial damage" is a local community responsibility and would be based on a more detailed assessment than was provided by HAZUS. Much of the substantially damaged buildings occur in one census block as shown in Figure 3. Table 2 shows the range of damage (1-50% of damage to a building) by building type. The building types most affected are residential, commercial, and industrial. Approximately 1,000 buildings could have at least minimum damage.

Table 2. Count of Buildings (#) by Range of Damage %

	None	1-10	11-20	21-30	31-40	41-50	Substantial	Total
Washington								
King								
Commercial	57	26	83	2	2	0	0	170
Industrial	66	39	277	12	0	0	5	399
Education	2	4	0	0	0	0	0	6
Agriculture	0	0	0	0	0	0	0	0
Religion	2	2	0	0	0	0	0	4
Government	0	2	0	0	0	0	0	2
Residential	676	14	91	304	52	107	30	1,274
Total	**803**	**87**	**451**	**318**	**54**	**107**	**35**	**1,855**
Total	**803**	**87**	**451**	**318**	**54**	**107**	**35**	**1,855**

Figure 4 depicts random density distributions of economic loss categorized by occupancy class. Loss categories depicted include residential, industrial and commercial occupancy classes. Each dot represents $100,000 of the total occupancy loss for each census block. Industrial properties are affected most, which would be expected due to the large industrial area present. Shelter estimations are shown in Figure 5. Approximately 15,500 individuals will be displaced and of those approximately 14,500 will require shelter. Debris estimates are shown in Figure 6. Debris is calculated for building and content debris which totals approximately 84,600 tons. Debris does not include debris generated from roads and utilities.

This analysis used the USACE 17,600 cfs Scenario which did not include simulated levee removals or specified failure points; therefore, levee overtopping with no catastrophic damage was assumed. Of the three analyses conducted, this first scenario caused the least damage and economic loss. Current levees along the Green River can contain approximately 13,000 cfs.

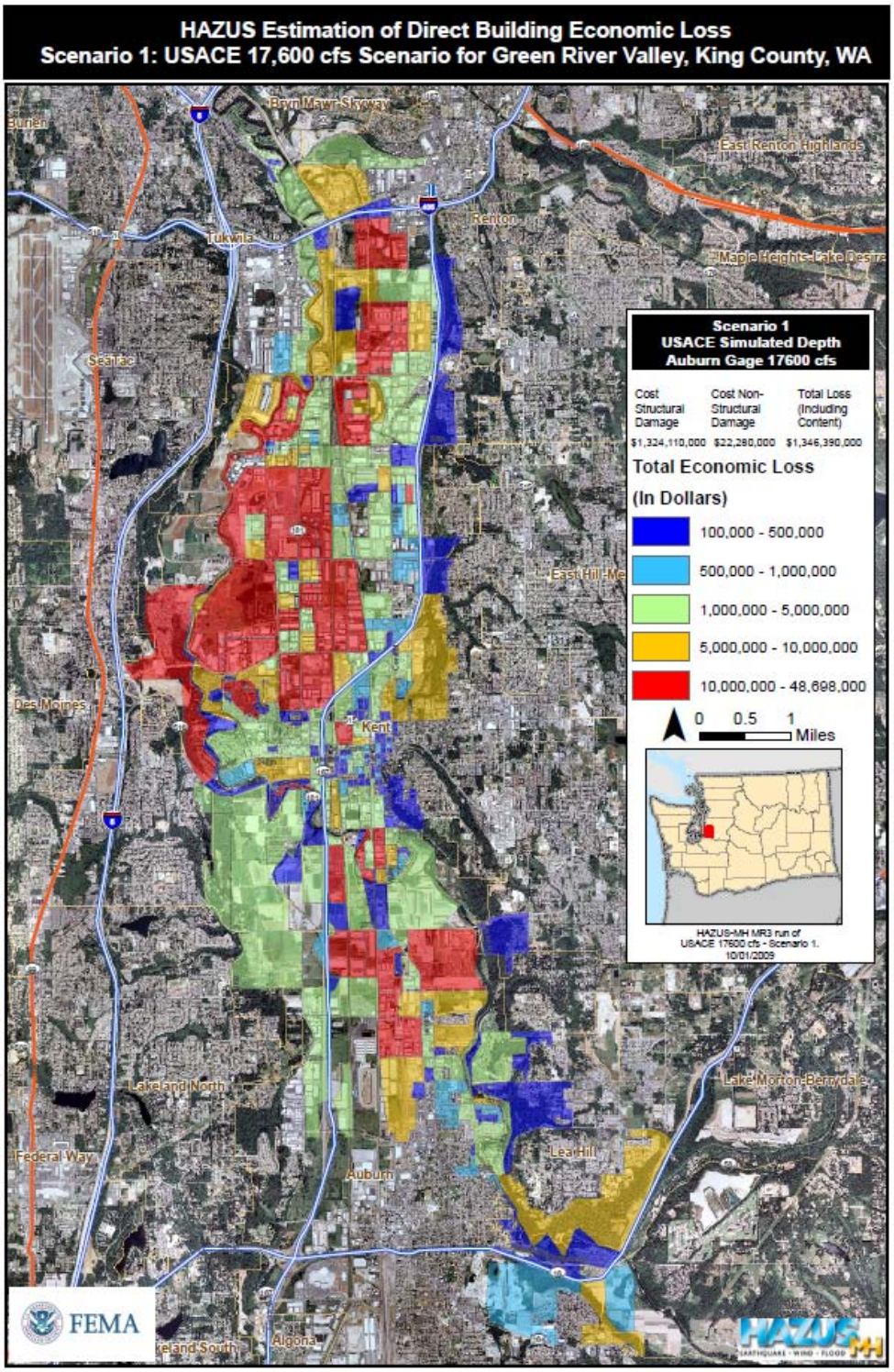

Figure 2. Total Economic Loss for the Green River valley based on the USACE 17,600 cfs Scenario (Scenario 1). Structural damage includes building cost, contents cost, and inventory cost. Remaining non-structural costs includes business interruption, relocation etc. Total economic loss is $1.35 billion. Red areas indicate $10-48 million of economic loss for each census block. Census blocks with losses below $100,000 were not shown.

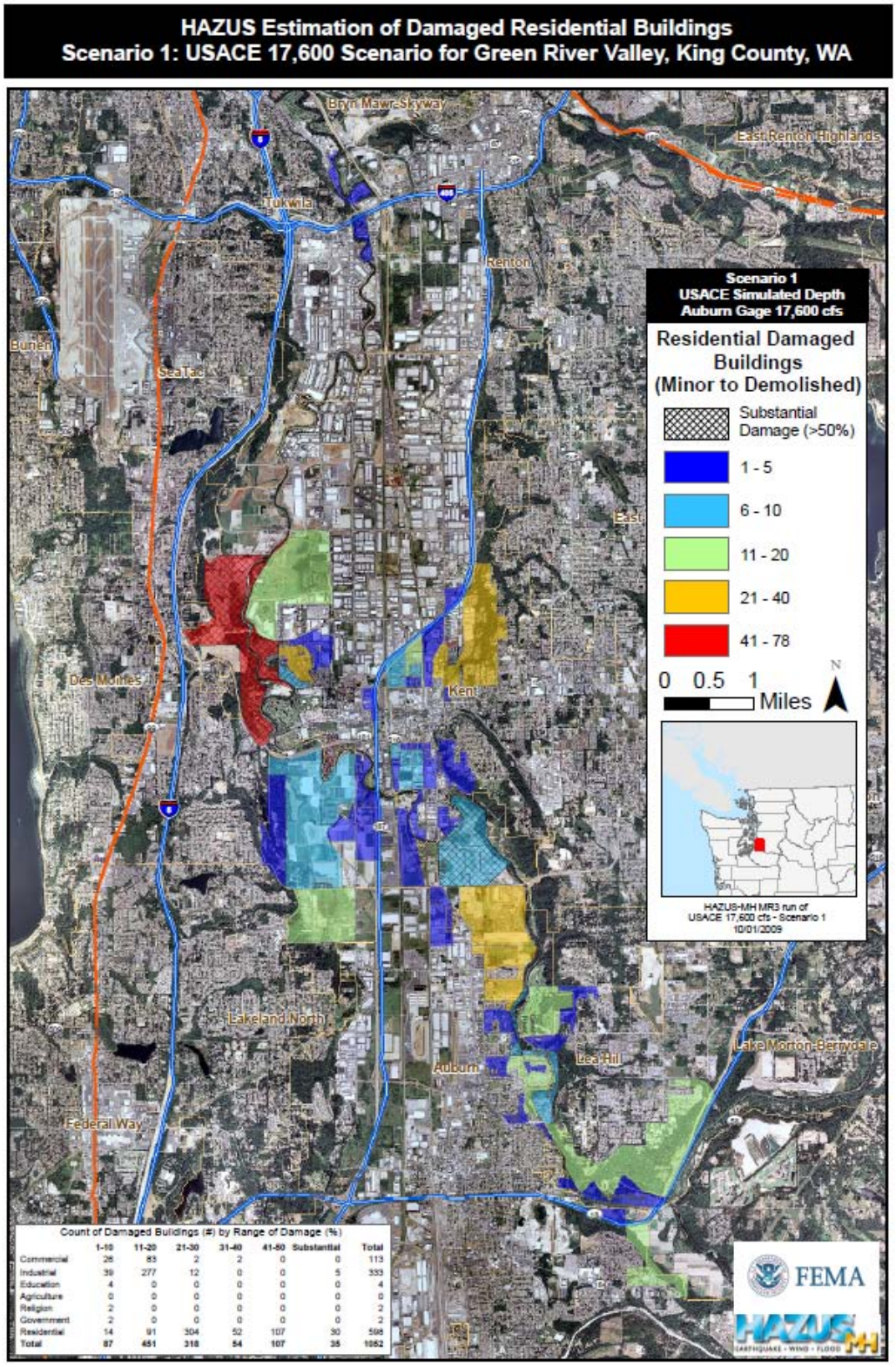

Figure 3. Number of residential buildings damaged for Scenario 1. The results estimate approximately 30 substantially damaged residential buildings and approximately 600 residential buildings with at least minor damage. Substantial damage also occurred for commercial and industrial structures. Total building damage count by building type is shown in the table.

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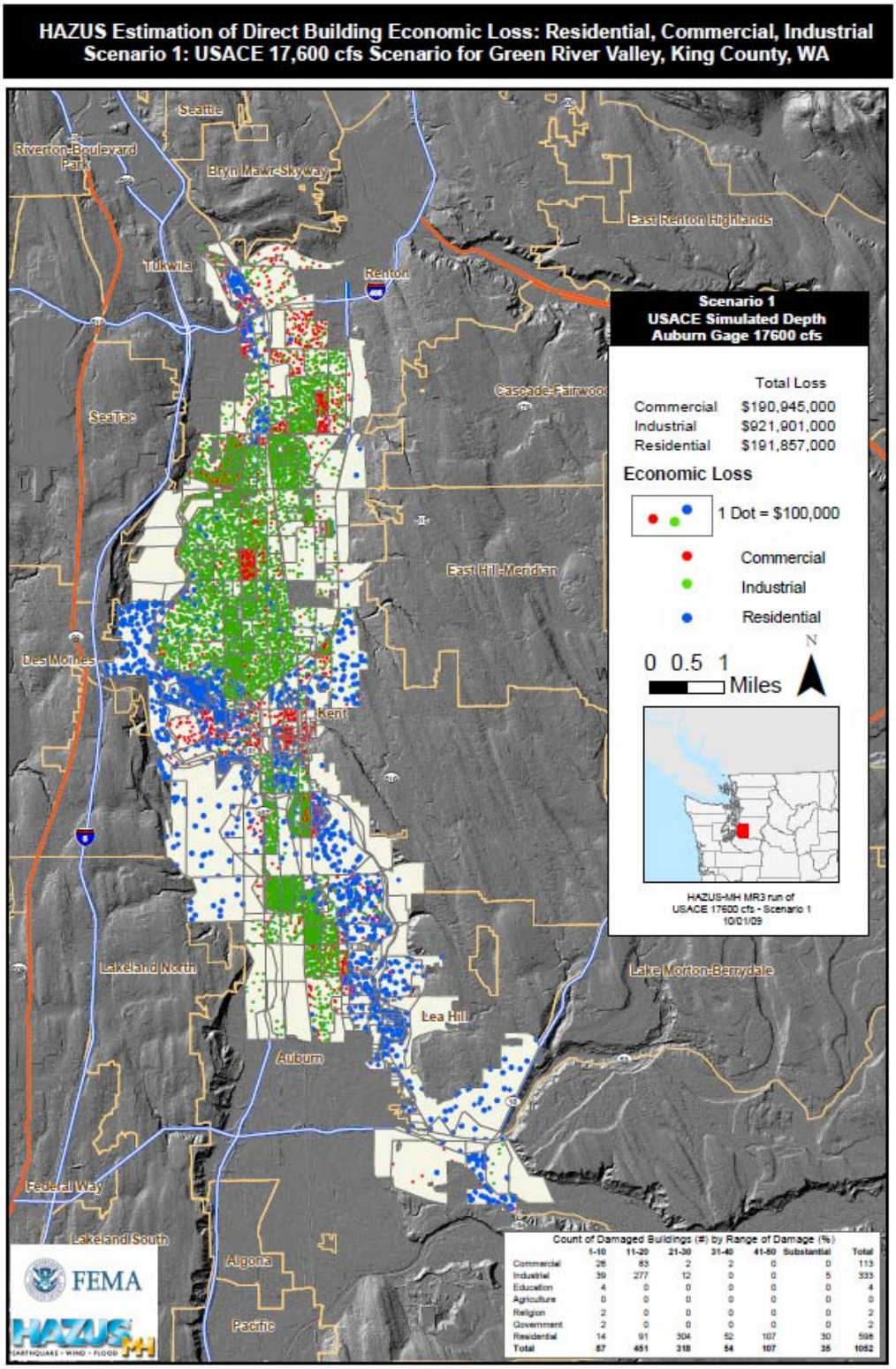

Figure 4. Random density distributions for economic loss for residential, commercial, and industrial building for Scenario 1. Economic loss points were derived from census blocks. Points do not represent specific locations, but rather identify clusters of occupancy types (i.e. residential). Industrial buildings are affected most in this scenario.

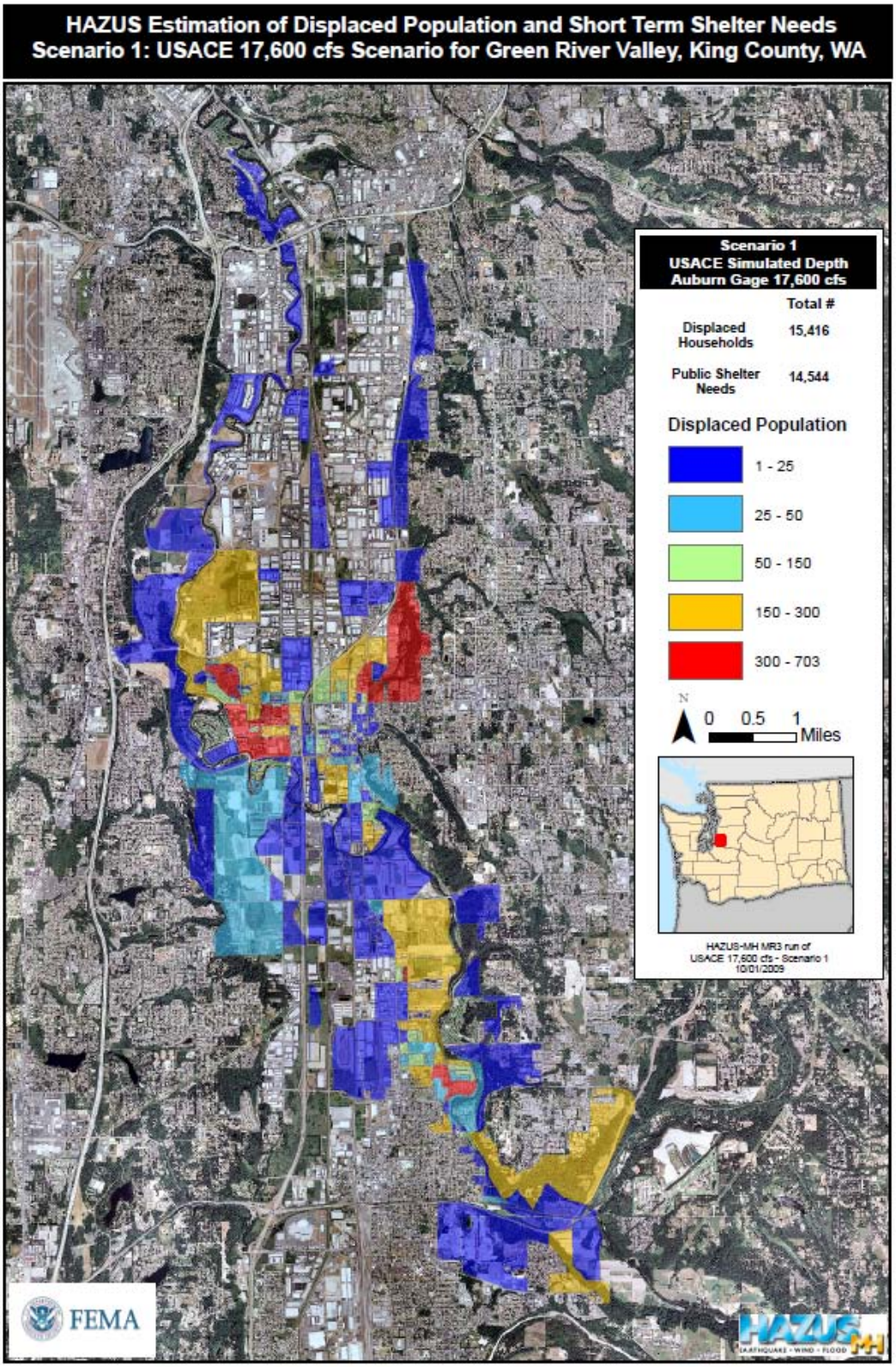

Figure 5. Displaced individuals and short term shelter needs for Scenario 1. Census blocks are mapped based on the number of displaced individuals. HAZUS estimated 15,416 people will be displaced and of those, 14,544 would need short term shelter.

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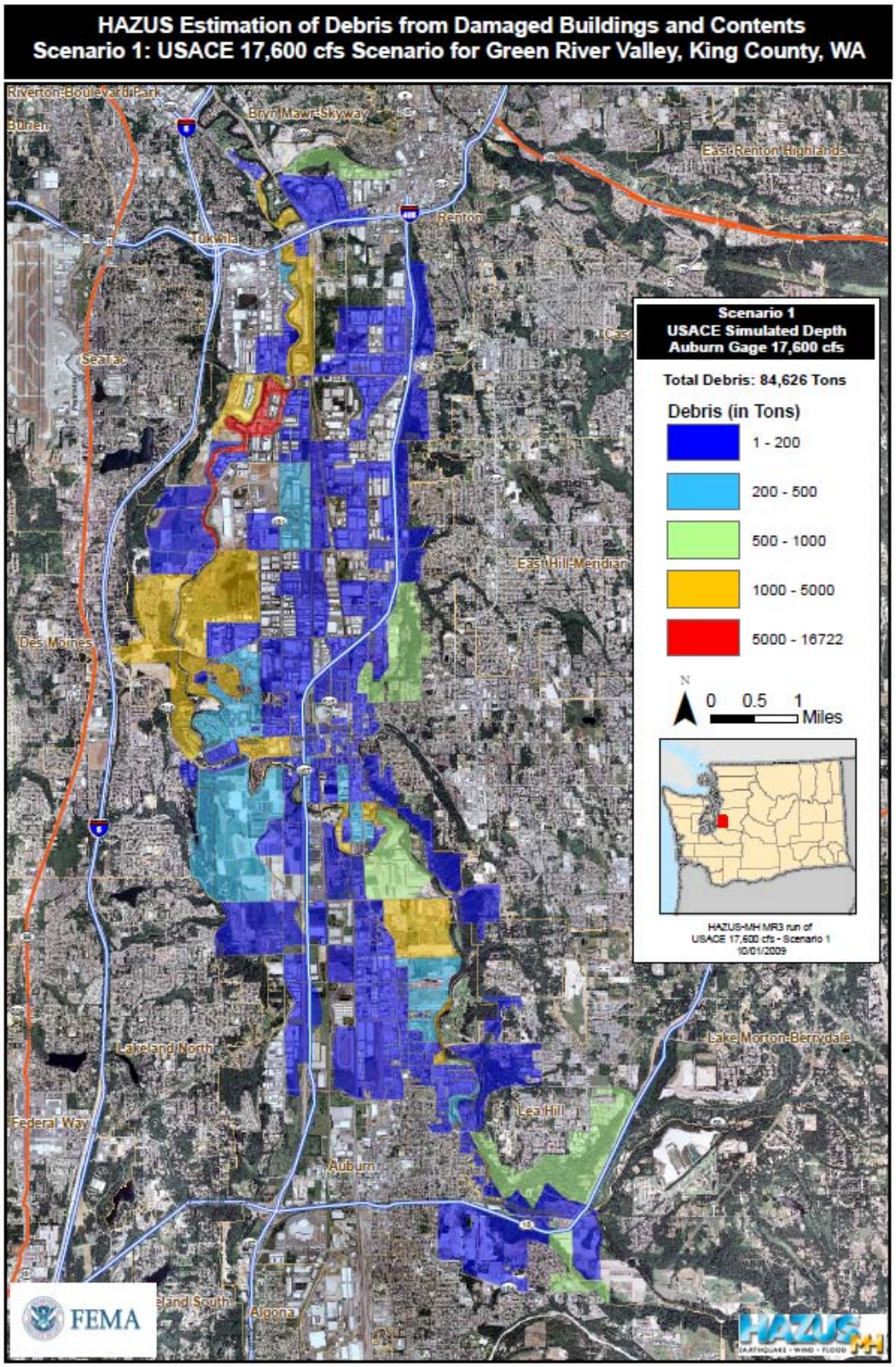

Figure 6. Debris Estimation for Scenario 1. Debris in tons is shown per census block. HAZUS calculates the estimated total debris generated for Scenario 1 to be 84,626 tons. Debris is generated from building and content debris, not from damage due to roads or utilities.

Scenario 2: King County Base (100 year) Flood Scenario (i.e. Preliminary FEMA Flood Insurance Study)

The second scenario used the King County Flood Hazard Study, which was submitted to FEMA as an appeal and will be incorporated into King County's DFIRM. Similar to Scenario 1, King County's study was prepared by nhc and uses comparable models and key assumptions. Unlike Scenario 1, this model uses the estimated base (1% annual chance) flood discharge of approximately 12,800 cfs. It also analyzes "with and without" levee conditions pursuant to Appendix H of FEMA's Guidelines and Specifications for conducting a Flood Insurance Study (See Links).

Scenario 2 uses HAZUS to compare the economic losses and damages associated with the "100 year flood" scenario where the Howard Hanson Dam is operating "normally." Losses shown in this scenario factor the individual and combined effects of six (6) different levee removal scenarios in order to simulate levees failing (Figure 7). Because we do not know the exact location of a potential levee failure, models systematically remove specified sections of levee and determine the resulting over-bank flood condition. The result is an "organized" escape of water from the channel (as opposed to a catastrophic levee failure which would have considerably higher velocities and associated damages in the immediate vicinity of the damaged levee). These various scenarios are ultimately combined to create a "worst case" inundation scenario and is the basis for FEMA's mapped base (1% annual chance) flood and Special Flood Hazard Area (SFHA). The King County study, and ultimately the official FEMA DFIRM reveals greater damages than the USACE 17,600 cfs scenario due to the way levees are modeled. The King County derived depth grid produced a total of $1.97 billion in economic losses (Table 3).

Table 3. Building-Related Economic Loss Estimates (in millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	122.63	110.80	272.50	2.08	508.00
	Content	91.00	208.83	739.25	8.97	1,048.05
	Inventory	0.00	5.86	394.60	0.07	400.52
	Subtotal	**213.63**	**325.48**	**1,406.34**	**11.12**	**1,956.57**
Business Interruption						
	Income	0.20	2.18	0.42	0.09	2.88
	Relocation	0.25	0.85	0.64	0.00	1.73
	Rental Income	0.61	0.64	0.20	0.00	1.45
	Wage	0.47	1.55	0.70	2.07	4.79
	Subtotal	**1.53**	**5.22**	**1.96**	**2.16**	**10.86**
ALL	**Total**	**215.15**	**330.70**	**1,408.30**	**13.28**	**1,967.43**

Economic loss is calculated by census block as shown in Figure 8. Economic loss is calculated by building, contents, and inventory losses as well as business interruption costs listed in Table 3. Damage to residential structures is shown in Figure 9. A minimum of 100 residential buildings could be substantially damaged, with approximately 600 residential buildings having at least minimal damage. Many of the

substantially damaged buildings occur in two census blocks as shown in Figure 9. Table 4 shows the range of damage by building type. The building types most affected are residential, commercial, and industrial. Approximately 1,300 buildings could have at least minor damage.

Table 4. Count of Buildings (#) by Range of Damage %

	None	1-10	11-20	21-30	31-40	41-50	Substantial	Total
Washington								
King								
Commercial	0	76	89	4	0	1	5	175
Industrial	0	227	294	23	5	3	27	579
Education	0	3	0	0	0	0	0	3
Agriculture	0	0	0	0	0	0	0	0
Religion	0	0	0	0	0	0	0	0
Government	0	1	0	0	0	0	0	1
Residential	259	19	94	235	64	102	107	880
Total	**259**	**326**	**477**	**262**	**69**	**106**	**139**	**1,638**

Figure 10 depicts random density distributions of economic loss categorized by occupancy class. Loss categories depicted include residential, industrial and commercial occupancy classes. Each dot represents $100,000 of the total occupancy loss for each census block. Industrial properties are affected most, which would be expected due to the large industrial area present. Shelter estimations are shown in Figure 11. Approximately 22,000 people will be displaced and of those approximately 21,000 will require short term shelter. Debris estimates are shown in Figure 12. Debris is calculated for building and content debris which totals approximately 208,800 tons. Debris does not include debris generated from roads and utilities.

This analysis of the King County Study produced higher damages and economic losses than Scenario 1. This was expected since Scenario 1 did not evaluate the impact of levees (or lack there of).

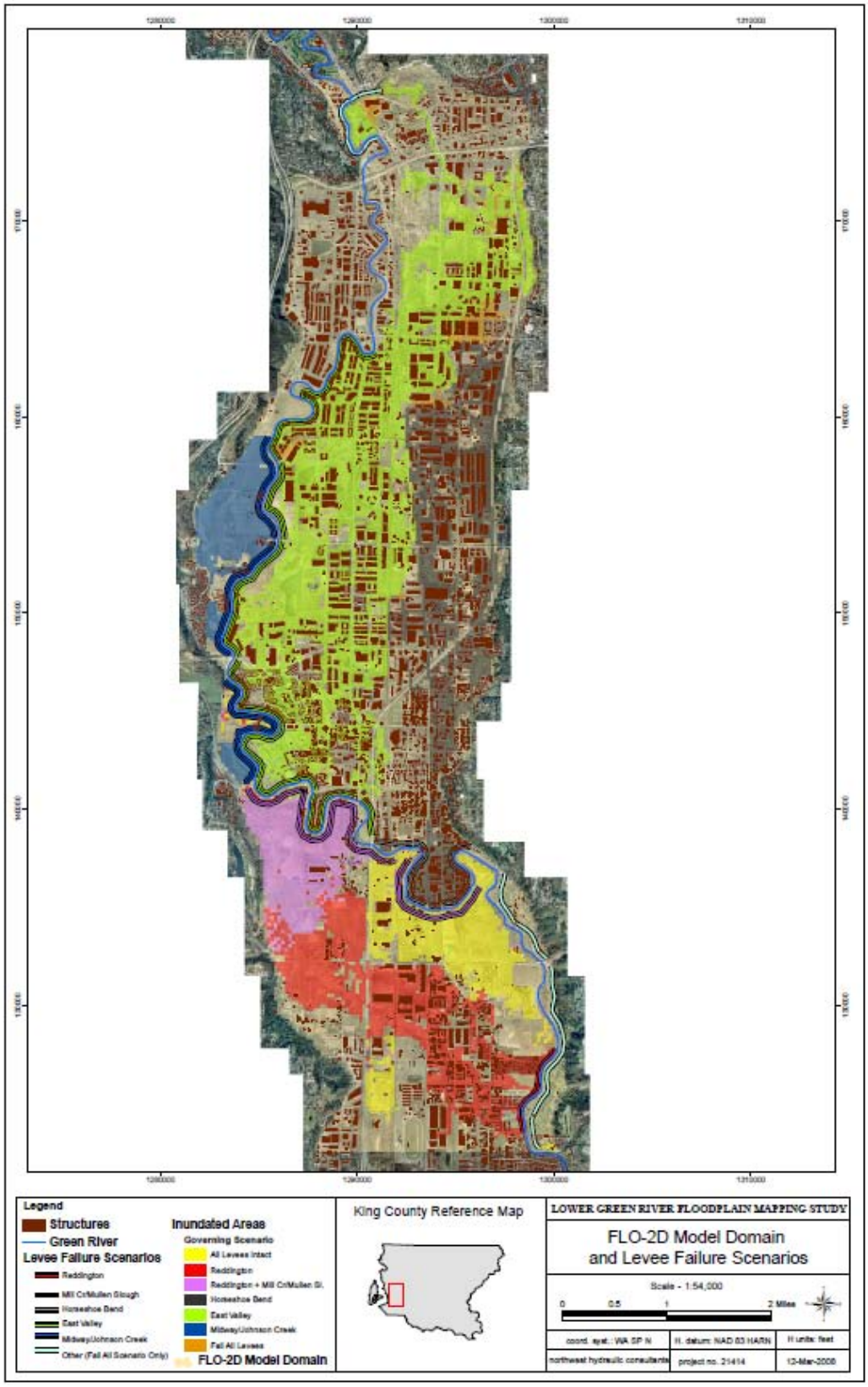

Figure 7. FLO-2D Model and Levee Failure Scenarios prepared by nhc for King County. For information see the Floodplain Mapping Study for Lower Green River by nhc (March 2008)

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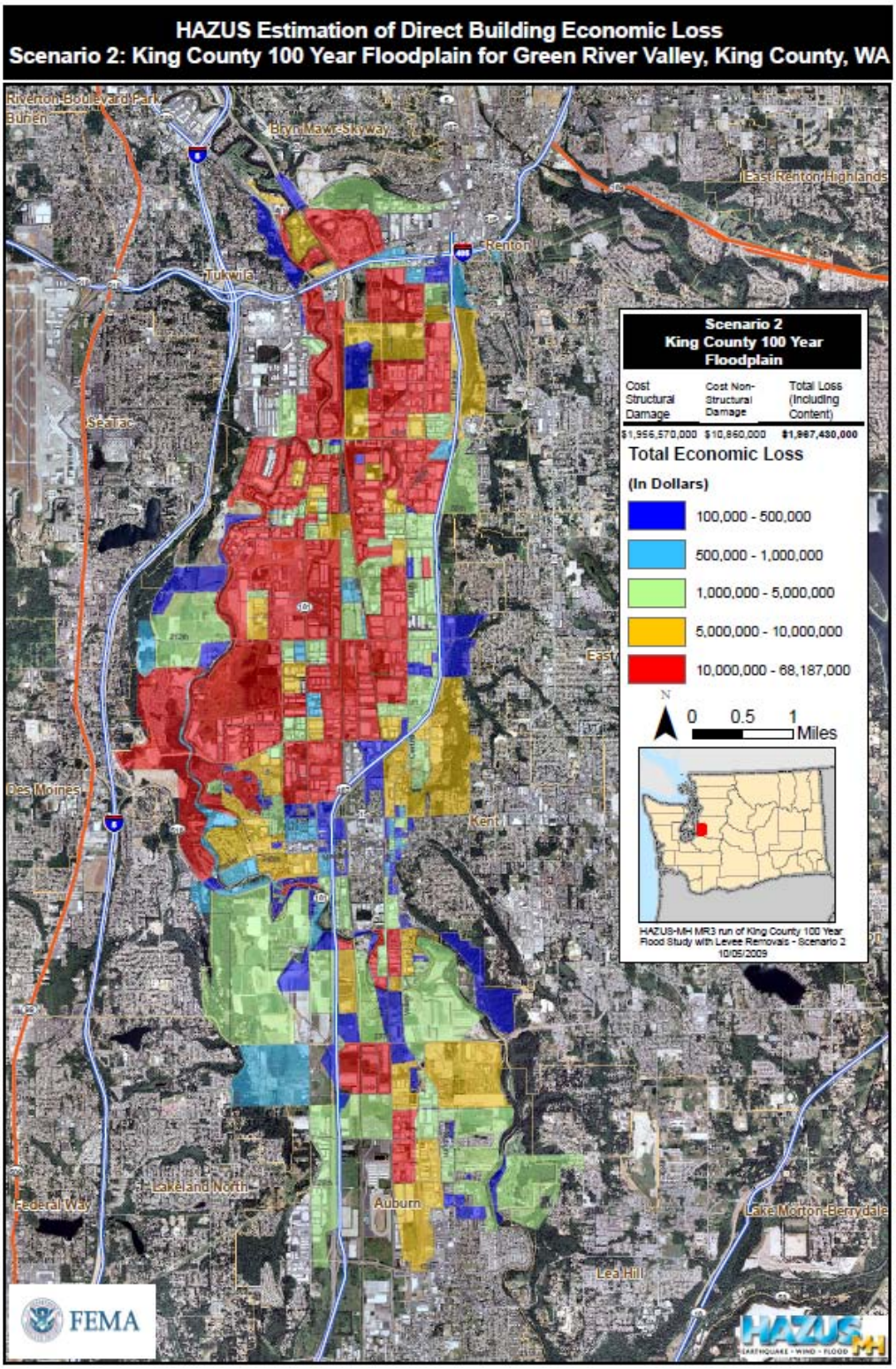

Figure 8. Total Economic Loss for the Green River valley based on the King County flood study (Scenario 2). Structural damage includes building costs, content costs, and inventory costs. Remaining non-structural costs includes business interruption costs, relocation costs etc. Total economic loss is $1.97 billion. Red areas indicate $10-68 million of economic loss for each census block. Census blocks with losses below $100,000 were not shown.

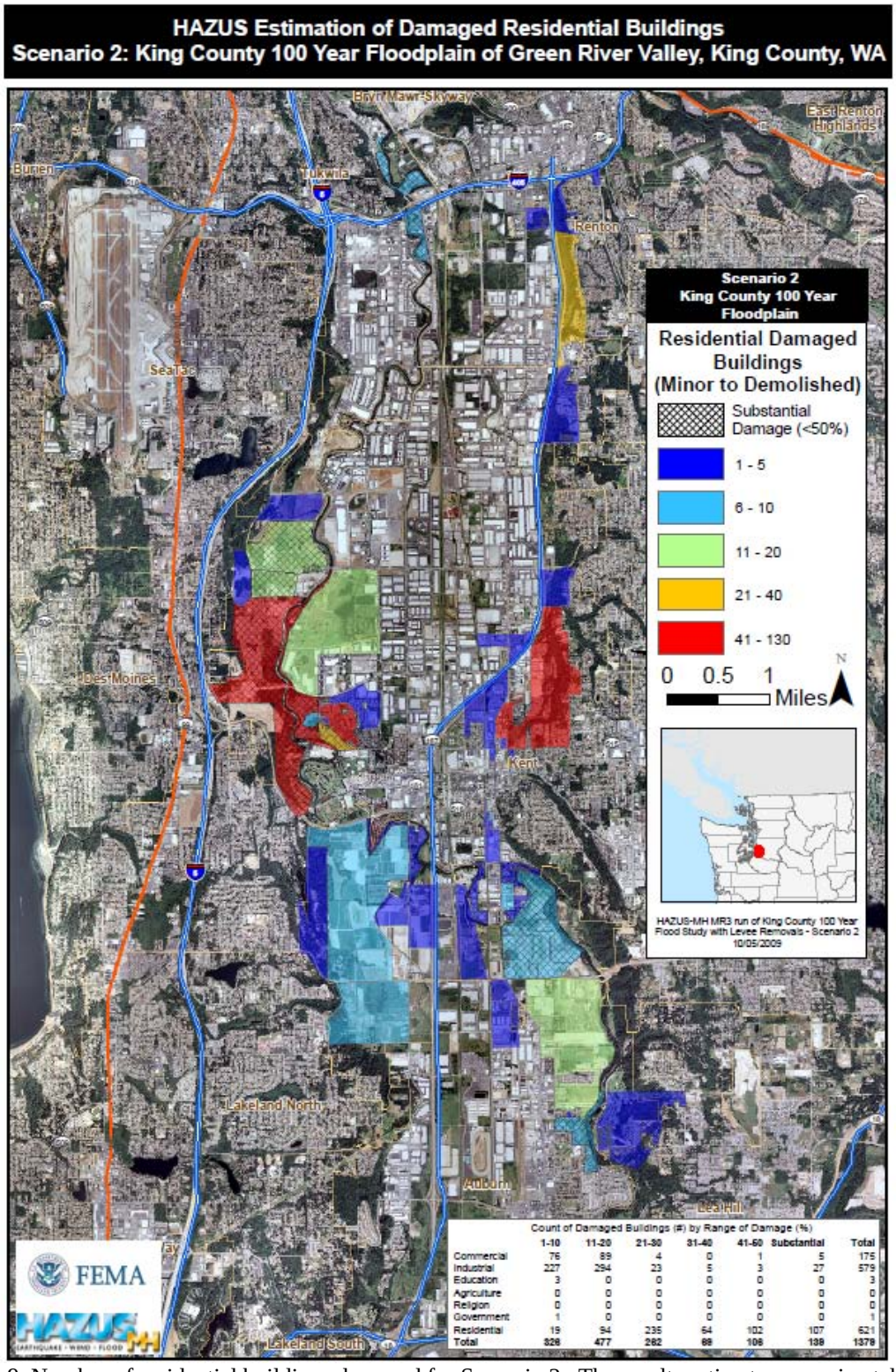

Figure 9. Number of residential buildings damaged for Scenario 2. The results estimate approximately 100 substantially damaged residential buildings and approximately 600 residential buildings with at least minor damage. Substantial damage also occurred for commercial and industrial structures. Total building damage count by building type is shown in the table.

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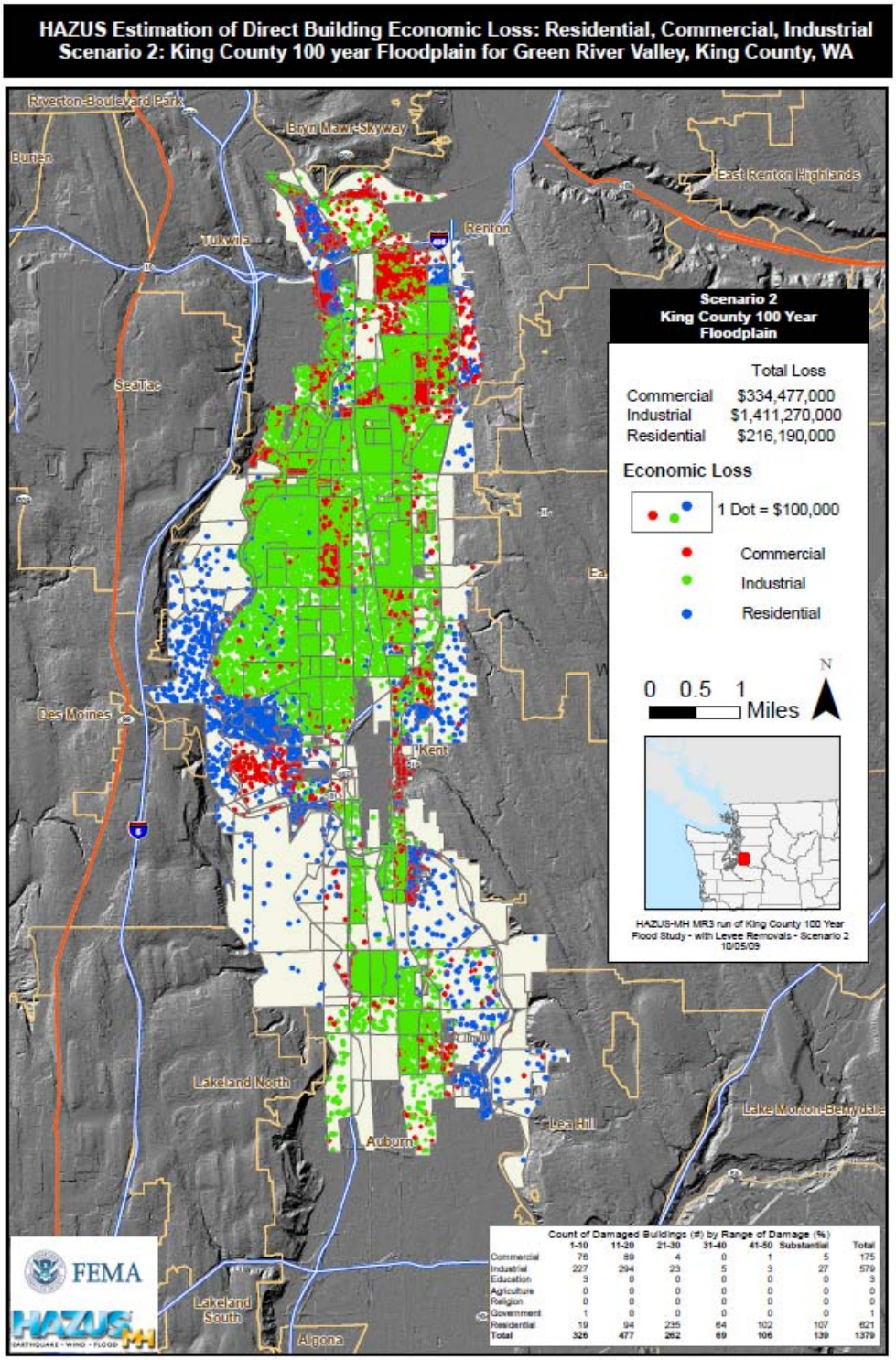

Figure 10. Random density distributions for economic loss for residential, commercial, and industrial properties for Scenario 2. Economic loss points were derived from census blocks. Points do not represent specific locations, but rather identify clusters of occupancy types (i.e. residential). Industrial buildings are affected most in this scenario.

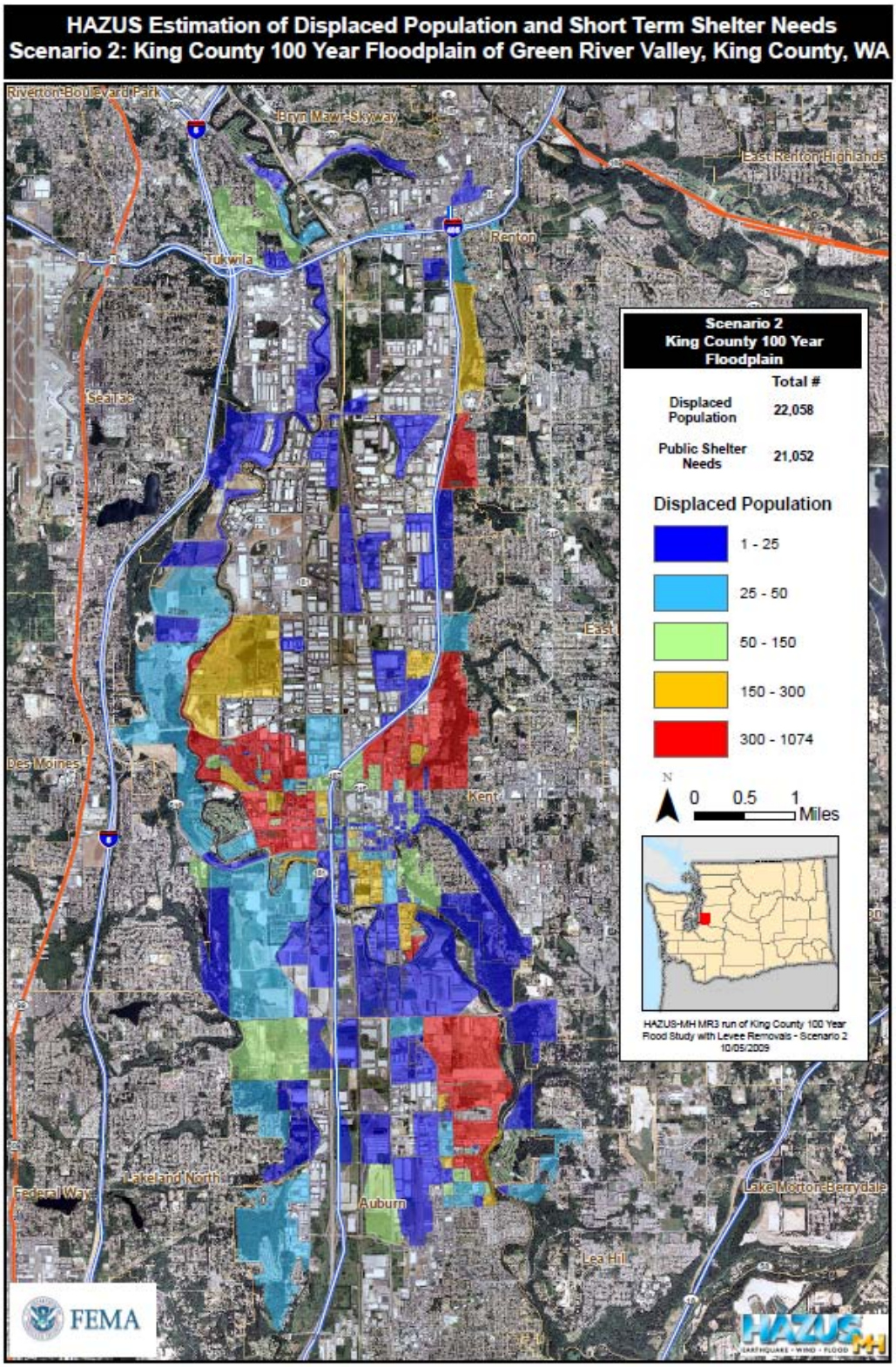

Figure 11. Displaced individuals and short term shelter needs for Scenario 2. Census blocks are mapped based on the number of displaced individuals. HAZUS estimated that 22,058 individuals will be displaced and of those 21,052 would need short term shelter.

HAZUS Disclaimer: The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant difference between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

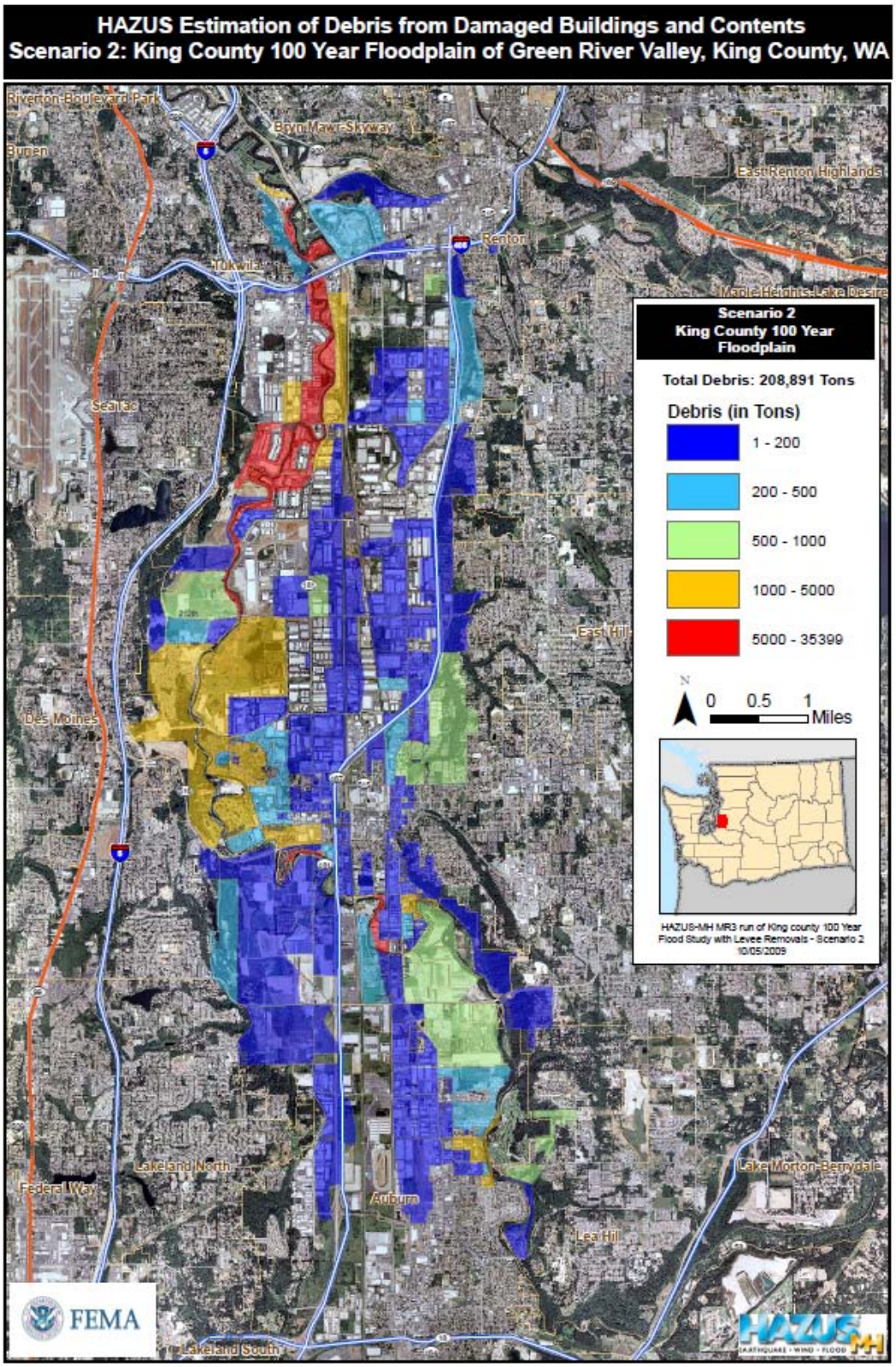

Figure 12. Debris Estimation for Scenario 2. Debris in tons is shown per census block. HAZUS calculates the estimated total debris generated for Scenario 2 to be 208,891 tons. Debris is generated from building and content debris, not from damage due to roads or utilities.

Scenario 3: USACE 17,600 cfs with Simulated Levee Removals

The final scenario combines the prior two scenarios in order to determine the increased economic losses and damage potential that exists while the Howard Hanson Dam is in disrepair. The depth grids imported into HAZUS are the result of applying the levee modeling assumptions from Scenario 2 with the water volume (17,600 cfs) used in Scenario 1. Of the three scenarios run to date, Scenario 3 is the worst case combination of high flows and levee failures run by FEMA. For comparisons, the hydraulic modeling assumptions made for both Scenarios 2 and 3 are the same. The difference is the discharge (i.e. 17,600 cfs vs. 12,800 cfs). This worst case scenario produced the largest damages and economic losses totaling $3.75 Billion (Table 5).

Table 5. Building-Related Economic Loss Estimates (in millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	197.76	296.20	475.21	8.53	977.70
	Content	146.56	516.27	1,329.50	45.93	2,038.26
	Inventory	0.00	12.78	681.50	0.07	694.35
	Subtotal	**344.32**	**825.25**	**2,486.20**	**54.53**	**3,710.31**
Business Interruption						
	Income	0.39	4.90	0.56	0.18	6.03
	Relocation	0.44	1.85	0.86	0.00	3.15
	Rental Income	1.09	1.40	0.27	0.00	2.76
	Wage	0.91	3.32	0.95	20.98	26.15
	Subtotal	**2.82**	**11.46**	**2.65**	**21.16**	**38.09**
ALL	**Total**	**347.14**	**836.72**	**2,488.85**	**75.69**	**3,748.39**

Economic loss is calculated by census block as shown in Figure 13. Economic loss is calculated by building, content, and inventory loss as well as business interruption costs listed in Table 5. Figure 14 shows economic losses above $1,000,000. Damage to residential structures is shown in Figure 15. A minimum of 130 residential buildings could be substantially damaged, with approximately 1,000 residential buildings having at least minimal damage. Many of the substantially damaged buildings occur in one census block as shown in Figure 15. Table 6 shows the range of damage by building type. The building types most affected are residential, commercial, and industrial. Approximately 2,200 buildings could have at least minor damage.

Table 6. Count of Buildings (#) by Range of Damage %

	None	1-10	11-20	21-30	31-40	41-50	Substantial	Total
Washington								
King								
Commercial	60	43	261	35	21	26	9	455
Industrial	110	56	538	133	49	21	31	938
Education	3	5	0	0	0	0	0	8
Agriculture	0	0	0	0	0	0	0	0
Religion	1	5	1	0	0	0	0	7
Government	0	5	1	0	0	0	0	6
Residential	778	37	158	442	89	184	132	1,820
Total	**952**	**151**	**959**	**610**	**159**	**231**	**172**	**3,234**
Total	**952**	**151**	**959**	**610**	**159**	**231**	**172**	**3,234**

HAZUS Disclaimer: The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant difference between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

Figure 16 depicts random density distributions of economic loss categorized by occupancy class. Loss categories depicted include residential, industrial and commercial occupancy classes. Each dot represents $100,000 of the total occupancy loss for each census block. Industrial properties are affected most, which would be expected due to the large industrial area present. Shelter estimations are shown in Figure 17. Approximately 22,000 individuals will be displaced and of those 21,000 will require short term shelter. Debris estimates are shown in Figure 18. Debris is calculated for building and content debris which totals approximately 282,300 tons. Debris does not include debris generated from roads and utilities.

This analysis used the USACE 17,600 cfs depth grid with levee removals. This scenario represents the worst case with all levees removed and a 17,600 cfs discharge at Auburn. However, storms causing greater than base flood inflows or varying dam operations for dam safety reasons could result in higher flows downstream. USACE modeled discharges for 19,500 cfs and 25,000 cfs which were not analyzed for this study. The higher discharges could result in greater damage, especially if levees fail.

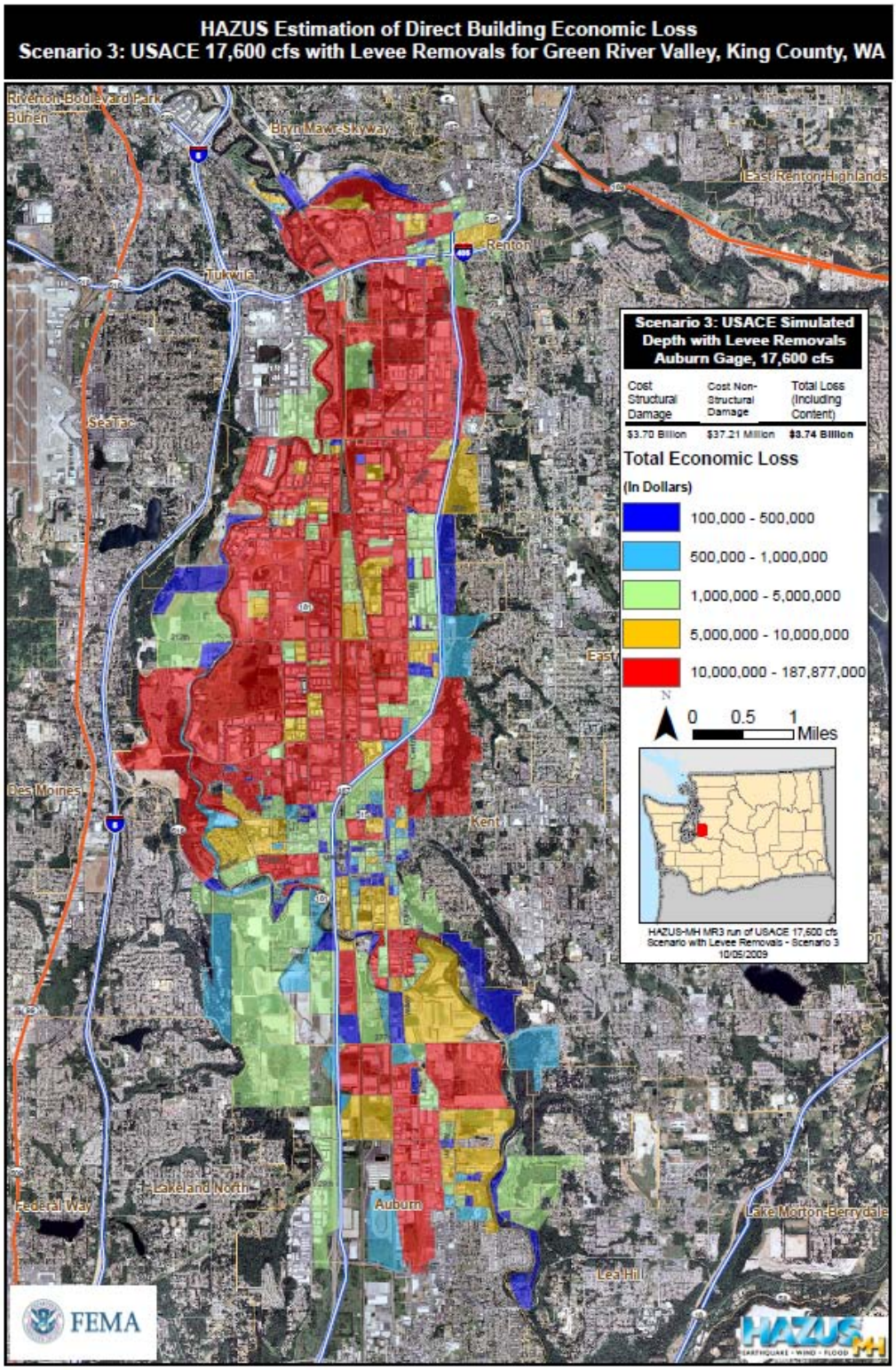

Figure 13. Total Economic Loss for the Green River valley based on the USACE 17,600 scenario with levee removals (Scenario 3). Structural Damage includes building cost, content cost, and inventory cost. Remaining non-structural cost includes business interruption costs, relocation costs etc. Total economic loss is $3.74 billion. Red areas indicate $10-187 million of economic loss for each census block. Census blocks with losses below $100,000 were not shown.

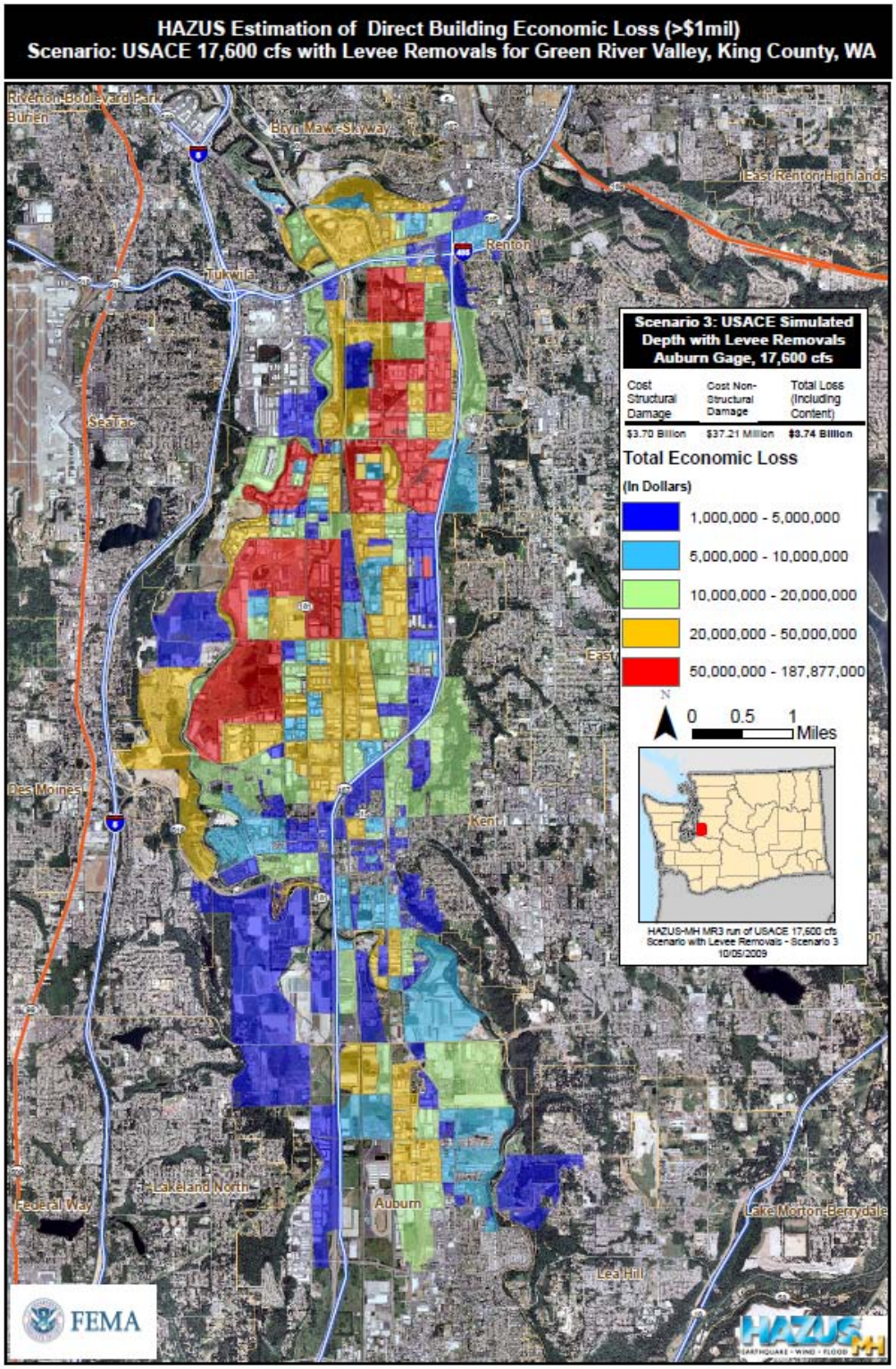

Figure 14. Total Economic Loss greater than $1 million for the Green River Valley based on the Scenario 3. Red areas indicate 50-187 million dollars of economic loss for each census block. Census blocks with losses below $1 million were not shown.

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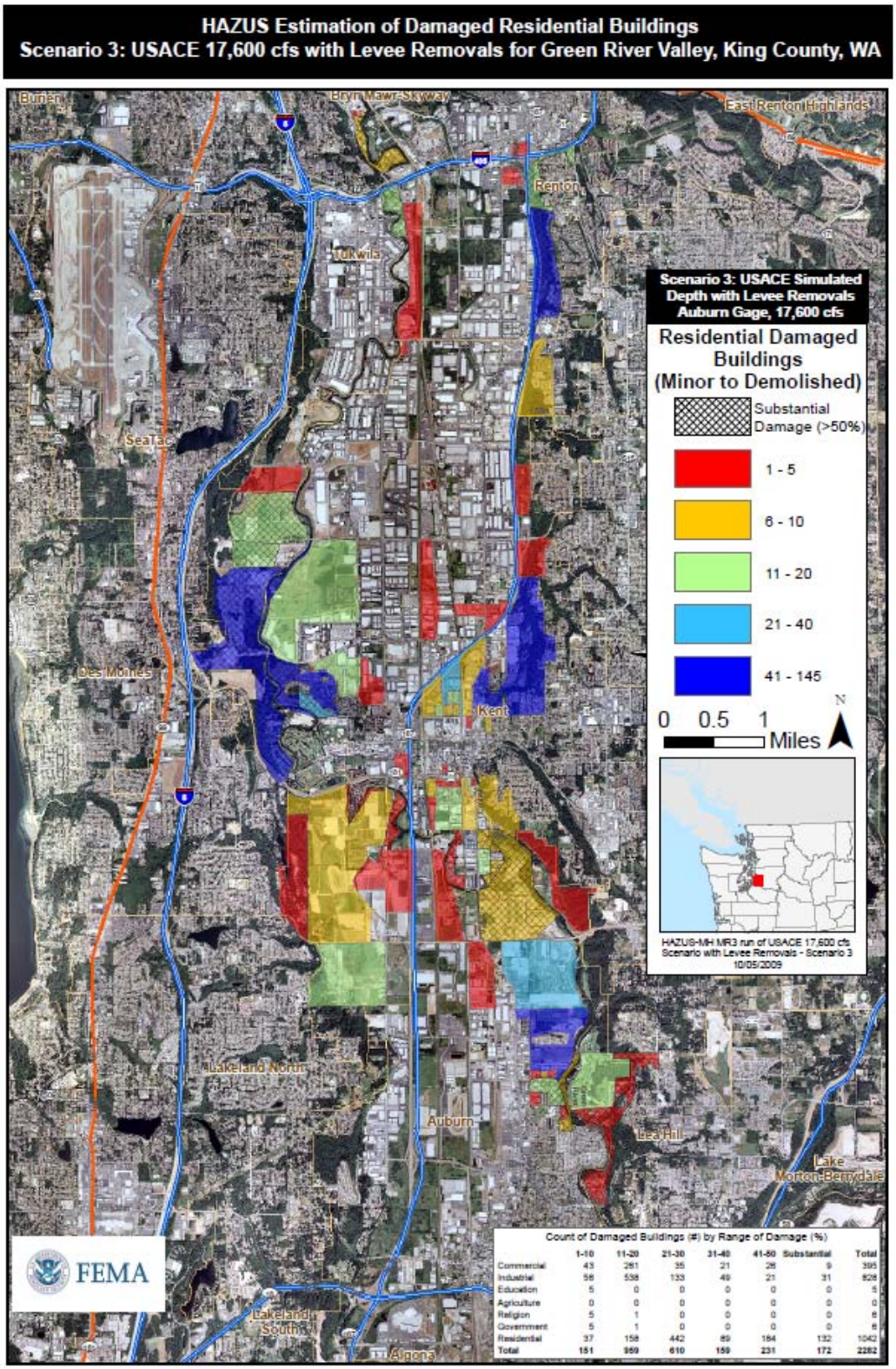

Figure 15. Number of residential buildings damaged for Scenario 3. The results estimate approximately 130 substantially damaged residential buildings and approximately 1,000 residential buildings with at least minor damage. Substantial damage also occurred for commercial and industrial structures. Total building damage count by building type is shown in the table.

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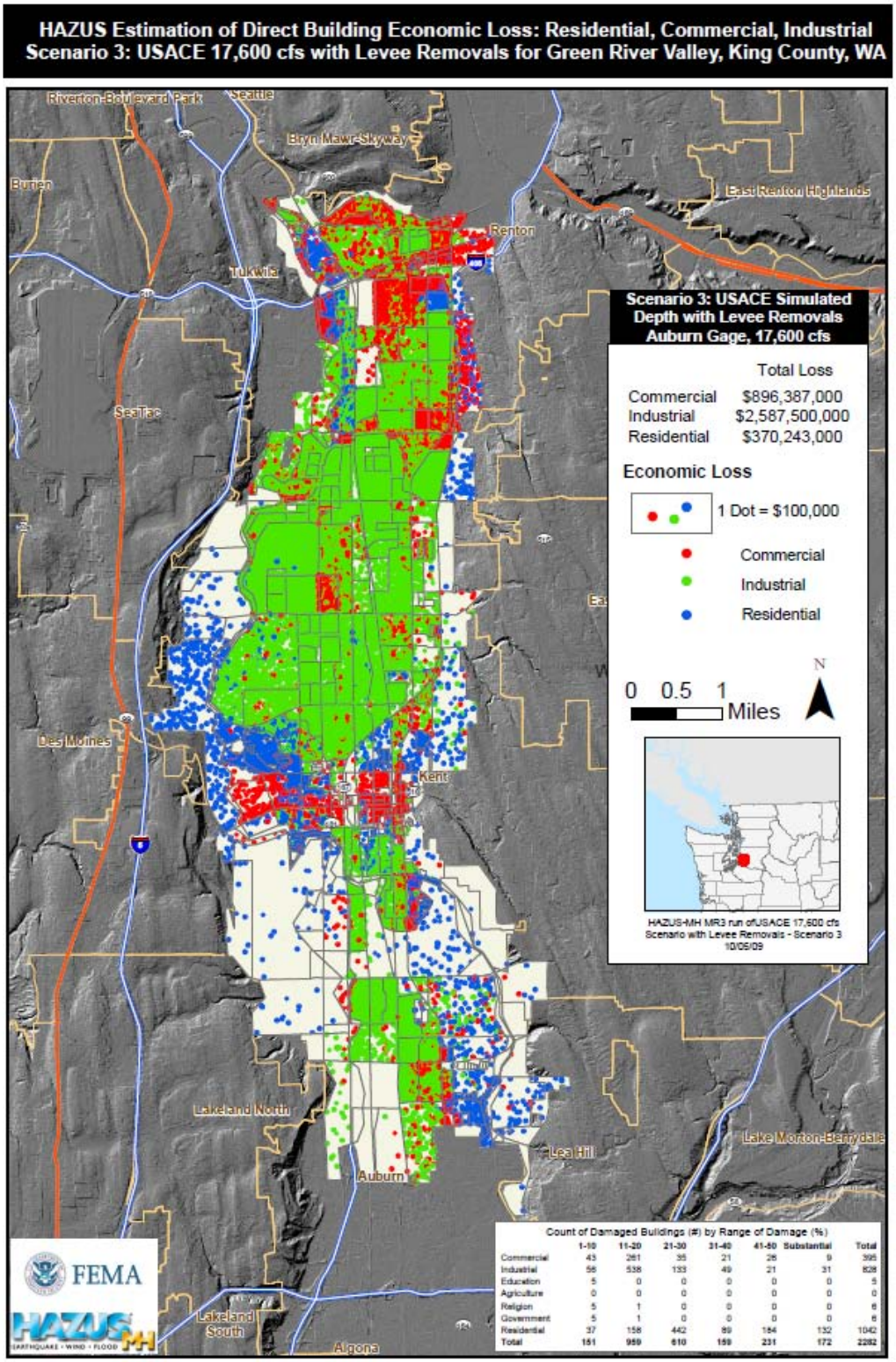

Figure 16. Random density distributions for economic loss for residential, commercial, and industrial properties for Scenario 3. Economic loss points were derived from census blocks. Points do not represent specific locations, but rather identify clusters of occupancy types (i.e. residential). Industrial buildings are affected most in this scenario.

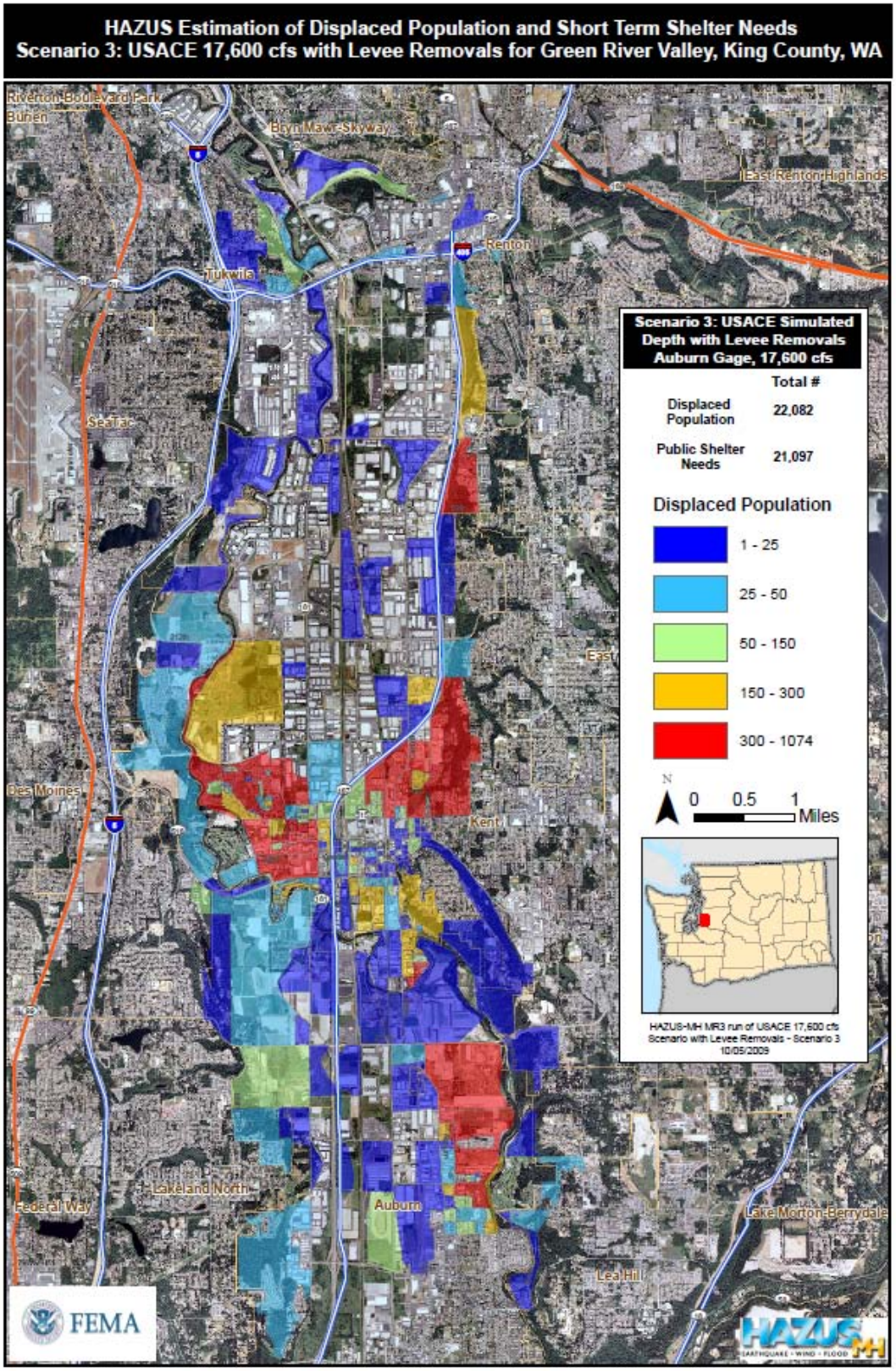

Figure 17. Displaced individuals and short term shelter needs for Scenario 3. Census blocks are mapped based on the number of displaced individuals. HAZUS estimated 22,082 individuals would be displaced and of those, 21,097 would need short term shelter.

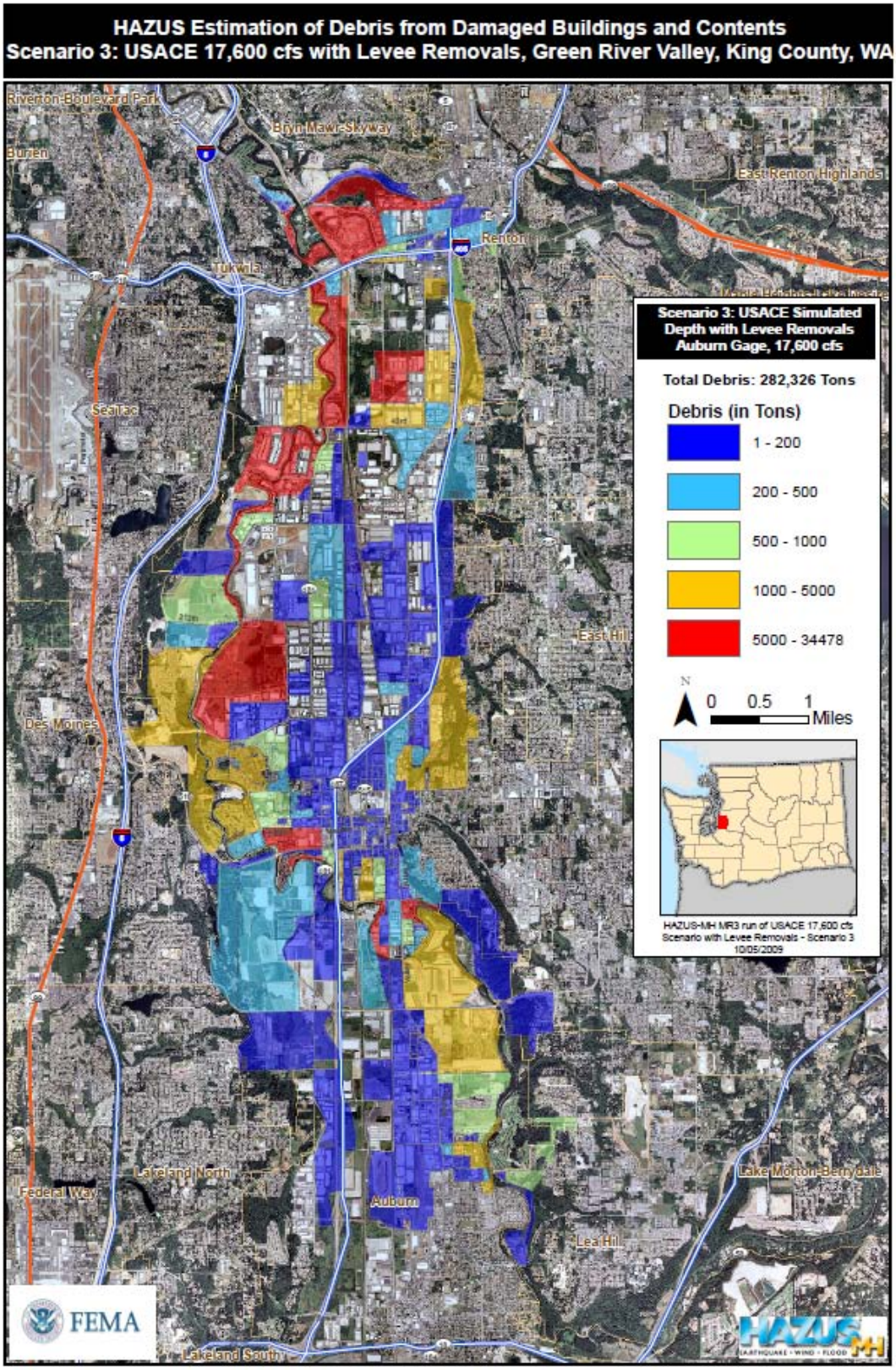

Figure 18. Debris Estimation for Scenario 3. Debris in tons is shown per census block. HAZUS calculates the estimated total debris generated for Scenario 3 to be 282,326 tons. Debris is generated from building and content debris, not from damage due to roads or utilities.

Essential Facilities

Essential facilities were provided by King County for fire and police stations, medical facilities, and schools. Essential facilities were not analyzed in HAZUS because first floor elevations were not available. Instead of a HAZUS analysis, the location of essential facilities were identified as being in a high risk zone or not, based on flood depth (Table 7). Values were obtained from parcel values, not from individual building data. Therefore the value may represent more buildings on the parcel than the essential facility. High risk is denoted with Yes or No, based on the flood depth at the essential facility. Figure 19 shows the location of all of the essential facilities.

Table 7. Essential Facilities within Flooding Extent

	Name	Address	City	Value	High Risk
Fire Stations					
	Station 51	444 Andover Park E	Tukwila	$1,343,400	N
	Station 71	504 W Crow St	Kent	$996,200	Y
	Station 76	20676 72nd Ave S	Kent	$1,594,000	Y
	Station 14	1900 Lind Ave SW	Renton	$1,176,176	Y
Police Stations					
	KC Criminal Investigation Division	401 4th Ave N	Kent	$255,600	N
	Kent Substation	20676 72nd Ave S	Kent	$1,549,000	Y
	Corrections Facility (Jail)	1230 Central Ave S	Kent	$640,545	Y
	Kent Police Headquarters	220 4th Ave S	Kent	$7,755,700	Y
	Tukwila sub-police station	641 South Center Mall	Tukwila	unknown	N
Schools					
	Kent Elementary	24700 64th Ave S	Kent	unknown	N
	St. Christopher Academy	318 3rd Ave S	Kent	$709,000	Y
	Thomas Academy	20 49th St NE	Auburn	$170,300	Y
	Cascade Middle School	1015 24th St NE	Auburn	$2,838,000	N
	Administration	300 SW 7th St	Renton	$2,215,500	Y
	Neely-O'Brien Elementary	6300 S 236th St	Kent	$2,921,100	Y
	Mill Creek Middle School	320 Central Ave N	Kent	$9,621,215	Y
Medical					
	Blood Bank	130 Andover Park E	Tukwila	unknown	Y

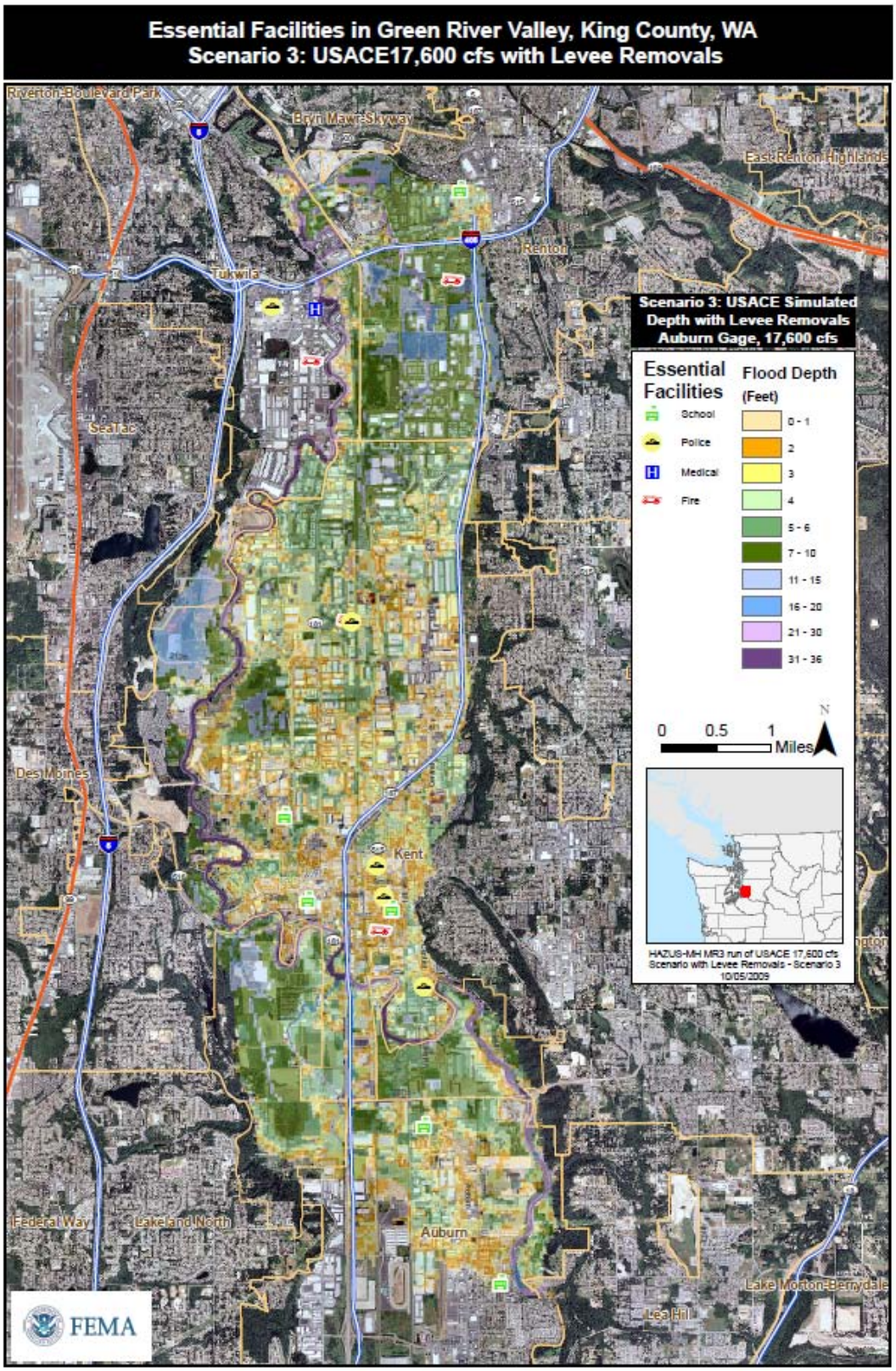

Figure 19. Essential Facilities in the Green River Valley. All essential facilities including fire, police, medical, and schools are shown. The depth grid for Scenario 3 is also shown in the background.

Depth Grid Comparison

Each scenario and corresponding depth grid, derived from FLO-2D, is shown in Figure 20. Scenario 3, which combines the higher discharges and multiple simulated levee removals, produced the largest damages in this study due to the deeper flood depths. Although the Tukwila 205 levee was not modeled by King County, the levee is only certified for a 100 year flood at a discharge of 12,800 cfs. If larger discharges were to occur, areas such as the South Center Mall could be affected in this final scenario. Direct revenue loss, primarily in the City of Tukwila, would be considerable.

Table 8 shows the total exposure values for the Green River Valley. Exposure values represent the value of the total structures (i.e. buildings), number of buildings, and the total population. These values are only for the Green River Valley, which comprise Auburn, Kent, Renton and Tukwila. Table 9 provides a comparison between each scenario including economic loss. The exposure value is calculated by the total economic loss divided by the total improvement value. In scenario 3, this would be $3.74 billion/$12.78 billion which would give an economic loss ratio of 29.3%. Therefore almost 30% of the structural improvement value would be lost. Much of this loss would occur in the large industrial warehousing areas to the east of South Center Mall (Fig. 17). In Scenario 3 approximately 22,000 people could be displaced which represents 63% of the total population (34,806 in 2000). The displaced population is believed to be much higher due to the population changes since 2000.

Table 8. Total Exposure Values for the Green River Valley

Exposure Values	Total Improvement Value	Total Buildings	Total Population
For Green River Valley	$12.78 Billion	5,134	34,806

Table 9. Scenario Comparison of HAZUS Results

Scenario	Discharge at Auburn	Total Economic Loss	Economic Loss Ratio	Substantially Damage Buildings	Displaced Population
Scenario 1 (USACE 17,600 cfs)	17,600 cfs	$1.35 Billion	10.5%	35	15,416
Scenario 2 (King County Flood Study)	12,800 cfs	$1.97 Billion	15.4%	139	22,058
Scenario 3 (17,600 cfs with simulated Levee Removals)	17,600 cfs	$3.74 Billion	29.3%	183	22,082

In addition to the depth comparison, we also created an “exceedance map” which shows the difference in water-surface elevation above the base (1% annual chance) flood (Scenario 2) and Scenario 3 (Figure 21). Again, much of the differences occur to the east of South Center Mall in the warehousing districts. Other areas show differences of 1-3 feet, which could influence building damage due to slab on grade building foundations.

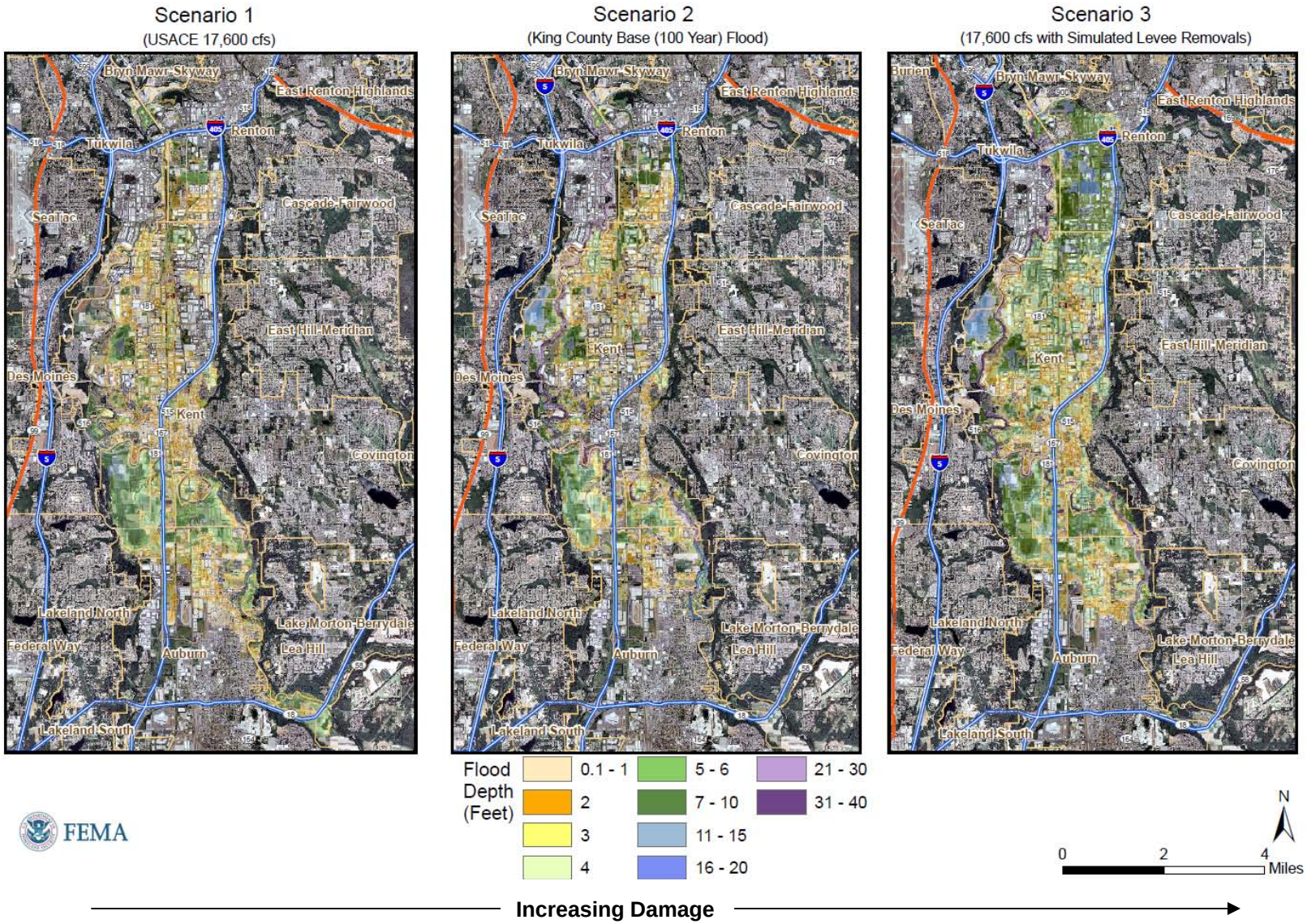

Figure 20. Depth Grids for Scenario 1 (USACE 17,600 cfs), Scenario 2 (King County base (100 year) flood study, and Scenario 3 (USACE 17,600 with simulated levee removals). Depth grids were created using FLO-2D numeric modeling. Simulated levee removal scenarios were only applied in Scenario's 2 and 3. Increasing damage is from left to right.

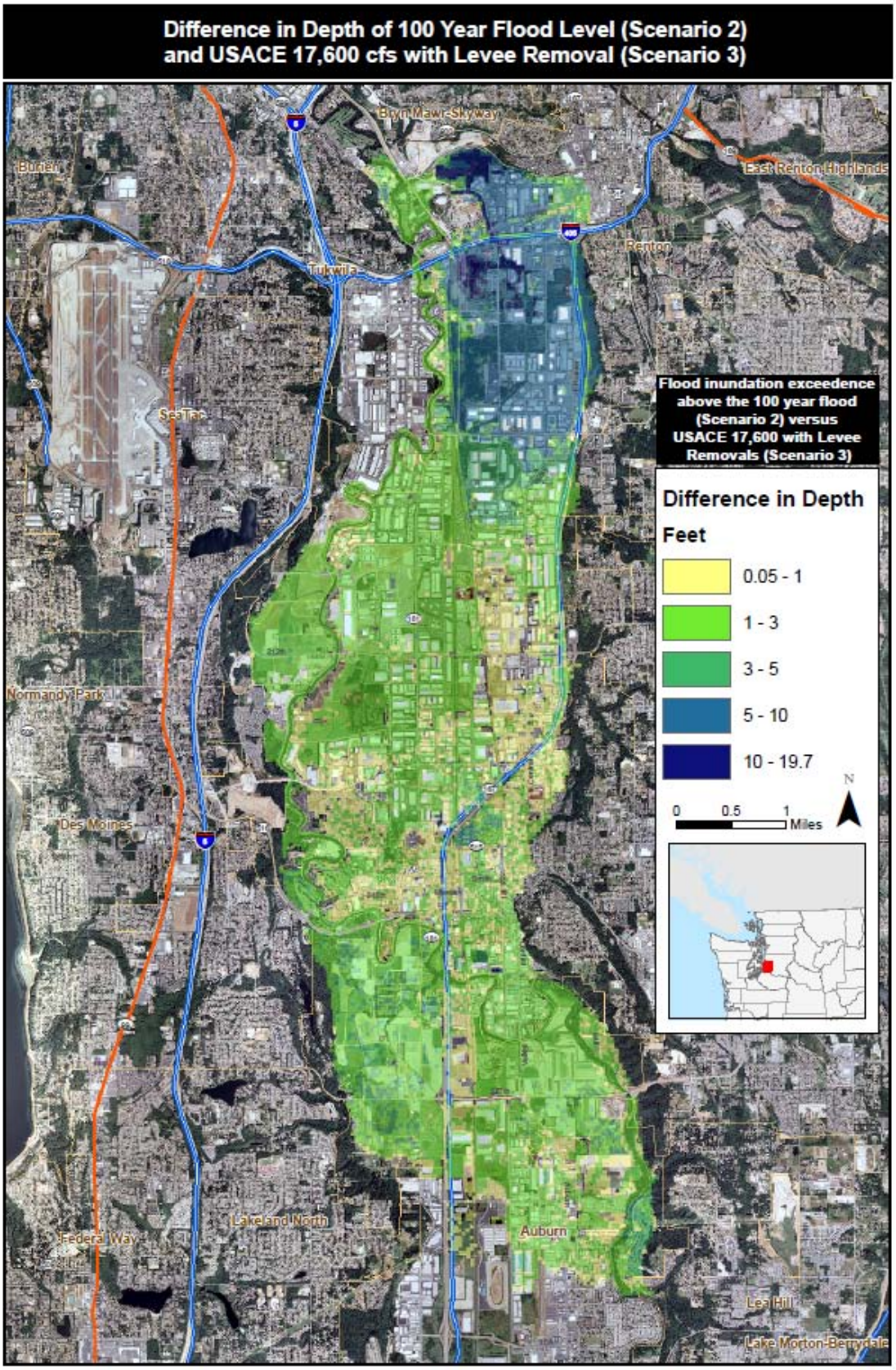

Figure 21. Exceedance map above the 100 year floodplain (King County Preliminary DFIRM) (Scenario 2) and the 17,600 cfs scenario with levee removals (Scenario3). The greatest exceedance occurs east of South Center Mall in the warehousing district. Other areas see little change of 1-3 feet.

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Summary

FEMA evaluated the impacts and effects of three different flooding scenarios occurring on the Green River using HAZUS-MH. Each scenario represents a situation whereby flooding occurs downstream of Auburn that is beyond the capability of the existing levee system. The products in this report reflect estimates of loss and damage that are likely to occur given the data modeled. There are many unknowns that could impact the actual damage figures. The selected scenarios allowed us to look at the relationships between the short term flooding potential where levees remain intact, the longer term conditions associated with the regulatory FEMA "100-year floodplain", and combination of the two conditions where the dam operation is restricted and levees are removed (to simulate levee failures). The scenarios apply the same methodology and models with varying results.

Scenario 1 is based on a depth grid provided by the United States Army Corps of Engineers (USACE) for a flow of 17,600 cfs as measured at the Auburn gauge. The key assumption in this scenario is that the levees remain intact (i.e. the channel and levees contain approximately 12,800 cfs while approximately 4,800 cfs overtops the levees and floods the overbank areas). Because a 2-dimentional unsteady model was used in the study, the model can calculate where the water is likely to go when it exceeds the leveed channel capacity. The likelihood of a flood of this magnitude depends on the allowed maximum flood pool elevation and the inflow to the dam. 17,600 cfs is a plausible flood scenario, but it is not the worst possible outcome given the variables.

Scenario 2 is based on one of the depth grids produced by the King County flood study (prepared by northwest hydraulic consultants, Inc., March 2008) which is being used by FEMA in the production of the revised Flood Insurance Study (and associated Rate Maps). The key assumptions in Scenario 2 are a base (1% annual chance) flood event with a volume of 12,800 cfs and a combination of six "with and without" levee scenarios modeled to simulate levee failure. The levee removal scenarios excluded the USACE 205 levee which is certified to provide 100 year protection. This scenario follows guidelines and specifications associated with a regulatory flood insurance study and assume that the Howard Hanson Dam is operating normally.

Scenario 3 is based on a combination of the prior two scenarios. The depth grids imported into HAZUS are the result of applying the levee modeling assumptions from Scenario 2 with the water volume (17,600 cfs) used in Scenario 1. Of the three scenarios run to date, Scenario 3 is the worst case combination of high flows and levee failures run by FEMA. However, storms causing greater than base flood inflows or varying dam operations for dam safety reasons could result in higher flows downstream. The maximum flow the USACE developed inundation depth grids for is 25,000 cfs. We did not model this possibility or the USACE 205 levee removal, since this is certified for a 100 year flood with a discharge of 12,800 cfs. In scenarios 1 and 3 this levee could be overtopped and potentially fail.

The Scenario 3 HAZUS outputs may be overly conservative because of the way levees fail in reality versus the way they are modeled (i.e. simulated removal of specified levee

segments as opposed to catastrophic failure points). A catastrophic levee failure would likely cause a different kind of damage to structures in proximity to the break than our models can show; however, we believe the methodology applied in these scenarios is scientifically sound and representative of national standards used by FEMA when conducting flood studies. Scenario 3 results most significantly impact the large warehousing districts to the east of South Center Mall. South Center Mall may still be affected (although not modeled here) due to overtopping of the sole existing "accredited" levee system protecting this area. Results from this report reveal future areas for operational response and recovery planning and may be helpful in planning for higher discharges related to the other possible reservoir pool restriction levels at Howard Hanson Dam.

Useful Links

King County Green River Revised Maps
http://www.kingcounty.gov/environment/waterandland/flooding/maps.aspx

USACE Howard Hanson Dam Information
http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=HHD&pagename=mainpage

FEMA Guidelines and Specifications for Flood Hazard Mapping Partners
http://www.fema.gov/library/viewRecord.do?id=2206

HAZUS User and Technical Manuals
http://www.fema.gov/plan/prevent/hazus/hz_manuals.shtm

Acknowledgments

We would like to acknowledge several departments that helped make this study possible. Thank you to King County Emergency Management, King County River and Floodplain Management Section, USACE Seattle District, Washington Emergency Management Division, Cities of Tukwila, Kent, Renton, and Auburn, and FEMA Region X staff, especially the GIS Section.

Appendix

A. Data Calculations

King County GIS Standard Data (April 2009) was used for this study. The GIS data was formatted to be used in HAZUS-MH MR3. Much of the data was already given such as square footage and improvement value, but other values had to be determined from existing data or from assumptions. The tables, fields, and calculations are shown below as well as the assumptions.

Table	**Fields Used**	Description
property_parcel_area	PIN	All joins were based on the PIN field
property_resbldg_etra	SQFTTOTLIVING SQFTFINBASEMENT SQFTGARAGEATTACHED	The total square footage= living + finished basement + attached garage. If no value was given the average improvement value/square footage was found to be 95.4 and was multiplied by the square footage to determine an improvement value.
property_commbldg_extra	BLDGNETSQFT	The net building square footage was chosen for the total square footage.
property_rpacct_maxbillyr_view	TAXABLEIMPSVAL	The taxable improvement value was chosen as the replacement value in HAZUS. This value was used for the residential, commercial, and condo properties. The improvement value was divided by 1000 prior to input into HAZUS. This is the format needed for HAZUS.
property_condocomplex_extr	NBRUNITS, AVGUNITSIZE	The average unit size was multiplied by the number of units in each building to determine the total square footage per building. If no value was given for the total improvement value the residential average of 95.4 was multiplied to obtain the total improvement value.
property_parcel_extra	PRESENTUSE	Present use was given for every parcel. This was used to determine HAZUS zoning/land use codes. Table is below.

HAZUS uses specified values for land use/zoning. Each present use, given for every parcel, was used to determine the appropriate HAZUS land use/zoning code. The present use and HAZUS codes are shown below.

Present Use	HAZUS_CODE
Single Family(Res Use/Zone)	RES1
Duplex	RES3
Triplex	RES3B
4-Plex	RES3B
Single Family(C/I Zone)	RES1
Houseboat	RES1
Mobile Home	RES2
Single Family(C/I Use)	RES1
Apartment	RES3E
Apartment(Mixed Use)	RES3E
Apartment(Co-op)	RES3E
Apartment(Subsidized)	RES3E
Condominium(Residential)	RES3C
Condominium(Mixed Use)	RES3C
Townhouse Plat	RES3C
Mobile Home Park	RES2
Condominium(M Home Pk)	RES2
Retirement Facility	RES6
Hotel/Motel	RES4
Rehabilitation Center	RES4
Residence Hall/Dorm	RES5
Group Home	RES4
Resort/Lodge/Retreat	RES4
Nursing Home	RES6
Shopping Ctr(Nghbrhood)	COM1
Shopping Ctr(Community)	COM1
Shopping Ctr(Regional)	COM1
Shopping Ctr(Maj Retail)	COM1
Shopping Ctr(Specialty)	COM1
Retail(Line/Strip)	COM1
Retail Store	COM1
Retail(Big Box)	COM1
Retail(Discount)	COM1
Office Building	COM4
Office Park	COM4
Medical/Dental Office	COM7
Condominium(Office)	COM4
Farm	AGR1
Greenhse/Nrsry/Hort Srvc	COM1
Mining/Quarry/Ore Processing	IND4
Bowling Alley	COM8
Campground	RES4
Driving Range	COM8
Golf Course	COM8
Health Club	COM8
Marina	COM10
Movie Theater	COM9
Ski Area	COM8
Skating Rink(Ice/Roller)	COM8
Sport Facility	COM8

Present Use	HAZUS_CODE
Parking(Assoc)	COM10
Auditorium//Assembly Bldg	COM9
Auto Showroom and Lot	COM1
Bank	COM5
Car Wash	COM1
Church/Welfare/Relig Srvc	REL1
Club	COM8
Conv Store without Gas	COM1
Conv Store with Gas	COM1
Restaurant(Fast Food)	COM1
Governmental Service	GOV1
Hospital	COM6
Parking(Commercial Lot)	COM10
Parking(Garage)	COM10
Restaurant/Lounge	COM1
School(Public)	EDU1
School(Private)	EDU1
Service Station	COM3
Tavern/Lounge	COM1
Post Office/Post Service	GOV1
Vet/Animal Control Srvc	COM7
Grocery Store	COM1
Daycare Center	RES4
Mini Lube	COM3
Warehouse	IND1
High Tech/High Flex	IND5
Industrial Park	IND1
Service Building	COM3
Industrial(Gen Purpose)	IND1
Industrial(Heavy)	IND1
Industrial(Lignt)	IND2
Air Terminal and Hangers	COM10
Mini Warehouse	IND1
Terminal(Rail)	COM1
Terminal(Marine/Comm Fish)	COM1
Terminal(Grain)	AGR1
Terminal(Auto/Bus/Other)	COM1
Utility, Public	COM4
Utility, Private(Radio/T.V.)	COM4
Terminal(Marine)	COM1
Historic Prop(Residence)	RES1
Historic Prop(Office)	COM1
Historic Prop(Retail)	COM1
Historic Prop(Eat/Drink)	COM1
Historic Prop(Loft/Warehse)	IND1
Historic Prop(Rec/Entertain)	COM8
Bed & Breakfast	RES4
Rooming House	RES4
Fraternity/Sorority House	RES5
Art Gallery/Museum/Soc Srvc	COM8

Once the building/parcel data was formatted correctly the data was aggregated by census block. Therefore every census block has a building count, square footage, and total improvement value for every HAZUS zoning class. This data was ultimately put into CDMS and updated in the statewide database.

Essential Facilities

Essential facilities included fire and police stations, medical facilities, and schools which were point data. Each essential facility had a parcel number which was joined in the same process as the parcels shown above. The essential facilities did not match up completely with the PIN field. Therefore some essential facilities were not included. To completely update the King County essential facilities more analysis would have to be done to determine the appropriate location of the essential facility and the correct parcel number. Some properties did not have an improvement value. This was fixed by determining the improvement value/square footage, as done previously, and was multiplied by the square footage to estimate an improvement value. The values used are shown below:

Schools	142.45
Police	343.64
Medical	389.74

Fire stations completely matched using the PIN. These estimates are only for a few of the essential facilities, many of the records did have improvement values.

B. Levee Removal Scenarios

Individual levee removal scenarios from the 100 Year flood study (Scenario 2) are shown below (Figures A.1-A.5). The affected levee is highlighted with the corresponding depth grid. All of the individual levee removal scenarios were combined to create the King County 100 year flood study (Scenario 2).

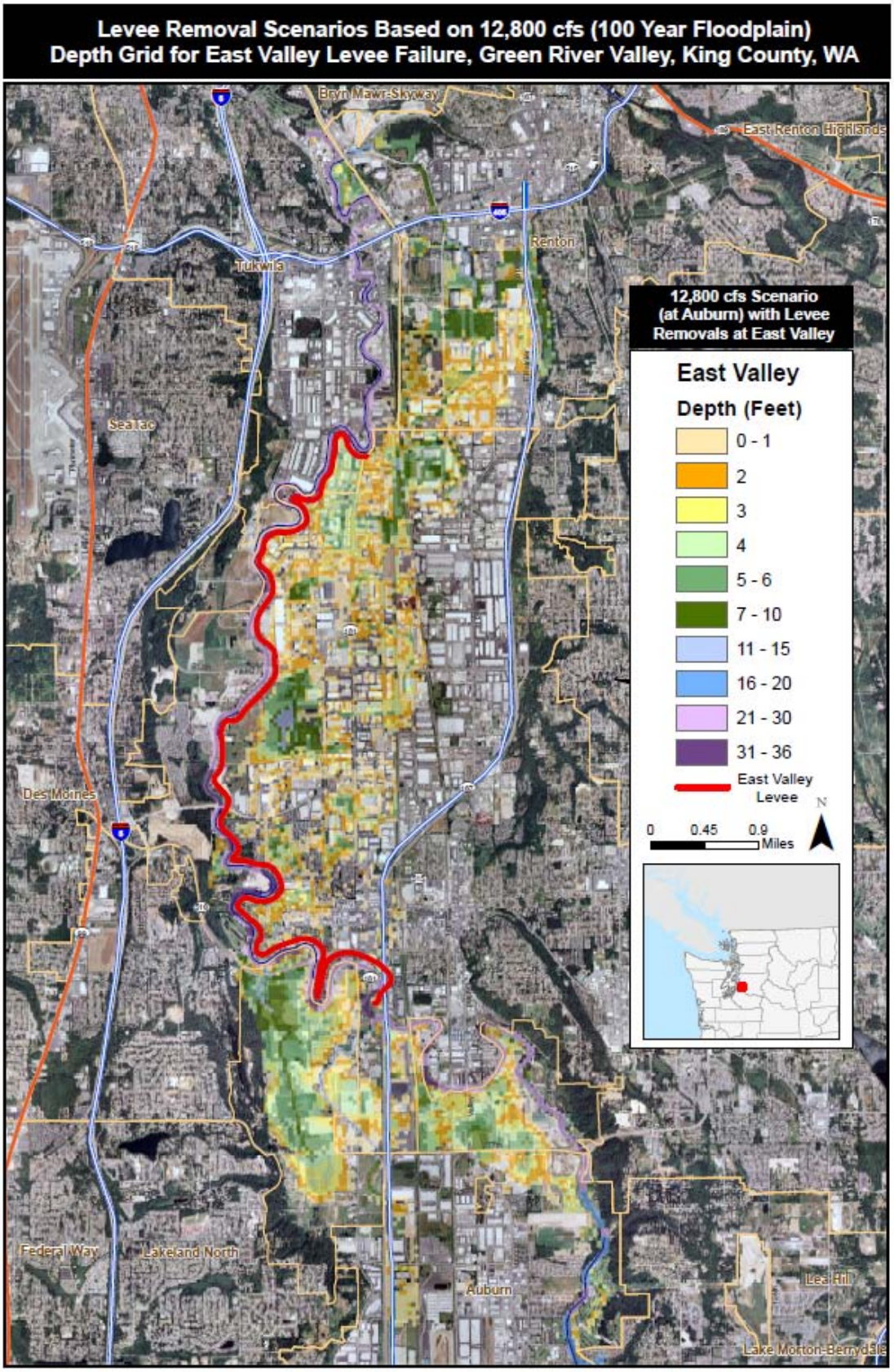

Figure A.1. Levee Removal Scenario for East Valley Levee. Removal of the East Valley Levee produces the corresponding depth grid, with much of the area being inundated with 1-10 feet of water.

HAZUS Disclaimer: The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant difference between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

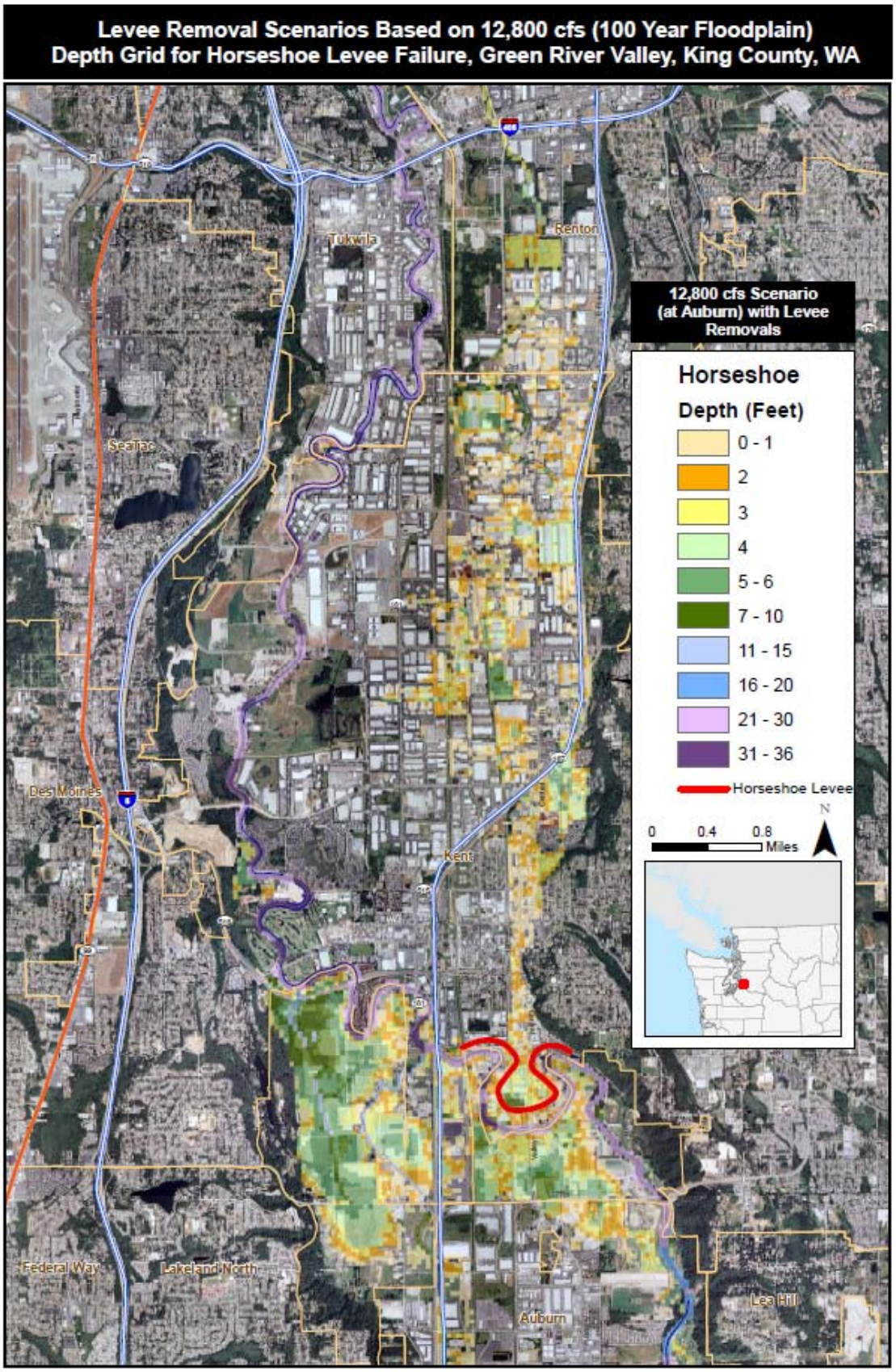

Figure A.2. Levee Removal Scenario for Horseshoe Levee. Removal of the Horseshoe Levee produces the corresponding depth grid, with much of the area being inundated with 1-10 feet of water.

HAZUS Disclaimer: The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant difference between the modeled results contained in this report and the actual social and economic losses following a specific flood. These results can be improved by using enhanced inventory data and flood hazard information.

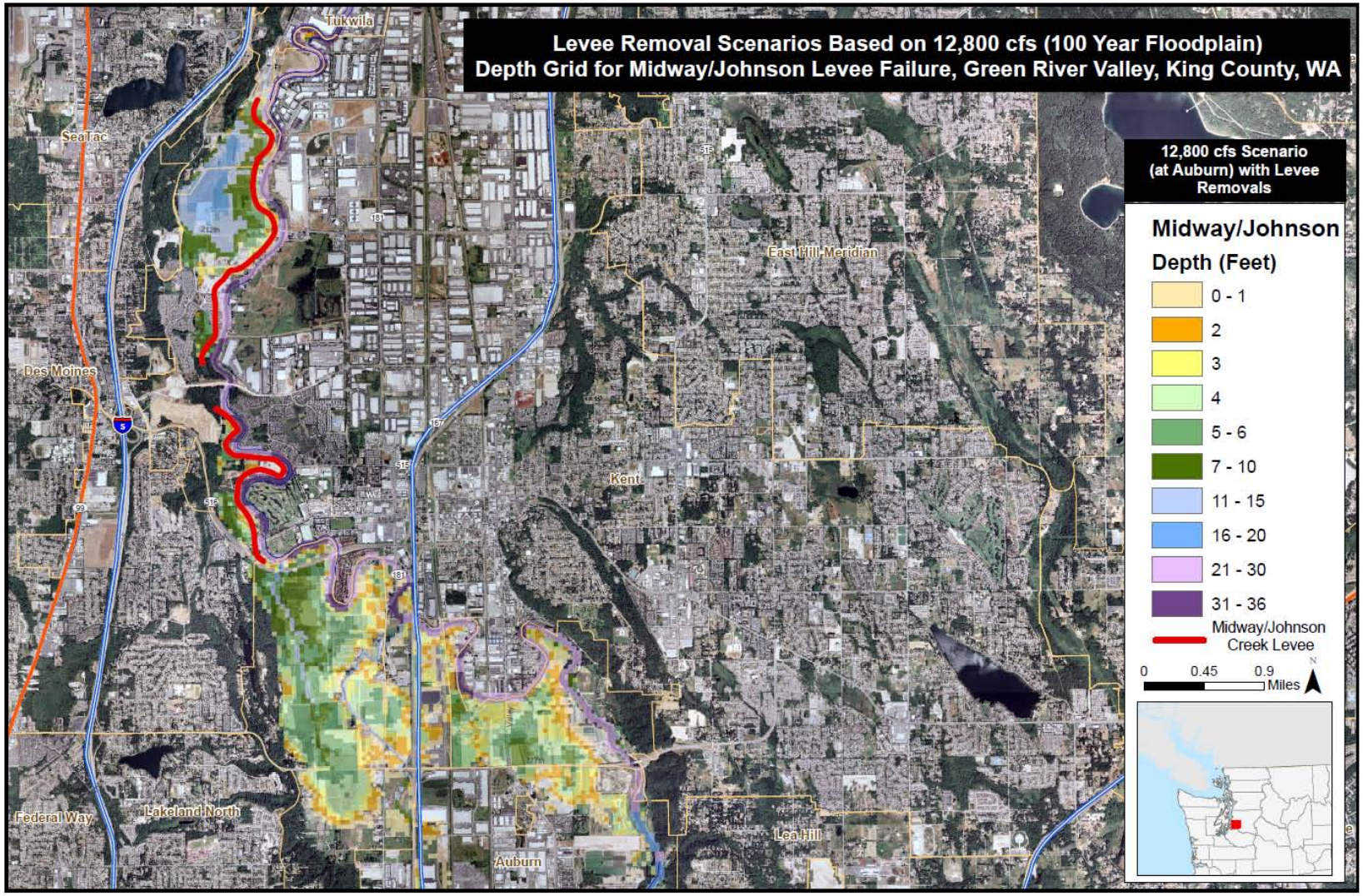

Figure A.3. Levee Removal Scenario for Midway/Johnson Levee. Removal of the Midway/Johnson Levee produces the corresponding depth grid, with much of the area being inundated with 1-10 feet of water.

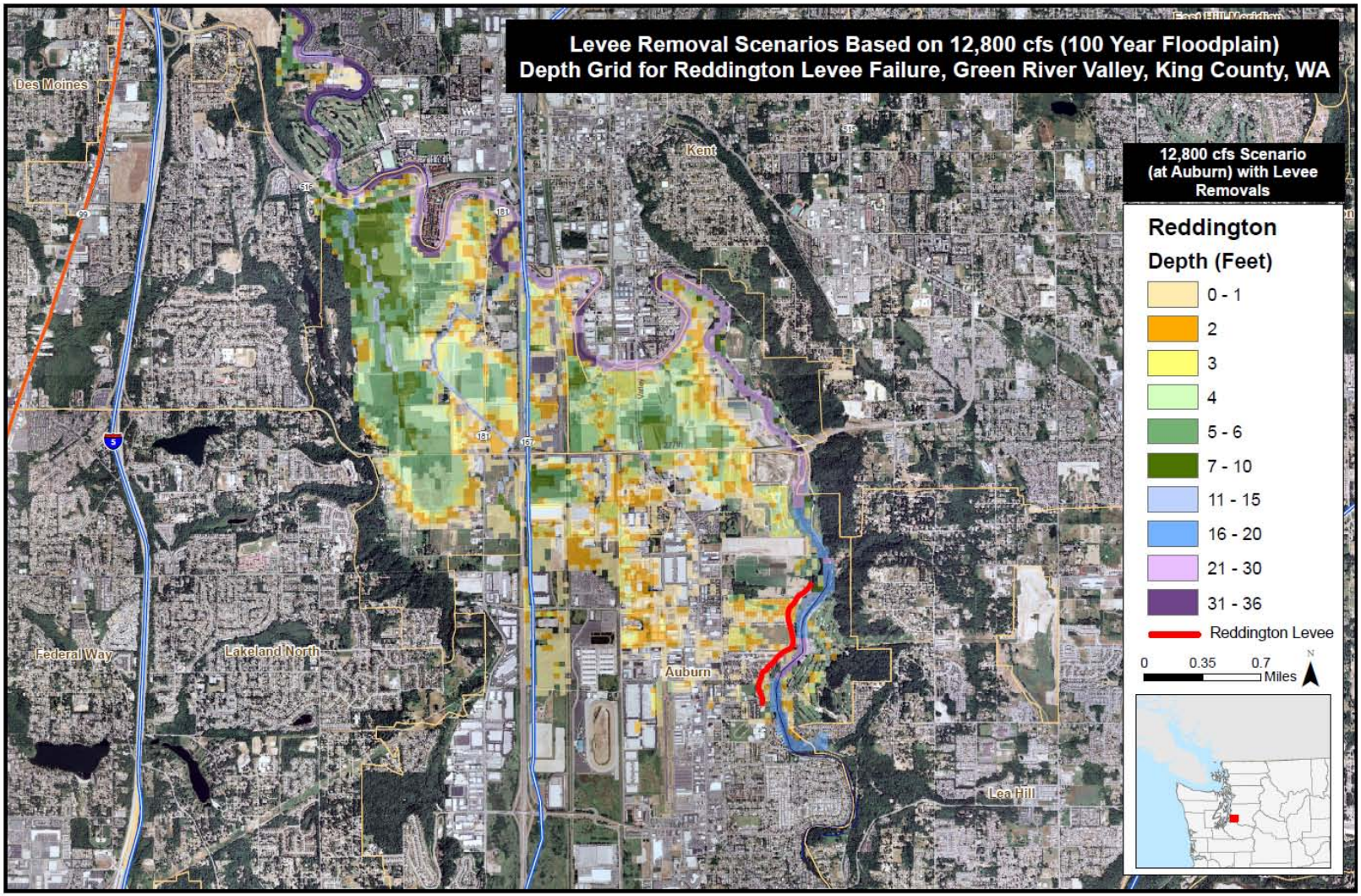

Figure A.4. Levee Removal Scenario for Reddington Levee. Removal of the Reddington Levee produces the corresponding depth grid, with much of the area being inundated with 1-10 feet of water.

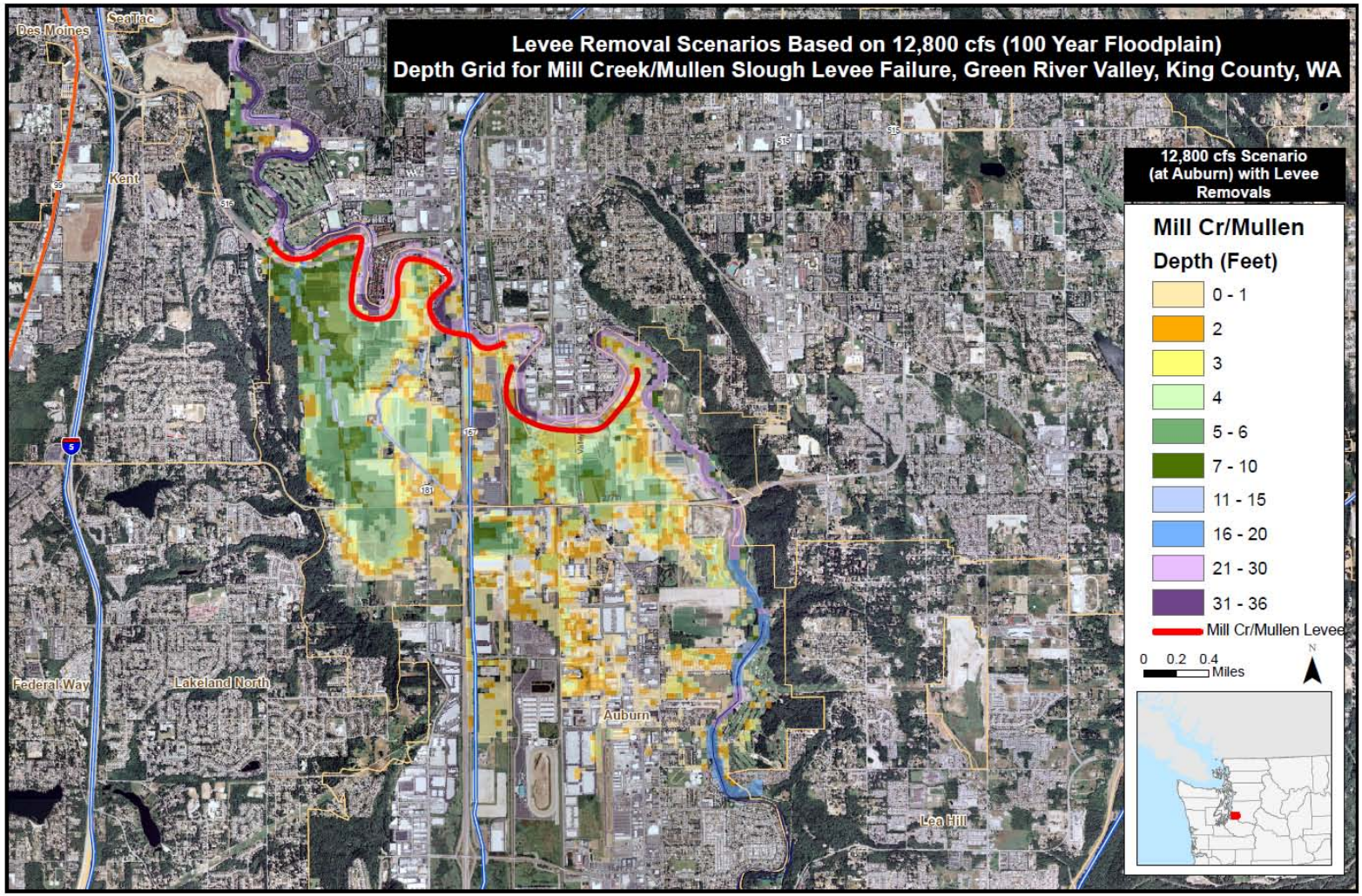

Figure A.5. Levee Removal Scenario for Mill Creek/Mullen Slough Levee. Removal of the Mill Creek/Mullen Slough Levee produces the corresponding depth grid, with much of the area being inundated with 1-10 feet of water.

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