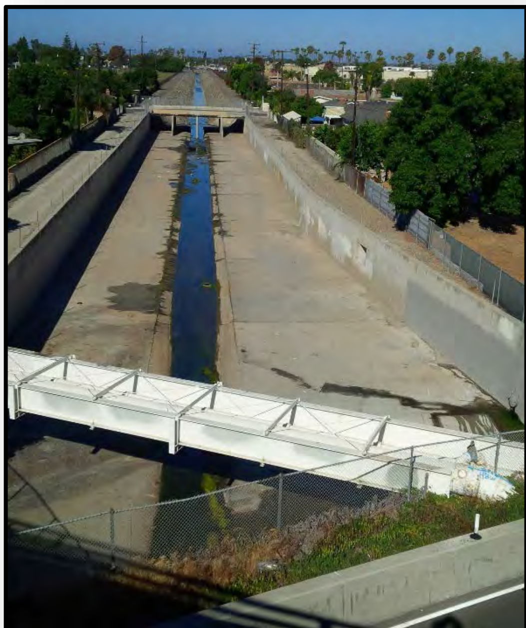
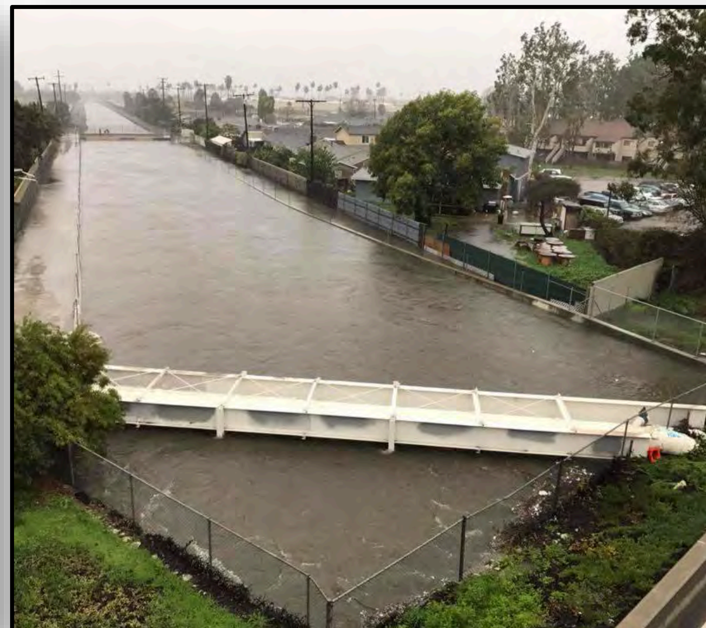
APPENDIX E - ECONOMICS

For

WESTMINSTER, EAST GARDEN GROVE

FLOOD RISK MANAGEMENT STUDY





October 2018

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Economic Appendix

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For

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FLOOD RISK MANAGEMENT STUDY

1.0 Purpose and Overview

The purpose of this economic analysis is to evaluate the benefits and costs of the recommended project to National Economic Development (NED). This analysis estimates economic benefits and costs consistent with ER 1105-2-100 *Planning Guidance Notebook* and the scope and intent of a feasibility study. This appendix details the economic methodology used to evaluate the array of alternatives for the Westminster Feasibility Study and determine the NED and Locally Preferred Plan (LPP).

The purpose of the study is to evaluate flood risk within the Westminster Watershed, taking into account the completion of channel improvements for the Santa Ana River. Portions of the study area are some of the only areas in Orange County that are at risk of inundation from a flood event with a one percent annual chance of exceedance (0.01 ACE). Under current channel (without project) conditions, nearly 400,000 people and 44,000 structures are at risk of inundation within the 0.002 ACE (500-year) floodplain. Estimated average annual damages within the 0.002 ACE exceed $107 million, including structure and structure content, auto, emergency and other associated costs, and traffic delay damages.

This study finds that at the current discount rate of 2.875 percent, the NED plan has annual net benefits of $101 million, and the LPP has annual net benefits of $86 million. The NED plan has a benefit-cost ratio (BCR) of 3.3 at a discount rate of 2.875 percent, and the LPP has a BCR of 2.2 at the current discount rate. The NED plan optimizes the scale of channel improvement measures within the flood risk system and is economically justified at both the current federal discount rate.

1.1 Problems and Opportunities

Risk of property damage and loss of life due to inundation since the 1950s has increased in the study area as a result of urbanization and continued development. The increase in the amount of infrastructure and people affected by inundation drives this increase in potential consequences and overall level of risk. Urbanization also changes the impermeable soil area, which can increase the amount of storm runoff by limiting percolation into the ground. During flood events, Pacific Coast Highway (PCH) regularly floods, which exacerbates heavy traffic along a major transportation route.

This study aims to reduce risks to property, infrastructure, and human lives by reducing the probability and severity of inundation in the floodplain area. Additionally, it aims to reduce costly delays to traffic in a densely populated area.

1.2 Methodology

Methodology used in the economic analysis described in this Appendix is in accordance with ER 1105-2-100 and a risk-based analysis in accordance with ER 1005-2-101 was conducted. Benefits were computed at Fiscal Year (FY) 2017 price levels, and were indexed to FY 2019 price levels for comparison with costs. The analysis uses the current federal discount rate for FY 2019 of 2.875 percent. The period of analysis is 50 years, with a project Base Year of 2035, and a construction period of 15 years.

1.3 Study Authority

The Westminster feasibility study is authorized by the Flood Control Act of 1936 and is being conducted in accordance with the resolution adopted by the House of Representatives Committee on Public Works on May 8, 1964 (Flood Control Act of 1938), which reads:

"Resolved by the Committee on Public Works of the House of Representatives, United States, that the Board of Engineers for Rivers and Harbors is hereby requested to review the reports on (a) San Gabriel River and Tributaries, published as House Document No. 838, 76th Congress, 3d Session; (b) Santa Ana River and Tributaries, published as House Document No. 135, 81st Congress, 1st Session; and (c) the project authorized by the Flood Control Act of 1936 for the protection of the metropolitan area in Orange County, with a view to determining the advisability of modification of the authorized projects in the interest of flood control and related purposes."

1.4 Historical Flood Events

Prior to this report, the most recent Economic Appendix for the Westminster Feasibility Study was completed in 2010. The 2010 appendix cites that significant flooding occurred in Orange County in 1825, 1862, 1914, 1916, 1938, 1969, 1983, and 1995. Since 2010, the most significant rainfall event occurred in February 2017 and closed portions of Pacific Coast Highway within the study area, but no significant structural damage was reported[1].

2.0 Study Area

2.1 Location

The Westminster feasibility study floodplain lies in Orange County, California, beginning west of Interstate-5 and continuing west until its confluence with the Pacific Ocean (see Figure 1). The study area is approximately 74 square miles and includes portions of the cities of Garden Grove, Westminster, Fountain Valley, Huntington Beach, Sunset Beach, and Seal Beach that lie within the without-project 0.002 ACE. The study floodplain is primarily a built-out, urban area, and the majority of the structures in the floodplain are residential. The 0.002 ACE floodplain also contains a significant number of public, industrial, and commercial structures, as well as public wetlands and an ecological reserve. The Westminster floodplain is susceptible to flood risk from the Santa Ana River, which is addressed by the Santa Ana River Mainstem (SARM) Project. This project is designed to reduce flood risk from the Santa Ana River and its tributaries, and reduces the risk of flooding significantly. For future with-project SARM conditions, the annual exceedance probability (AEP) is one percent in the reaches that overlap with the Westminster 0.002 ACE floodplain.

2.2 Floodplain Delineation

Figure 1 displays the 0.002 ACE floodplain and corresponding census tracts. The floodplain extends across 76 portions of, or entire census tracts within Orange County.

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[1] Taken from the OC Register February 19, 2017.

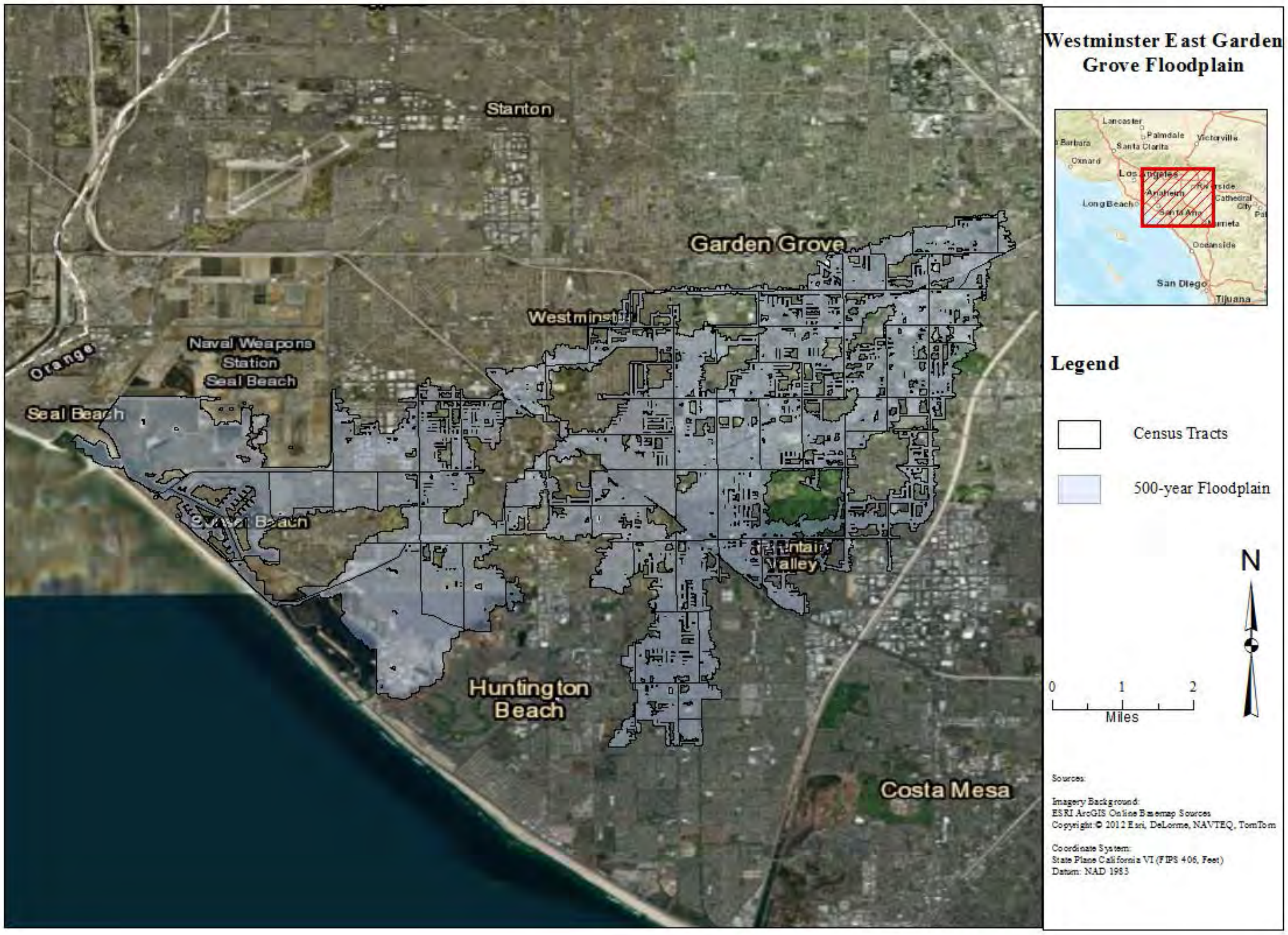

Figure 1. Westminster 500-year Floodplain

2.3 Impact Area and Reach Delineation

For the hydraulic and economic analyses, the study area is divided into four channels (C02, C04, C05, C06), and 24 economic impact areas (EIAs). Naming conventions for these impact areas differ from that of the construction reaches. Both impact areas and construction reaches are depicted in Figure 2.

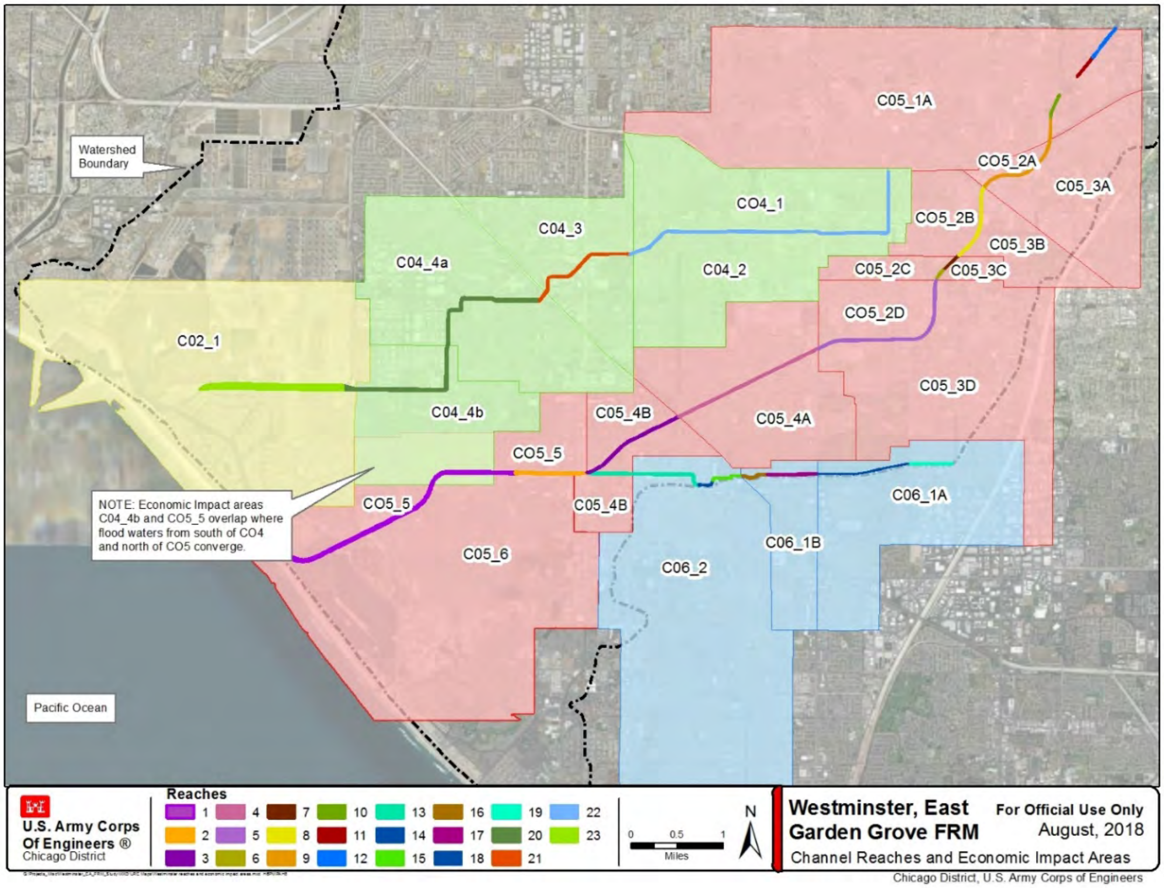

Figure 2. Westminster Watershed Impact Areas

As displayed in Figure 2, impact areas C04_4b and C05_5, used in the economic analysis, overlap within the floodplain. The methodology used to account for this overlap, and the impact it has on economic damages is discussed in Section 3. Systems C02/04 and C05/06 are not separable, given their overlapping floodplains.

The channels within the study area vary by reach in construction material and geometry. The following types of channels are found throughout the Westminster channel system:

1. Concrete rectangular channels – vertical channel walls with concrete lined sides and bottom
2. Riprap-lined trapezoidal channels – sloped channel walls that are lined with riprap and have a soft bottom
3. Concrete-lined trapezoidal channels – sloped channels that are lined with concrete and have a concrete bottom
4. Enclosed culverts – rectangular or box conduits that are not exposed at the surface
5. Leveed channels – earthen berms are located along channels in the flattest downstream extents of the watershed
6. Steel sheet pile channels – rectangular channels composed of vertical sheet pile walls with a soft bottom.

2.4 Socio-Economics

This section presents data on the socio-economic characteristics of the population within the floodplain. This data helps inform the potential impact a flood event could have on the surrounding population, and highlights the geographic location of economically vulnerable populations. Data is shown for the 0.002 ACE floodplain, and was taken from the American Community Survey (ACS) 2016 estimates on factfinder.census.gov. Because data is available at the census-tract level, estimates were calculated using entire census tracts when a portion of the census tract lies within the floodplain. Therefore, the population estimates may overestimate population at risk by a small degree.

2.4.1 Population

Figure 3 displays population density by census tract. Lighter pink areas denote a lower population density while dark red census tracts denote a higher population density. The highest population density by census tract within the floodplain corresponds with channel C05, east of I-405 and west of I-5.

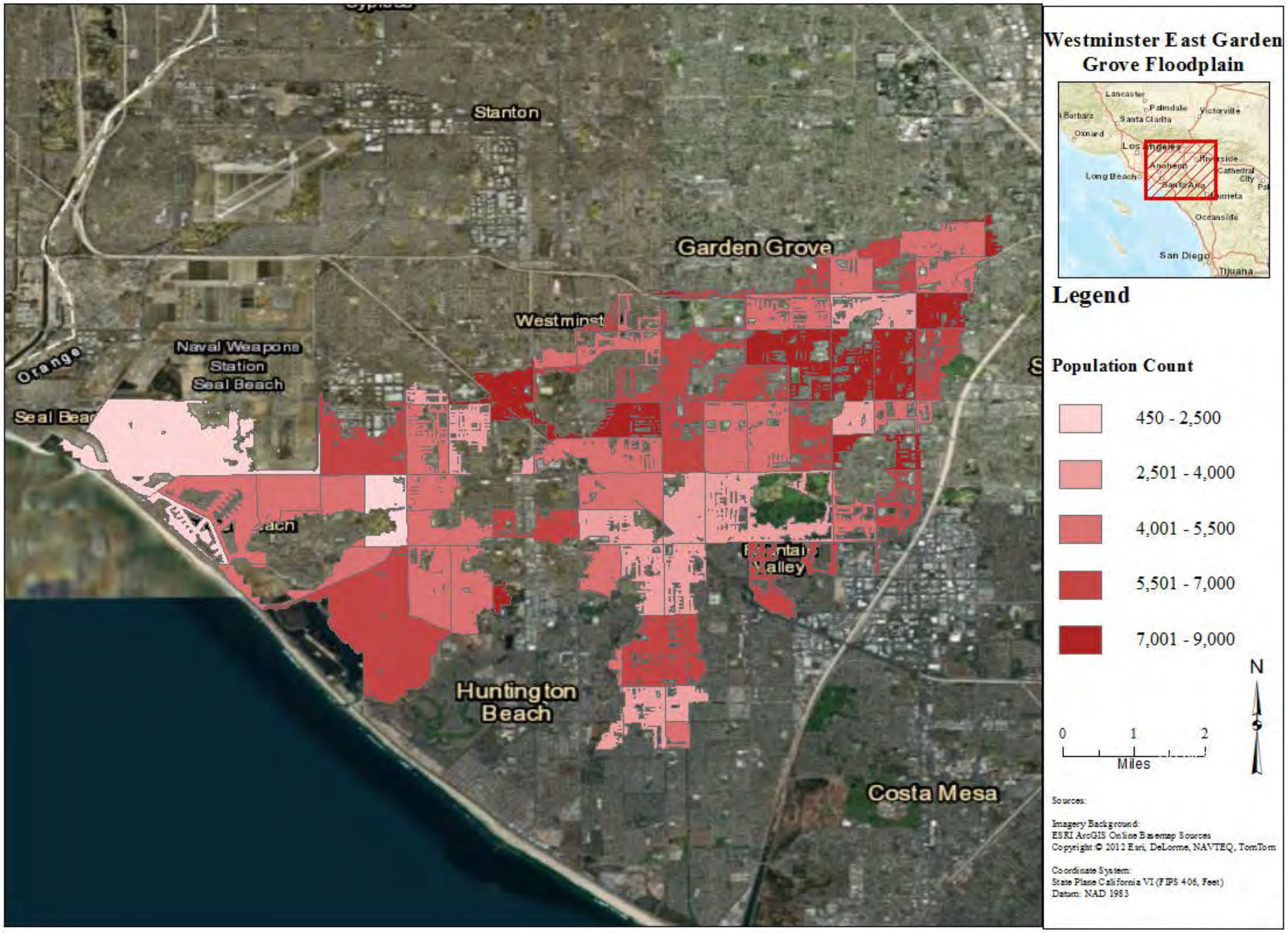

Figure 3. Floodplain Population

Table 1 presents the population count by flood channel, and the total floodplain. There are 29 census tracts in C02/04 impact areas and 63 census tracts in C05/06 impact areas. Since a portion of these EIAs overlap, some census tracts are included in both C02/04 and C05/06. The total population at risk of inundation in the 0.002 ACE floodplain is nearly 400,000, and the population above 65 years of age at risk in a flood event is nearly 60,000.

Table 1. Population by Census Tract

Location	Census Tract Count*	Population Count‡	Population above 65 years
C02-04	29	142,805	23,961
C05-06	63	341,869	47,270
Floodplain Total	76	397,393	57,315

**Some census Tracts are contained in both C02/C04 and C05/C06, so the sum of the channel counts does not equal the total count*

‡Population count includes population for entire census tracts, rather than only the portion that lies in the floodplain

2.4.2 Demographics

Poverty, financial, and housing unit characteristics help identify the vulnerability of the population in the event of a 0.002 ACE flood. The tables and figures below describe these characteristics, and include census data for the poverty count, the number of individuals who speak a language other than English, the relationship between average household size and income, and the relationship between median home value and income. All data was taken from 2016 ACS estimates found on census.gov, at the census-tract level. Statistics for census tracts where a portion of the tract lies within the floodplain are included in the tables below.

Table 2. Demographics by Study Location

Location	Poverty Count	Percent of Population below poverty line	Speaks a language other than English	Percent of Population that speaks another language
C02-04	22,026	15.4	70,648	50.4
C05-06	47,270	15.5	191,127	55.9
Floodplain Total*‡	61,499	15.5	213,654	53.8

**Some census Tracts are contained in both C02/C04 and C05/C06, so the sum of the channel counts does not equal the total count*

‡Population count includes population for the entire census tract, rather than only the portion that lies in the floodplain

Table 2 shows that over 61,000 people, or 15.5 percent of the population in the floodplain is below the poverty line. This estimate is higher than both the state poverty rate of 14.3 percent, and the national poverty level of 12.7 percent, according to 2016 census bureau data. The percent of the population in the floodplain that speaks a language other than English is 53.8 percent, while the national estimate is 19.7 percent.

The areas of the floodplain with the highest concentration of poverty can be seen in Figure 4, which shows income level by census tract, and household size. The figure shows that higher income areas tend to be closer to the coast, while lower income levels are found in census tracts located a few miles inland. Additionally, average household size tends to be higher in census tracts where the median income is lower, while household size is smaller in higher-income census tracts. The portion of the floodplain in lighter shades of blue is therefore more economically vulnerable in event of a flood, and damages to homes and property in this area would be significantly impactful.

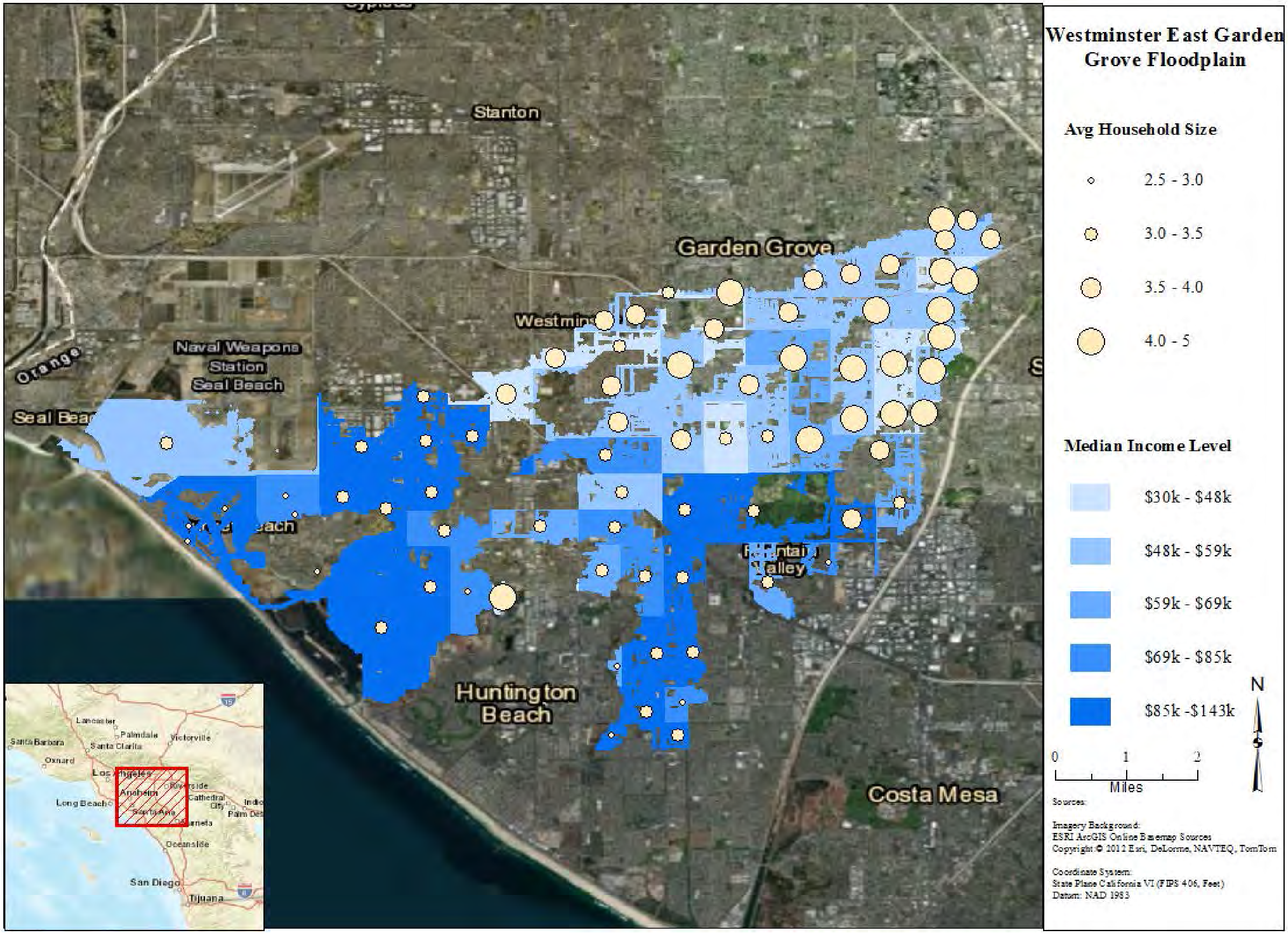

Figure 4. Household Size and Income

Table 3 shows income and housing statistics for the floodplain, by study area. The median income in C02/04 is significantly higher than in C05/06. The maximum median income in a census tract in the floodplain is $140,242 while the minimum is $30,670. The census tract with the lowest income is located in impact area C04_3, just east of I-405 in the city of Westminster. The census tract with the highest median income is located in impact area C05_6, near PCH in Huntington Beach. The lowest median home value in a census tract is $91,500, located in west Santa Ana, and the highest median home value for a census tract is $1.2 million, located in Sunset Beach.

Table 3. Income and Household Characteristics

Location	Median Income, $	Median Home Value, $	Home Value to Income Ratio	Average Household Size	Percent Owner Occupied	Percent Renter Occupied
C02-04	76,961	524,800	6.8	3.4	55.7	44.3
C05-06	60,179	495,800	8.2	3.6	54.9	45.1
Floodplain Total*	61,679	503,650	8.2	3.5	54.6	45.4

**Some census Tracts are contained in both C02/C04 and C05/C06; entire census tracts with a portion in the floodplain are included in statistics*

The median home value to income ratio is 6.8 in C02/04 and 8.2 in C05/06. Since the national average home value to income ratio is 3.31, overall mortgage debt is likely higher in the 0.002 ACE floodplain than average mortgage debt nationally. Approximately 45 percent of housing units in the floodplain are occupied by renters, while about 55 percent are occupied by owners. The average household size in a census tract is 3.5.

2.4.3 Structures and Land Use

The study floodplain is primarily a built-out, urban area, and the majority of the structures in the floodplain are residential. The 0.002 ACE floodplain also contains a significant number of public, industrial, and commercial structures, as well as public wetlands and an ecological reserve.

Figure 5 displays structures by use and includes residential, commercial, industrial and public structures. The figure shows that the number of residential structures in the floodplain is higher than commercial, industrial, or public structures.

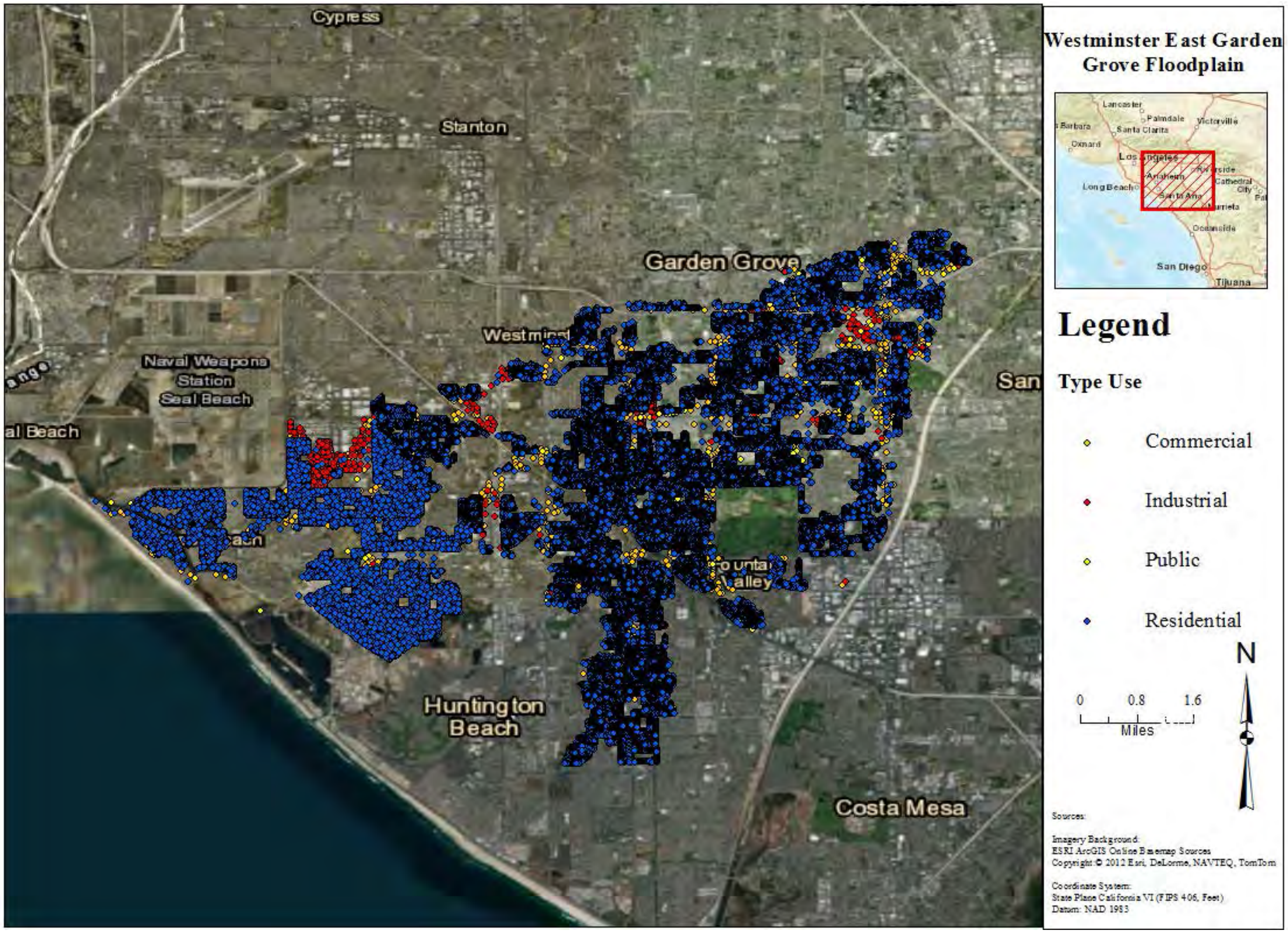

Figure 5. Structure Inventory by Use

Table 4 shows the structure count by zoned land use and channel. There are approximately 43,653 structures in the 0.002 ACE floodplain. Residential development in the floodplain is most common, with over 95 percent of the structures in the study being residential. Eighty-four percent of the residential structures in the floodplain are single family structures, 9.6 percent are multi-family structures, and 6 percent are mobile home units. Nearly four percent of all structures are either commercial or industrial.

Table 4. Number of Structures by Use and Impact Area

Zoned Land Use	C02	C04	C05	C06	Total by Use
Residential	2,982	10,382	20,554	7,941	41,859
Single Family Residential	2,264	8,864	16,861	7,324	35,313
Multi-Family Residential	235	1,053	2,156	585	4,029
Mobile Home	483	465	1,537	32	2,517
Commercial	46	292	539	139	1,016
Industrial	11	288	296	25	620
Public	11	36	98	13	158
Total by Channel	3,050	10,998	21,487	8,118	43,653

Note: Multiple structures are contained in both C02/C04 and C05/C06; these structures were analyzed under both reach conditions, and therefore damages may be overestimated in the analysis below

Channel C05 has the highest number of total structures, and contains nearly 50 percent of residential structures in the floodplain. The methodology used to develop the structure inventory and structure and content values is detailed in Section 3, below.

Table 5 displays depreciated structure and content values, in 2019 price levels. Total structure value in the floodplain area is $12.2 billion, and total structure content value is $11.7 billion. The high total content value relative to total structure value can be explained by the high number of residential structures in the floodplain, which have a structure to content value ratio of 1. In C02/04, EIA C04_3 accounts for the largest portion of depreciated structure and content value. C06_2 accounts for 20 percent of total depreciated structure and content value in C05/06, the largest portion of any of the impact areas in these channels. C05_4a and C05_6 also account for a significant share of structure and content value in C05/06.

Table 5. Structure and Content Values, 2019 PL ($000's)

Impact Area	Structure Value	Content Value	Total Value	% of Channel Total
C02/04	3,907,622	3,703,101	7,610,723	100
C02_1	416,490	396,230	812,720	11
C04_1	278,435	272,472	550,908	7
C04_2	875,571	836,444	1,712,015	22
C04_3	1,511,244	1,441,429	2,952,673	39
C04_4a	304,178	294,565	598,742	8
C04_4b	521,703	461,961	983,665	13
C05/06	4,439,156	4,296,062	8,735,218	100
C05_1A	437,492	413,342	850,834	10
C05_2A	16,839	15,797	32,636	0
C05_2B	124,268	120,694	244,962	3
C05_2C	79,819	77,610	157,430	2
C05_2D	178,281	169,599	347,880	4
C05_3A	65,094	64,020	129,114	1
C05_3B	99,824	89,776	189,600	2
C05_3C	29,187	31,151	60,338	1
C05_3D	459,100	440,070	899,171	10
C05_4A	709,341	689,499	1,398,840	16
C05_4B	231,250	217,761	449,011	5
C05_5	258,559	253,315	511,874	6
C05_6	589,823	583,746	1,173,569	13
C06_1A	180,928	164,349	345,277	4
C06_1B	99,500	98,068	197,568	2
C06_2	879,850	867,264	1,747,114	20
Total	12,785,934	12,295,225	25,081,159	

3.0 Methodology

This section details the methodology used to develop the HEC-FDA analysis, discusses uncertainty, and describes how the structure inventory and structure values were developed.

3.1 HEC-FDA Analysis

The random and unpredictable nature of flood events means that future damage is unknown, and is best represented by a range of possible damage values and their likelihood in a probability distribution. The metric of interest in computing equivalent annual benefits is the expected annual damage (EAD) value, because it captures the mean of the probability distribution of annual damage. The USACE Hydrologic Engineering Center developed a software, HEC-FDA 1.4.2, which uses Monte Carlo simulation to obtain a random sample of the contributing relationships and compute stage-damage functions, exceedance probability-discharge curves, and conditional stage-discharge relationships, in order to generate the EAD estimates. In other words, knowledge uncertainties are incorporated into EAD estimates using Monte Carlo simulation. Each iteration of a Monte Carlo simulation randomly samples the uncertainty distributions, and the resulting values are used to transform the flow and stage distributions to a damage distribution and integrate it in order to compute the EAD. Thousands of iterations of this process are used to infer the EAD distribution. The EAD is therefore the probability weighted average of all possible peak annual damages, where damage is a continuous random variable.[2]

In order to compute the EAD values, HEC-FDA requires the following data:

1. **Structure Inventory Data –** This includes a structure identification number, a use category (industrial, commercial, single family residence, etc.), stream location identified by cross sectional or grid data, ground or first floor elevation, and depreciated structure and content value. This data was compiled using ArcGIS 10.3.1 and Microsoft Excel, and imported into the HEC-FDA program.
2. **Hydrologic and Hydraulic Data** – This data includes water surface profiles, exceedance probability discharge relationships, stage/discharge relationships, and levee fragility curves. Water surface profiles were developed in HEC-RAS and GEO-FDA software by hydraulic engineers and imported into the HEC-FDA program.
3. **Depth/Damage Functions for Structures and Structure Contents –** Depth-damage relationships for non-residential structures were obtained from the Sacramento District's expert elicitation report, *Technical Report: Content Valuation and Depth-Damage Curves for Non-residential Structures*. Depth-damage relationships for residential structures were obtained from EGM 04-01.
4. **Risk and Uncertainty Parameters –** Uncertainty parameters discussed in section 3.2 of this report were also entered into HEC-FDA.

Discharge-exceedance probability, stage-discharge, and damage-stage functions derived at a damage reach index location are used to compute the damage-exceedance probability function. Monte Carlo simulation is a computationally efficient method of obtaining the damage-exceedance probability function due to uncertainty in input parameters. This numerical integration process requires all these relationships, and risk and uncertainty parameters to be input into HEC-FDA. Expected annual damage values are obtained from the cumulative distribution function produced in successive iterations of the Monte Carlo process.

3.2 Primary Sources of Uncertainty

There are many sources of uncertainty when estimating flood risk. These uncertainties are accounted for in the HEC-FDA portion of the analysis. The primary sources of uncertainty present in the calculation of economic damages include: storm water discharge, water surface elevations, levee performance, structure elevations, structure and structure content values, and depth-damage relationships.

1. **Levels of Storm Water Discharge –** The amount of rainfall from storm events with equal probabilities can vary by location throughout the watershed. Variability in storm intensity, elapsed time during rainfall, ground permeability, soil, ambient temperature, and other physical factors can

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[2] This process is described in more detail in the HEC-FDA User's Manual Version 1.4.1 available at http://www.hec.usace.army.mil/software/hec-fda/documentation/CPD-72_V1.4.1.pdf

also cause variation in the location and timing of rainwater entering the channel. This variation causes uncertainty in the level of storm water discharge at any location along the river.

In addition to natural variation arising from physical factors, there is uncertainty in the modeling of water discharges for a storm event due to limited historical meteorological and stream gauge data. This data can often be incomplete or limited in sample size (length of record for time-series data). Discharge-probability distributions in this study were computed using the graphical method and were based on a period of record length of 30 years. HEC-FDA calculates 95 percent confidence intervals for storm discharges that are used in economic computations.

2. **Water Surface Elevation –** The shape of the riverbed, water temperature, location and amount of debris, and obstructions in the channel can affect the water surface elevation for a specific location along the river. When the water surface elevation exceeds the top of the levee elevation, water flows onto the floodplain. Thus uncertainty affects water surface elevations in the floodplain and in the channel. To address this uncertainty, a standard deviation with standard normal distributions were input into HEC-FDA for water surface elevations. For the without project condition, a standard deviation of 1.0 feet, held constant at the 0.2 ACE was used; a standard deviation of 0.75 feet was used for both the minimum and maximum project alternatives, becoming constant at the 0.1 ACE and 0.02 ACE, respectively.
3. **Levee Performance –** There is uncertainty about how an existing levee will perform under certain water surface elevations, how interior water-control facilities will perform, and the thoroughness of closures or openings in an existing levee. For this analysis, geotechnical failure functions were assigned to impact areas C02_1, C05_5, and C05_6, which have existing levees. For all other impact areas, top of bank elevations were entered, and it is assumed that the there is no breach prior to overtopping.[3]
4. **Structure Elevations –** Structure elevation is key in determining the depth of flooding inside of a structure during a flood event. First floor structure elevation is the aggregate of topographical elevation and foundation height. Both of these elevations are prone to uncertainty; topographical elevation uncertainty stems from the level of detail of the survey used to develop the data, while foundation height uncertainty is caused by assigning a standard foundation height by structure type based on sample statistics, rather than surveying each individual structure. Structures were sampled and surveyed by strata, as outlined in Section 3.3. It is assumed that joint distribution error and corresponding probability distribution functions are normally distributed with a mean error of zero.
5. **Depreciated Structure and Content Replacement Values –** The depreciated replacement values for structures and contents are used to determine economic damages in the floodplain and are a function of structure type, condition, and size. Since surveying every structure in the floodplain was not feasible for this study, uncertainty arises in these values. A combination of stratified sampling, assessor data, and Google Earth Pro was used to determine the condition and square footage of the structure, as outlined in Section 3.3. *Marshall & Swift* multiplier values per square foot and uncertainties for structure condition and corresponding estimates of depreciation were used to calculate the structure and content value for each structure. Errors for structure value estimates are assumed to be normally distributed with a mean error of zero, and standard deviations range from 10 to 15 percent of mean structure value. Structure content values are estimated as a percentage of the structure value, based on structure type and the depth-damage function.

[3] Levee fragility parameters used in the current analysis were preliminary estimates provided in July 2018. Refined geotechnical functions will be included in the final analysis. Changes to geotechnical functions could significantly impact the without project damages and with project benefits presented in this report.

6. **Depth-Damage Relationships** – Depth-damage functions are used to calculate the percent damage a structure will incur at a specific water elevation in a flood event. This is another calculation that is subject to variation between structure and flood event. The methodology used to construct depth-damage relationships for non-residential structures was developed by an expert-opinion elicitation process, conducted by USACE Sacramento District and published in *Technical Report: Content Valuation and Depth Damage Curves for Nonresidential Structures*, *May 2007*. This report provides non-residential depth-damage curves for structure contents by structure type, as well as content-to-structure value ratios and associated standard errors.

   Depth-damage functions and associated standard errors for residential structures and their contents were developed by the Institute for Water Resources (IWR) and published in *Economic Guidance Memorandum 04-01: Generic Depth-Damage Relationships for Residential Structures with Basements, October 2003.*The depth-damage functions and standard error estimates are based upon previous damages that occurred during flood events in the United States.

   Depth damage functions for other damage categories are described in the discussion of damages by category in the following sections.

3.3 Engineering Inputs

3.3.1 Hydraulic and Hydrologic Inputs

H&H inputs including water surface profiles and corresponding relationships were used to compute expected annual damages through Monte Carlo sampling of discharge-exceedance probability relationships, stage-discharge relationships, and stage-damage relationships and their uncertainties. Uncertainty parameters for the exceedance-probability relationship and stage-discharge relationship were developed by H&H engineers. For the exceedance-probability relationship, uncertainty is based on an Equivalent Record Length (N) of 30 year gage record for all project conditions and reaches. For the stage-discharge relationship, uncertainty is as follows:

<u>Without / Existing Project Condition</u>
Normal Distribution with a standard deviation of 1 foot, becoming constant at the 5 year profile

<u>Minimum Channel Improvements</u>
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 10 year profile

<u>Maximum Channel Improvements</u>
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 50 year profile.

These values are based on how river stages within the channel react to various flows and is not expected to change during the period of analysis. Additional detail regarding the estimation of these parameters can be found in the H&H Appendix.

3.3.2 Geotechnical Inputs

Levee fragility curves were developed by geotechnical engineers to address potential levee failure in the leveed impact areas including C02_1, C05_5, and C06_6. In these areas, in addition to overtopping, levees could potentially fail, increasing flow outside of the channel and damage to structures. Under the without-project condition, there is a 15 percent chance of levee failure at the probable no-failure point (PNP), and an 85 percent chance of levee failure at the probable failure point (PFP) elevation for all three leveed reaches. Geotechnical functions for leveed reaches were input into FDA using corresponding PNP and PFP elevations. As noted previously, levee fragility curves used in this report were provided in July

2018. Updated levee fragility curves will be used in the final report, and could impact the values for without project damages and with project benefits presented in this report.

3.4 Damages to Structures and Structure Contents

Residential, commercial, industrial, and public structures in the floodplain are at risk of being damaged when flood events occur that exceed the system capacity. To value the economic losses resulting from these damages, an inventory of structures within the floodplain was developed. Depreciated replacement costs of these structures and their contents were then calculated and flood damages for varying probabilistic events were estimated. Due to time and budget constraints, the structure inventory for this study was developed using the inventory for the Santa Ana River Mainstem 2017 Economic Reevaulation Report, which has a 0.002 ACE floodplain that fully encompasses the Westminster 0.002 ACE floodplain. The following section describes the development of the structure inventory in detail.

3.4.1 Structure Inventory

Structure inventory for the feasibility study was developed using existing structure inventory from the Santa Ana River Mainstem floodplain, which contains the Westminster floodplain. This structure inventory was last updated in 2017 and is comprised of a) previously existing structures that were included in the 2013 Santa Ana River Mainstem Economic Reevaluation Report (hereafter 2013 ERR) and b) structures that were identified as newly constructed since 2013 using a combination of tax assessor data and Google Earth Pro historical imagery, which were added to the Santa Ana River Mainstem 2017 Economic Reevaluation Report (hereafter 2017 ERR).

Because it would have been prohibitively costly and time-consuming to re-survey all structures in the floodplain, the price level for structures included in the 2013 ERR were updated to October 2016 price levels through updated Marshall & Swift multipliers for each occupancy time. A sample review of structures from the 2013 ERR database was performed using Google Earth to verify that there was minimal change in structure use or condition from 2013 to 2016. Therefore, the methodology used to update price levels is considered appropriate. Any error arising from this methodology would be trivial, due to the minimal variation in percent changes between *Marshall & Swift* occupancy categories and the large number of structures in the inventory.

Structures originally included in the 2013 ERR were evaluated using data collected during field surveys. Structures were identified as lying in the floodplain using geo-referenced parcel tax assessor data in ArcGIS.[4] This data included geographic coordinates, the zoned type-use of each parcel (residential, commercial, industrial, public, or agricultural), street address, structure square footage, and other parcel characteristics. The geographic spread and large number of structures in the floodplain made a survey of 100 percent of the structures impractical. Instead, a sample of structures in the floodplain was randomly selected and subsequently stratified by study area location, reported land use, home value, industrial zone or year of construction[5]. The allocation of parcels between strata was based on optimal and proportional

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[4] Portions of parcels intersecting the floodplain were included in the analysis.

[5] Study area location refers to the floodplain areas discussed throughout the report (i.e. lower Santa Ana, upper Santa Ana River, Oak Street drain, Santiago Creek, etc.). Reported land use refers to the land use reported in the tax assessor records (i.e. Single Family Residency, Multifamily Residence, Industrial, Commercial, etc.). Home value refers to the value of residential parcels reported in the 2010 census data. Year of construction refers to the year of the building's construction, sometimes reported in the tax assessor records. Industrial zone refers to general geographic zones where industrial structures are clustered. Whether home value, year of construction, or industrial zone were used to stratify the parcel data depends up on the parcels' reported land use and data availability.

allocation methods.[6] Parcels were randomly selected within strata using a uniform random number generator. The uncertainty parameters for first floor elevation and structure and content values differ between structures that were sampled and structures that weren't sampled in the random selection and subsequent survey. For example, the standard deviation for the first floor elevation of a single family residential structure that was sampled is 0.85 feet, while the standard deviation for the first floor elevation for same type of structure that wasn't surveyed is 1.1 feet. Correspondingly, the coefficient of variation for the structure value and structure content value for sampled and non-sampled structures varies by structure type. Uncertainty parameters for all structure types, both sampled and non-sampled, are normally distributed with a mean error of zero.

In order to add structures built between 2013 and 2017 to the structure inventory, tax assessor data was obtained from the Orange County Flood Control District. This data included parcel numbers but lacked structure-specific data (square footage, year built, etc.) for buildings constructed since 2013. In order to obtain square footage and building classification for valuation purposes, data was imported into Google Earth Pro, and new structures were identified by comparing historical images from April 2013 and February 2016 (dates are based on available Google Earth images at the time of analysis). New and previously existing structures were exported from ArcGIS to Google Earth Pro, and satellite imagery was used to verify the location, and classify the type and condition of the new structure. Square footage was estimated by exporting the parcel data from ArcGIS 10.3.1 to Google Earth Pro, and using the measurement tool and aerial photographs to estimate approximate square footage of the structure.[7] Additionally, based upon typical structure characteristics identified in the 2013 survey and Google Earth, all structures were assumed to have a foundation height of 0.5 feet for single and multi-family residences and three feet for mobile homes, and were assumed to be single story. Thus square footage is an approximation of actual square footage, but is conservative, and any bias present in square footage measurements would bias the damage estimates downward. Ground elevation was added to foundation heights to estimate the first floor stage for each structure in the floodplain. In order to extract Westminster data from the SARM structure inventory, structures were georeferenced, then extracted from within the Westminster 0.002 ACE floodplain using ArcGIS 10.3.1. For structures with high structure values (structures larger than 10,000 square feet), values were updated to reflect their specific category type and square footage, rather than the type and square footage assigned during the stratified sampling and assignment process outlined above. Structure inventory data was projected into CCS83, Zone VI (US Feet), which corresponds with the projection of hydraulic inputs.

The structure inventory, as well as water surface profiles developed by H&H Engineers, were then imported into GEO-FDA. GEO-FDA was used to assign a ground elevation and an impact area in C02/04 or C05/06. Structures were then imported into HEC-FDA for analysis. As shown above in Figure 2, there is a small portion of economic impact areas C04_4b and C05_5 that overlap. There are 855 structures included in both C04_4b and C05_5. In order to prevent the exclusion of damages in the event of inundation in one area and not the other, structures lying in the overlapping area were included in both C02/04 and C05/06 in the analysis, and thus there is potential bias in the results. However, this upward

[6] Residential structures were assigned to optimally allocated strata (using the optimal allocation sampling method), based on home value data found in the tract level census data, when accurate year of construction data did not exist. All other strata were proportionally allocated (using the proportional allocation method) with respect to land use, with some manual adjustment to the proportions when previous survey results suggested a higher allocation would increase statistical efficiency.

[7] It was assumed that each 1,000 square ft. of multi-family residence was one unit. Thus to determine the number of units in a multi-family residence, the total square footage was divided by 1,000. Only one structure per MFR is included in the structure count in Table 4, although each structure represents more than one unit.

bias in damages is assumed to be minor, and would occur only if both impact areas were inundated for the same probabilistic flood event at the structure location.

3.4.2 Structures Built After 1991

According to the Water Resources Development Act of 1990 (WRDA90) Section 308, new or improved structures built within the 100-year (0.01 ACE) floodplain after July 1, 1991 with first floor elevations lower than the 100-year flood elevation, should be excluded from the structures used to calculate NED benefits for flood damage reduction projects. To ensure this study is compliant with Section 308, FEMA's 100-year floodplain from Flood Insurance Rate Map (FIRM) data was gathered from ArcGIS online and analyzed in ArcMap 10.3.1. Of the three structures in the Westminster floodplain that were built since 2013, none are located within the FEMA 100-year floodplain. For the portion of the structure inventory that was developed prior to 2013, it was determined that the majority of the structures were constructed prior to 1990, and that any remaining structures posed trivial risk to the study's overall findings. This factor, combined with the frequency of missing date of construction data in the tax assessor records, was reason to make no further attempt in identifying or structures built between 1991 and 2013.

3.5 Other Damages Categories

In addition to damages to structures and their contents, various other damages are incurred in a flood event, including cleanup costs, other public assistance, and damages to vehicles. This section explains these categories in more detail and justifies them as flood damage reduction categories that should be included in the calculation of with-project benefits.

3.5.1 Cleanup Costs

ER 1105-2-100 requires that emergency expenses, which include hazardous and toxic waste cleanup, be included in damages estimates for flood events. Structures that are inundated in a flood event require post-flood cleanup in order to remove floodwater, sediment, debris, mold, mildew, and toxins. These cleanup costs are considered a damage category in the calculation of with-project benefits and can vary based on depth of flooding. A depth-damage curve is used to estimate the cost incurred for a given level of inundation in a structure. Depth-damage functions for cleanup costs come from USACE Sacramento District's *Technical Report: Content Valuation and Depth Damage Curves for Nonresidential Structures, May 2007.*

For cleanup costs, a maximum value of ten dollars per square foot for each structure is assumed; the maximum value is applied for flood depths greater than or equal to three feet, while flood depths less than three feet are assigned a portion of the maximum value.

3.5.2 Vehicle Damages

Due to the high number of residential structures in the floodplain, this analysis includes vehicle damages for single family, multi-family, and mobile home residential structures. Damages to autos in commercial, industrial, and public parking lots are not included in the analysis. Automobile damages are calculated as a function of the number of vehicles per residence, estimated average value per vehicle, estimated percentage of vehicles removed from the floodplain in an evacuation, and the depth of flooding above the ground elevation.

Assuming that each single family residence and each 1,000 square feet of multi-family residence comprises one household, 2.4 vehicles were assigned to each household. This is based on county-level census data. Consistent with guidance in EGM 09-04, it is estimated that for any given flood event with a warning time of less than six hours, fifty percent of the vehicles will be removed from the floodplain.

Depreciated replacement values for vehicles are based on average private-seller used auto prices in the study area. Weighted averages of used auto prices from autotrader.com and craigslist.com within a ten mile radius of a central zip code in the floodplain were used. The average cost per vehicle was valued at $15,395. Adjusting for the average of 2.4 vehicles per household and number of vehicles removed in a flood event, the average auto replacement cost is $18,474. Standard errors associated with weighted average vehicle values were computed and input into FDA. An automobile depth-damage function was used to determine the percentage of damage to the vehicle in a flood event. Depth damage functions for this study were taken from EGM 09-04. Damages for autos begin once flood depth reaches 0.5 feet and reach 100 percent damage at a flood depth of 9 feet. It is assumed that the elevation of vehicles parked at residential structures is equal to the ground elevation of the corresponding residential structure, since an attached garage or carport would likely have the same elevation as the rest of the structure.

3.5.3 Other Emergency Costs

Other emergency costs incurred in flood events come from FEMA's Individuals and Households Program (IHP) and include the following: Housing Assistance (HA) to repair damaged homes, replace a damaged house, or rent temporary housing; and Other Needs Assistance (ONA), which includes clean-up items, personal property, moving and storage, and medical, dental, and funeral expenses. This analysis uses public assistance to calculate the public assistance to housing assistance ration in terms of dollars per claim. Public Assistance includes debris removal, emergency protective measure, and the repair, replacement, or restoration of certain publicly-owned and non-profit facilities damaged in a flood event.

For emergency costs in this report, historical FEMA claims data from 1998 – 2016 was used to determine average amounts per claim made for public and other needs assistance (PA/ONA). The average PA is $7,934 and the average ONA is $826, with a combined PA/ONA of $8,761.

Similar to automobile and cleanup costs, other emergency costs are assigned a depth-damage function that associates a specific depth of flooding to a percentage of the emergency costs in the HEC-FDA program. Fifty percent of the emergency costs are incurred when the flood depth reaches 0.5 feet, while flood depths one foot or greater incur 100 percent of the emergency damage cost. This assumes that structures which are inundated one foot or more above the first floor elevation would incur public and other needs assistance related costs as reflected in the historical FEMA claims data.

3.6 Traffic Delay Analysis

In addition to causing physical damages, flood events also cause increased traffic delays when major roads become inundated. These delays are quantified as the opportunity cost of time and count as a justifiable damage category.

Direct damage functions were developed by USACE Chicago District using a DynusT (Dynamic Urban Systems for Transportation) provided by Metropia. This model utilized route, capacity, and usage data from the Southern California Association of Governments (SCAG) Transportation Program.

The baseline SCAG data included a breakdown of trips by trip length and purpose, consistent with the guidance outlined in Appendix D of ER 1105-2-100. This base transportation dataset was paired with closures identified by the hydraulic model for the without project condition, including depths and durations for closure locations. The contractor then ran DynusT for each of the provided closure scenarios, to estimate the number of trips and hours of delay generated for each event. The result was a summary of delay durations aggregated by economic impact area (see Figure 2).Table D-4 of Appendix D was utilized to weight the value of time saved as a percentage of hourly family income, based on delay length and trip purpose. The median wage for the Orange County Metropolitan Area, estimated at $27.22, was provided by the Bureau of Labor Statistics Occupational Employment and Wages in Anaheim-Santa Ana-Irvine as of May 2017.

The total delay cost by event and impact area were used to develop direct-stage-damage functions at each impact area modeled to have significant closures for the without project condition. The uncertainty around the most-likely estimate was defined using a triangle distribution, where the minimum was estimated to be equal to 75 percent of the most likely estimate and the maximum equal to 185 percent of the most likely estimate. The minimum estimate was based on professional judgment, while the maximum was based on the total modeled impact resulting from flooding for the entire network (not just those impacts within an impact area). These relationships were then sampled for each project alternative within HEC-FDA to estimate delays avoided/reduced (benefits) provided by the implementation of each alternative in each impact area. Appendix D further details the methodology used in the traffic delay analysis.[8]

3.7 Advanced Bridge Replacement

In accordance with IWR-88-2, this analysis includes advanced bridge replacement benefits. Bridges replaced during project construction extend the life of current bridges for stream and river crossings, thus providing economic benefit. This economic benefit can be claimed to partially offset the cost of the bridge replacement. Benefits are calculated using the additional useful life that is extended by the bridge replacement.

Bridges will be replaced at 48 stream crossings, including pedestrian crossings, under the maximum project improvements, which are discussed in further detail below. –All bridges replaced in Reaches 1 and 23 under the maximum project improvements will also be replaced under the minimum project improvements; none of the other reaches for the minimum project improvements include bridge replacements. Benefits are calculated to include these bridge replacements, for the maximum and minimum project improvements respectively.

3.8 National Flood Insurance Program Operating Costs

EGM 06-04 provides guidance on including the reduction in flood insurance program operating costs as a benefit to the project, as a result of fewer structures being within the 100-year floodplain. Under the maximum project condition, total structures in the 100-year floodplain would be reduced by 6,562. For the minimum project condition, the number of structures in the 100-year floodplain would be reduced by 4,947. The benefit in flood insurance operating costs is calculated by multiplying the number of structures in the floodplain under each project condition by the average price of operating costs per policy, and subtracting the product for the minimum or maximum condition from the without project condition. This methodology assumes that each structure in the 100-year floodplain represents one household that carries a flood insurance policy. The price per policy was taken from EGM 06-04, which represents an estimated average cost per policy for administration of the National Flood Insurance Program. The most recent estimate was given in FY 2006. As a result, for this analysis the average cost per policy was indexed to FY 19 price levels using the Bureau of Labor Statistics CPI. This benefit category is included with other benefits in Tables 12 and 13, below, and accounts for a very small portion of overall project benefits.

[8] The appendix describing the traffic delay analysis will be provided with the final version of this report.

3.9 Life Safety

In accordance with ER 1105-2-101, life loss qualifies as an NED damage category. A life safety analysis includes the estimation of the population at risk and associated statistical estimates for life loss. While the current analysis does not include life loss estimates, the final report will include life loss and associated statistics calculated in HEC-FIA. Including this in the analysis will impact the estimated damages and benefits presented in this report.

4.0 Without Project Damages

This section describes the analysis of damages that are expected to occur in the absence of a Federal project to address flood risks in the study area. These damages include damages to structure and structure contents, transportation delay costs, and other damages, which include cleanup costs, vehicle damages, temporary relocation and housing costs, and emergency costs.

HEC-FDA software was used to calculate economic damages for the study. Expected and equivalent annual flood damages are the basis for calculating with-project benefits, and are crucial to the evaluation of the project. Expected annual damages are equal to the mean of all possible values of damage that are derived through Monte Carlo sampling of discharge-exceedance probability relationships, stage-discharge relationships, and stage-damage relationships and their uncertainties. Uncertainty parameters for the exceedance-probability relationship and stage-discharge relationship were developed by H&H engineers. For the exceedance-probability relationship, uncertainty is based on an Equivalent Record Length (N) of 30 year gage record for all project conditions and reaches. For the stage-discharge relationship, uncertainty is as follows:

<u>Without / Existing Project Condition</u>
Normal Distribution with a standard deviation of 1 foot, becoming constant at the 5 year profile

<u>Minimum Channel Improvements</u>
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 10 year profile

<u>Maximum Channel Improvements</u>
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 50 year profile.

These values are based on how river stages within the channel react to various flows and are not expected to change during the period of analysis. Additional detail regarding the estimation of these parameters can be found in the H&H Appendix.

Equivalent annual damages are equal to expected annual damages that have been discounted to present values and annualized. Equivalent annual damages are normally calculated for the base and future years, and interpolated for in-between years. Since hydrologic conditions were modeled to be the same in the base and future years, equivalent annual damages and expected annual damages are the same values in this analysis. This section presents expected annual damages, and as the result of time-dependent variance in hydrologic, hydraulic, and economic data, the values in this section are estimates only.

4.1 Without Project Expected Annual Damage Estimates

Expected annual damage is the mean damage for the damage reach, obtained by integrating the damage exceedance probability curve. Structure and structure contents include the cost of the damage to the physical structure and the contents inside it, based on a depth-percent damaged relationship as previously described. Structure and structure contents include damages to residential, public, commercial, and industrial structures. Other related flood damages include damages to residential vehicles, emergency, and cleanup costs. Values were calculated in fiscal year (FY) 2017 price levels and indexed to 2019 price levels for comparison with costs later in the report. Table 5 displays expected annual damages by reach and use type.

Table 6. Without-Project Expected Annual Damages for Structure and Structure Contents, 2019 PL ($000's)

Reach	Residential	Commercial	Industrial	Public	Total
C02_1	3,329	66	28	990	4,412
C04_1	15	0	0	0	15
C04_2	16	1	0	0	18
C04_3	0	0	0	0	0
C04_4a	33	3	0	0	36
C04_4b	485	60	379	1,237	2,160
C05_1A	66	4	1	1	72
C05_2A	27	6	39	0	72
C05_2B	128	44	37	7	216
C05_2C	33	0	0	0	33
C05_2D	429	1	16	0	446
C05_3A	132	27	56	8	223
C05_3B	67	11	6	0	84
C05_3C	0	0	0	0	0
C05_3D	526	38	1	147	712
C05_4A	11,188	531	31	54	11,805
C05_4B	97	63	1	0	161
C05_5	3,532	123	60	1,480	5,195
C05_6	48,007	444	1,774	0	50,225
C06_1A	139	0	0	0	139
C06_1B	20	1	0	0	21
C06_2	552	7	1	1	561
Total	68,821	1,430	2,430	3,925	76,607

Under the existing condition of the floodplain, annual damages for structures and contents total more than $76 million. Damages to residential structures account for nearly 90 percent of without-project damages. Commercial and industrial damages combined account for five percent of without-project damages, and public structures also make up five percent of without-project damages. EIA C05_6 contains 65 percent of structural damages, while C05_4A and h C05_5 account for 15 and 7 percent of damages, respectively. Combined, these three impact areas account for over 90 percent of without project structure and content damages.

Table 6 shows additional without-project damages for 'Other' flood damage categories, which include clean-up costs, other emergency costs as defined above, and damages to residential vehicles.

Table 7. Without-Project Other Flood Damage Categories Summary 2019 PL ($000's)

Reach	Clean-up	Emergency	Vehicle	Total
C02_1	511	850	610	1,971
C04_1	2	2	2	7
C04_2	3	3	3	8
C04_3	0	0	0	0
C04_4a	4	3	2	9
C04_4b	176	167	116	460
C05_1A	8	55	45	108
C05_2A	10	5	4	19
C05_2B	22	15	5	42
C05_2C	3	5	2	9
C05_2D	42	303	176	521
C05_3A	27	18	11	56
C05_3B	7	7	3	17
C05_3C	0	0	0	0
C05_3D	99	181	161	441
C05_4A	1,387	1,567	1,644	4,598
C05_4B	19	18	27	64
C05_5	532	429	435	1,396
C05_6	4,367	6,278	3,950	14,595
C06_1A	8	14	3	25
C06_1B	3	3	3	8
C06_2	58	78	54	190
Total	7,288	10,002	7,254	24,545

Emergency costs account for 40 percent of other damages, while clean-up and auto damages each account for 30 percent of other damages. C05_6 accounts for 59 percent of other damages, while C05_4a accounts for 19 percent.

Tables 8 and 9 show equivalent annual damages by use, aggregated by channel. It is important to note that because some impact areas overlap in C04 and C05, damages for structures in the overlapping area are included in the table below for both channels. As previously explained, this was to avoid a downward bias in the damage estimates. Damage estimates below are only biased upward if flooding occurs in both channels at the same structure location for a particular flood event.

Table 8. Without-Project Expected Annual Damages by Use, 2019 Price Level ($000's)

Channel	Residential	Commercial	Industrial	Public	Total
C02-C04	3,877	130	407	2,227	6,642
Reach C02	3,329	66	28	990	4,412
All Reaches C04	549	64	380	1,237	2,230
C05-C06	64,944	1,299	2,023	1,699	69,965
All Reaches C05	64,234	1,291	2,022	1,698	69,245
All Reaches C06	711	8	1	1	720
Total	68,821	1,430	2,430	3,925	76,607

Table 8 shows that C05/C06 account for approximately 91 percent of residential structure damage. This includes damages to single family and multi-family residences, and damage to mobile homes. Structure and structure content damages total more than $68 million annually.

Table 9 shows that emergency costs account for the largest portion of 'other' flood damages, followed by clean-up and vehicle damages. Total 'other' flood damages are estimated to be more than $24 million annually under the without project condition in the study area.

Table 9. Without-Project Expected Annual Damages by Use, 2019 Price Level ($000's)

Channel	Clean-up	Emergency	Vehicle	Total
C02-C04	696	1,026	733	2,455
Reach C02	511	850	610	1,971
All Reaches C04	185	176	123	484
C05-C06	6,592	8,976	6,522	22,090
All Reaches C05	6,524	8,881	6,462	21,867
All Reaches C06	69	95	59	223
Total	7,288	10,002	7,254	24,545

Table 10 shows total without-project expected annual damages by floodplain channel, and includes traffic delay costs, which represent the value of time associated with traffic delays caused by a flood event.

Table 10. Without-Project Expected Annual Damages by Channel 2019 Price Level ($000's)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Traffic Delay Costs	Total Without Project Damages
Reaches C02-C04	6,642	2,455	801	9,897
Reach C02	4,412	1,971	281	6,664
All Reaches C04	2,230	484	520	3,233
Reaches C05-C06	69,965	22,090	5,567	97,622
All Reaches C05	69,245	21,867	4,899	96,010
All Reaches C06	720	223	668	1,612
Total	76,607	24,545	6,368	107,519

Table 10 shows that under without project conditions, expected annual flood damages exceed over $107 million in damages over a fifty year period. More than $76 million of this sum is comprised of damages to structures and their contents, nearly $24 million is attributed to ‘other’ flood damages including emergency, cleanup, and damages to vehicles, and over $6.3 million is due to estimated traffic delay costs caused by a flood event.

Without-project expected annual damages computed for this analysis are significantly higher than past analyses. This is primarily attributable to the following: updated hydraulic and hydrologic data, the development of a new and larger floodplain (particularly the inclusion of C02), the inclusion of levee fragility curves, changes to the FDA software, and updated price levels. Updated hydraulic and hydrologic data resulted in discharge flows and stages that are higher for more frequent events in all channels. Because economic damages are computed based on stage-discharge and stage-damage relationships, it is expected for damages to be higher, particularly for lower frequency events, considering the updated data. As part of the updated H&H data, the floodplain was also expanded to included areas that weren’t previously included in the analysis. The number of structures and the absolute value of damages to structures is also expected to be higher as a result. Previous analyses also did not include geotechnical functions for leveed reaches. Since including probabilistic values and stages for levee failure increases uncertainty, it is expected that damages will be significantly increased in leveed reaches (C05_5, C05_6, and C02_1), which is the case in this analysis. Additionally, this study uses FDA 1.4.2 to calculate expected damages. Changes to the FDA software since previous studies were conducted allow for wider confidence intervals at the upper end of the exceedance probability curve, which more accurately captures uncertainty, but also leads to larger damage estimates than previous versions of the software. Lastly, this study uses a structure inventory that uses FY 2017 price levels, and then indexes those to FY 2019 values. This change in price level should also be taken into account when comparing values to previous analyses, particularly when comparing to the 2010 analysis.

4.2 Without-Project Performance

Without-project performance statistics help inform the risk of a flood event of a specific frequency. Three components are indicators of project performance: the annual exceedance probability (AEP) is the likelihood flooding occurs in any given year; the long-term risk is the probability that flooding occurs in a period of 10, 30, or 50 years; and the assurance is the probability that flooding doesn't occur, conditional on a flood event of 0.02, 0.01, and 0.002 frequency occurring. The table below shows these statistics by reach for the without-project condition.

Table 11. Without-Project Condition Project Performance (%)

		Long-Term Risk[2]			Assurance[3]		
Reach	AEP[1]	10 year	30 year	50 year	2.00%	1.00%	0.20%
Reaches C02-C04							
C02_1	74.46	99.00	99.00	99.00	5.91	5.70	4.57
C04_1	0.07	0.70	2.08	3.44	99.47	99.40	99.13
C04_2	0.09	0.85	2.54	4.20	99.35	99.27	98.86
C04_3	0.01	0.11	0.34	0.56	99.00	99.00	99.00
C04_4a	5.55	43.52	81.98	94.25	54.76	52.02	42.02
C04_4b	5.94	45.82	84.09	95.33	67.07	65.80	62.49
Reaches C05-C06							
C05_1a	2.07	18.90	46.66	64.92	92.12	90.13	82.29
C05_2a	10.49	66.98	96.40	99.00	68.21	66.42	63.26
C05_2b	17.54	85.47	99.00	99.00	20.74	18.16	13.10
C05_2c	8.39	58.36	92.78	98.75	45.75	43.31	35.35
C05_2d	24.21	93.74	99.00	99.00	11.53	8.79	4.24
C05_3a	6.09	46.67	84.83	95.68	77.65	75.65	75.44
C05_3b	14.75	79.73	99.17	99.00	30.92	28.54	24.02
C05_3c	0.02	0.16	0.48	0.80	99.00	99.00	99.00
C05_3d	2.15	19.52	47.86	66.23	90.95	90.19	88.49
C05_4a	12.80	74.59	98.36	99.00	68.45	66.84	62.45
C05_4b	1.09	10.34	27.93	42.06	92.89	92.12	89.77
C05_5	87.52	99.00	99.00	99.00	7.82	7.70	7.57
C05_6	81.92	99.00	99.00	99.00	12.02	10.25	7.52
C06_1a	99.00	99.00	99.00	99.00	0.01	0.01	0.01
C06_1b	0.44	4.28	12.29	19.63	93.97	91.44	91.02
C06_2	1.75	16.15	41.06	58.56	81.13	76.48	74.91

[1]Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed below has occurred

Table 11 shows that there is more than an eighty percent chance that a flood will occur in any given year in reaches C05_5, C05_6, and C06_1a. Correspondingly, in these reaches the assurance is low; there is a one percent chance that no flooding occurs, given the occurrence of a 0.002 ACE in reach C06_1a, and a seven percent chance no flooding occurs given the occurrence of a 0.002 ACE in reaches C05_5 and C05_6. In all three of these reaches, there is a 99 percent chance flooding will occur within 10, 20, or 30 years. Since C05_5 and C05_6 contain more than 25 percent of the structures in channel C05 and have a high probability of flooding, the without-project condition poses significant risks. This is reflected in the high equivalent annual damages estimates for C05, shown above.

5.0 With-Project Benefits

Hydrologic and hydraulic data were developed for a 'maximum' channel improvement alternative and a 'minimum' channel improvement alternative e. Minimum channel improvements include improvements in impact areas C05_2D, C05_3D, C05_4A, C05_4B, C05_5, C05_6, all impact areas in C06 and C02, and all impact areas in C04, except C04_3. Maximum channel improvements include improvements in all reaches, except for C05_1A. Improvements under the minimum and maximum alternatives were formed based on strategies that include reducing the impacts of flooding by improving channel conveyance, increasing channel capacity by increasing flood water storage, and improving downstream conveyance to balance improvements to conveyance and capacity upstream. The minimum channel improvement alternative focuses on improving channel conveyance, while the maximum channel improvement alternative focuses on improving channel conveyance and increasing channel capacity. Additional details on the plan formulation strategy can be found in Appendix H. This section explains the results of the minimum and maximum with-project conditions, and provides the basis for formulation of the NED plan.

With-project benefits are defined as the difference between without-project damages and with-project damages computed in HEC-FDA, and are the benefits achieved by taking action as opposed to the study area remaining in its current state. Benefits by channel are shown in Table 12, below.

5.1 Minimum and Maximum Expected Annual Benefit Summaries

Table 12. With-Project Minimum Improvement Expected Annual Benefits, 2019 Price Level ($000's)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Traffic Delay Benefits	Bridge Benefits	Flood Insurance Benefits	Total With-Project Benefits
Reaches C02-C04	6,601	2,445	748	48	129	9,841
Reach C02	4,376	1,962	281	48	35	6,667
All Reaches C04	2,226	483	466	-	94	3,175
Reaches C05-C06	69,367	21,870	5,058	1,140	873	97,435
All Reaches C05	68,672	21,651	4,400	1,140	829	95,863
All Reaches C06	695	219	658	-	44	1,572
Total	75,969	24,315	5,805	1,188	1,002	108,279

With-project benefits for the minimum improvement in the channels total over $108 million annually. The majority of this is attributed to structure and structure content benefits, which total nearly $76 million. These are the estimated damages to structures avoided if the minimum improvement measures are built in the specified channels. The benefits for clean-up, emergency, relocation, and auto categories total over $24 million. Traffic delay benefits from the avoidance of traffic delays total nearly $6 million. Advanced bridge replacement benefits, which are the benefits gained by extending the functional life of bridges in certain channels, are just over $1 million. Flood insurance benefits, which is the value of the benefit in policy operating costs due to flood reduction, is approximately $1 million.

Table 13. With-Project Maximum Improvement Expected Annual Benefits, 2019 Price Level ($000's)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Traffic Delay Benefits	Bridge Benefits	Flood Insurance Benefits	Total With-Project Benefits
Reaches C02-C04	6,614	2,449	799	4,859	188	14,910
Reach C02	4,392	1,967	281	48	25	6,688
All Reaches C04	2,221	482	518	4,812	163	8,033
Reaches C05-C06	69,939	22,080	5,546	8,242	1141	106,949
All Reaches C05	69,219	21,857	4,879	7,730	1093	103,684
All Reaches C06	720	223	667	513	48	2,124
Total	76,553	24,530	6,345	13,101	1,330	121,859

Table 13 shows estimated with-project benefits when all of the maximum improvement measures are in place. Structure and structure contents account for just over half of total annual benefits, at $76 million. Other flood benefits account for over $24 million, traffic delay benefits total $6.3 million, bridge benefits account for $13 million, and flood insurance benefits account for $1.3 million of total benefits. Total with-project benefits under the maximum improvement condition are over $121 million, which is approximately $14 million more than total with-project benefits for minimum improvement measures. Implementing the maximum improvement plan would nearly reduce expected annual damages by over 97 percent, nearly eliminating without-project damages. Additionally, since the maximum improvement plan requires a significant number of bridge replacements and modifications, there are substantial benefits associated with advanced bridge replacement.

5.2 Expected Annual Damages by Annual Chance Event

In addition to knowing a range of possible values of damage reduced, it is also helpful to see damages by flood event. Table 15 below compares expected annual damages for without, minimum, and maximum improvement conditions, by percent annual chance event and impact area, for the 0.1, 0.02, 0.01, and 0.002 annual chance events.

Table 14. Expected Annual Damages by Flood Event, FY 2019 Price Levels ($000) [1]

	0.1 ACE			0.02 ACE			0.01 ACE			0.002 ACE		
Location	Without	Max	Min	Without	Max	Min	Without	Max	Min	Without	Max	Min
C02-C04	25,178	0	0	179,043	0	8	211,516	0	3,527	237,493	791	6,313
C02_1	25,178	0	0	84,103	0	0	92,383	0	3,370	99,008	0	5,417
C04_1	0	0	0	0	0	0	0	0	0	0	404	0
C04_2	0	0	0	0	0	0	0	0	0	0	234	0
C04_3	0	0	0	0	0	0	0	0	0	0	153	0
C04_4a	0	0	0	1,712	0	0	2,310	0	0	2,789	0	0
C04_4b	0	0	0	93,228	0	8	116,822	0	157	135,696	0	896
C05-06	308,138	0	2,172	837,578	0	16,486	1,031,074	0	28,162	1,233,689	130,266	45,921
C05_1A	0	0	0	1,032	0	0	16,885	0	0	29,567	3,519	0
C05_2A	71	0	0	1,458	0	0	1,847	0	2,234	2,159	0	7,569
C05_2B	808	0	887	6,007	0	5,967	7,449	0	7,741	8,602	0	9,161
C05_2C	0	0	0	1,575	0	406	1,990	0	1,192	2,322	0	2,181
C05_2D	5,501	0	924	13,152	0	6,408	17,148	0	10,384	20,345	125,218	15,933
C05_3A	0	0	0	10,176	0	0	12,602	0	1,024	14,543	0	2,728
C05_3B	331	0	264	2,680	0	3,515	3,165	0	5,303	3,553	0	6,733
C05_3C	0	0	0	0	0	0	0	0	0	0	452	0
C05_3D	0	0	0	8,688	0	0	70,398	0	0	119,767	0	0
C05_4A	75,179	0	0	289,828	0	0	316,659	0	0	338,124	0	0
C05_4B	0	0	0	0	0	0	3,790	0	0	39,142	0	0
C05_5	53,293	0	0	73,524	0	0	76,053	0	60	78,076	708	290
C05_6	172,454	0	0	428,361	0	0	465,834	0	1	495,813	370	256
C06_1A	500	0	96	1,099	0	191	2,692	0	223	3,967	0	1,070
C06_1B	0	0	0	0	0	0	0	0	0	6,196	0	0
C06_2	0	0	0	0	0	0	34,562	0	0	71,514	0	0
Total	333,316	0	2,172	1,016,621	0	16,494	1,242,590	0	31,689	1,471,182	131,057	52,234

The 0.002 ACE, or the 500-year event, is the lowest probability event analyzed, and would cause the highest expected economic damages in the floodplain, while the 0.1 ACE, or 10-year event, is a higher probability event and would result in the lowest expected economic damages for the events displayed above. For the 0.002 annual chance event, estimated annual damages are more than $1.4 billion dollars. This decreases to $131

million for the maximum with-project condition and $52 million for the minimum with-project condition. For the 0.1 annual chance event, expected annual damages are $333 million under without project conditions, and are reduced to zero under the maximum improvement condition and $2 million for the minimum channel improvement condition.

5.3 With-Project Performance

The project performance statistics for maximum improvement project conditions and minimum improvement project conditions are displayed below.

Table 15. With-Project Maximum Improvement Project Performance (%)

		Long-Term Risk[2]			Assurance[3]		
Reach	AEP[1]	10 year	30 year	50 year	2.00%	1.00%	0.20%
Reaches C02-C04							
C02_1	0.12	1.21	3.58	5.89	99.00	99.00	99.00
C04_1	0.28	2.79	8.14	13.20	98.42	96.68	71.28
C04_2	0.30	2.95	8.60	13.92	98.13	96.39	70.23
C04_3	0.21	2.10	6.16	10.05	96.70	95.04	87.20
C04_4a	0.02	0.22	0.66	1.10	99.00	99.00	99.18
C04_4b	0.01	0.10	0.30	0.50	99.00	99.00	99.00
Reaches C05-C06							
C05_1a	0.27	2.72	7.94	12.88	99.00	99.00	99.00
C05_2a	0.03	0.34	1.03	1.70	99.00	99.30	98.70
C05_2b	0.20	1.99	5.86	9.58	98.60	94.75	78.13
C05_2c	0.12	1.14	3.39	5.59	98.39	96.82	91.42
C05_2d	0.61	5.97	16.86	26.48	89.58	82.73	49.60
C05_3a	0.04	0.37	1.11	1.84	99.00	99.19	98.48
C05_3b	0.19	1.93	5.68	9.29	99.01	95.25	77.15
C05_3c	0.61	5.98	16.88	26.52	91.43	81.27	48.84
C05_3d	0.03	0.30	0.91	1.51	99.00	99.35	97.93
C05_4a	0.03	0.32	0.95	1.58	99.00	99.33	98.96
C05_4b	0.05	0.46	1.38	2.29	99.00	99.00	96.65
C05_5	0.79	7.64	21.21	99.00	90.83	84.82	44.77
C05_6	0.43	4.26	12.24	19.55	96.61	91.91	60.73
C06_1a	0.01	0.10	0.30	0.50	99.00	99.00	99.00
C06_1b	0.04	0.39	1.17	1.95	99.00	99.00	97.59
C06_2	0.01	0.10	0.30	0.50	99.00	99.00	99.00

[1]Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed below has occurred

Table 17 shows that in C05_5, the annual exceedance probability (AEP) decreases from 87 percent under the without-project condition to 1 percent under the with-project condition for the maximum channel improvement alternative. In C06_1A, the AEP decreases from 99 percent to 0.01 percent under the without project condition. Maximum channel improvements also result in an increase in the probability that no flooding occurs in specific channels, when there is a flood event. In C06_1a, the assurance increases from 0.01 percent under the without project condition to 99 percent under the maximum improvement condition for the 0.002 ACE. This same number increases from 12 percent to 96 percent for the 0.02 ACE in reach C05_6. The maximum improvement measures significantly decrease the probability of flooding in these impact areas.

Table 16. With-Project Minimum Improvement Project Performance (%)

		Long-Term Risk[2]			Assurance[3]		
Reach	AEP[1]	10 year	30 year	50 year	2.00%	1.00%	0.20%
Reaches C02-C04							
C02_1	1.30	12.22	32.36	47.87	80.84	70.28	38.78
C04_1	0.01	0.11	0.33	0.54	99.00	99.00	99.00
C04_2	0.01	0.11	0.34	0.56	99.00	99.00	99.00
C04_3	0.01	0.10	0.30	0.50	99.00	99.00	99.00
C04_4a	0.10	1.01	2.99	4.93	99.06	98.82	98.12
C04_4b	3.40	29.23	64.55	82.25	56.39	40.37	31.85
Reaches C05-C06							
C05_1a	0.06	0.58	1.74	2.89	99.00	99.00	99.00
C05_2a	1.34	12.58	33.19	48.94	87.78	86.58	79.44
C05_2b	24.12	93.67	99.00	99.00	11.16	9.73	5.38
C05_2c	3.23	27.97	62.62	80.61	64.79	58.37	38.42
C05_2d	10.15	65.72	95.97	99.00	13.97	9.49	2.98
C05_3a	1.34	12.61	33.26	49.03	89.68	88.82	82.09
C05_3b	19.05	87.92	99.00	99.00	20.77	18.51	11.33
C05_3c	0.01	0.11	0.32	0.53	99.00	99.00	99.00
C05_3d	0.03	0.27	0.81	1.35	99.00	99.00	99.42
C05_4a	0.04	0.39	1.18	1.96	99.00	99.00	99.00
C05_4b	0.01	0.10	0.30	0.50	99.00	99.00	99.00
C05_5	1.71	15.81	99.00	99.00	77.63	72.14	40.24
C05_6	1.43	13.44	35.15	99.00	81.97	73.98	38.72
C06_1a	99.00	99.00	99.00	99.00	0.01	0.01	0.01
C06_1b	0.03	0.25	0.75	1.24	99.00	99.00	98.83
C06_2	0.01	0.10	0.30	0.50	99.00	99.00	99.00

[1]Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed below has occurred

Table 18 displays project performance under minimum channel improvement conditions. In C02_1, the probability that flooding will occur in any given year decreases from 74 percent under the without-project condition to 1 percent under the minimum project improvements. The probability no flooding will occur given that a 0.002 annual chance event occurs increases from five percent under the without-project condition to 38 percent with minimum project improvements for C02_1. The two tables above show that maximum channel improvements provide a higher level of risk reduction to some areas, particularly C05_6 and C06_1A, than minimum channel improvements.

6.0 Costs

Costs for minimum and maximum channel improvement measures are used to calculate net benefits and the benefit-cost ratio, in order to formulate the NED plan. These costs include construction costs by reach, interest during construction, contingency costs, operation and maintenance, and lands, easements, rights of way and relocations (LERRDs), which includes costs for replacing necessary bridges in the project area. Table 18 shows project first costs by channel for minimum and maximum improvement measures.

Table 17. Construction Costs by Plan, FY 2019 Price Levels ($000)

	Plan		% of Construction Cost by Component -	% of Construction Cost by Component -
Project Component	Minimum Improvement	Maximum Improvement	Min Plan	Max Plan
C02-C04	333,276	643,254	40	44
Reach C02	281,160	281,160	34	19
Reach C04	52,116	362,093	6	25
C05-C06	373,806	716,218	45	49
Reach C05	351,003	651,231	43	44
Reach C06	22,802	64,987	3	4
Non Reach-Specific	116,459	116,459	14	8
Flood Wall	19,380	19,380	2	1
Widen Warner Ave	59,191	59,191	7	4
Remove Tide Gates	8,512	8,512	1	1
Mitigation	9,375	9,375	1	1
Real Estate	20,000	20,000	2	1
Total Construction Costs[1]	823,541	1,475,931	100	100

[1] Construction costs include bridge replacement costs by reach; annual O&M costs not included

Table 19 shows that channels C05 and C06 together comprise the majority of first costs for the maximum and minimum plans. . The total first cost for minimum channel improvements is $823 million, and the total first cost for maximum channel improvements is more than $1.4 billion.

Table 20 shows total annual costs, including annualized investment cost and operation and maintenance costs, for minimum and maximum improvements under the current federal 2.875 percent rate.

Table 18. Alternative Plan Costs in FY 2019 Price Levels ($000)

Cost Category	Plan	
	Minimum Plan, 2.875%	Maximum Plan 2.875%
Construction Costs[1]	711,398	1,041,834
LERRDs	112,143	434,097
Total First Costs	823,541	1,475,931
Interest During Construction	429,133	613,819
Gross Investment	1,252,674	2,089,750
Interest and Amortization	42,907	73,243
Operation and Maintenance	617	1,166
Total Annual Costs	43,524	74,409

[1] Includes PED, S&A, and contingency costs

In table 19, construction costs include construction and construction management, and PED (pre-construction, engineering and design), LERRD (lands, easements, rights of way, relocations, and disposals) are added to construction costs to derive estimates of total first costs. Gross investment costs include the project first cost and interest during construction. Investment costs are annualized for the 50-year period of analysis to compute annual investment costs. Interest during construction is based on a 15 year construction schedule, which is described in more detail in Section 7.

The table shows that total first costs, including construction costs and lands and damages, are over $823 million for the minimum plan, and exceed $1.4 million for the maximum plan. Accordingly, interest during construction is significantly higher for the maximum plan. Average annual costs including operation and maintenance for the minimum plan are nearly $43 million, and nearly $73 million for the maximum plan.

7.0 Benefit-Cost Analysis

7.1 Benefit-Cost for Minimum and Maximum Improvement Plans

In order to identify the NED plan, a benefit-cost analysis was completed for minimum improvement measures and maximum improvement measures. The net benefits below used for plan formulation are shown without interest during construction. Interest during construction based on a 15-year construction schedule is detailed in section 7.3.

7.2 Plan formulation

Based on with-project net benefits for minimum and maximum channel improvements, an incremental analysis was completed that analyzed net benefits by reach to combine minimum and maximum measures into one plan. This plan is the NED (National Economic Development) plan, and also the TSP (Tentatively Selected Plan). The incremental analysis by reach, and the formulation of the TSP is shown below.

Table 19. Plan Formulation Summary Table FY 2019 Price Levels, 2.875% ($000)

Reach	Impact Area	Minimum Plan: Total First Cost	Minimum Plan: Average Annual Cost	Minimum Plan: Average Annual Benefits	Minimum Plan: Average Annual Net Benefits	Maximum Plan: Total First Cost	Maximum Plan: Average Annual Cost	Maximum Plan: Average Annual Benefits	Maximum Plan: Average Annual Net Benefits	NED Plan: Total First Cost	NED Plan: Average Annual Cost	NED Plan: Average Annual Benefits	NED Plan: Average Annual Net Benefits
1 & 2	C05_5 & C05_6	307,764	11,801	75,789	63,989	307,764	11,801	75,789	63,989	307,764	11,801	75,789	63,989
3	C05_4B	13,896	554	258	-296	57,010	2,210	929	-1,281	13,896	554	258	-296
4	C05_4A	14,623	598	17,492	16,894	54,344	2,121	18,128	16,008	14,623	598	17,492	16,894
5	C05_2D & C05_3D	14,720	598	2,045	1,447	73,589	2,866	3,684	818	14,720	598	2,045	1,447
6 & 7	C05_2C & C05_3C	0	0	276	276	82,744	3,214	3,359	145	0	0	276	276
8	C05_2B & C05_3B	0	0	75	75	28,980	1,131	1,094	-36	0	0	75	75
9	C05_2A & C05_3A	0	0	526	526	46,799	1,838	1,585	-253	0	0	526	526
10, 11, 12	C05_1A	0	0	230	230	0	0	209	209	0	0	230	230
13,14,15	C06_2	13,740	541	884	343	44,177	1,715	1,320	-395	13,740	541	884	343
16 &17	C06_1B	4,996	198	43	-155	15,156	592	124	-469	4,996	198	43	-155
18 & 19	C06_1A	4,065	161	689	528	5,654	221	728	507	4,065	161	689	528
20	C04_4b & C04_4a	281,160	10,707	6,713	-3,994	281,160	10,707	6,713	-3,994	281,160	10,707	6,713	-3,994
21	C04_3	42,817	1,670	3,186	1,516	142,041	5,483	5,124	-360	42,817	1,670	3,186	1,516
22	C04_1 & C04_2	0	0	2	2	104,739	4,063	492	-3,571	0	0	2	2
23	C02_1	9,299	371	80	-291	115,314	4,476	2,581	-1,895	9,299	371	80	-291
Channel Construction Subtotal		707,081	27,198	108,290	81,091	1,359,472	52,436	121,859	69,422	707,081	27,198	108,290	81,091
Non Reach-specific Costs													
	Flood Wall (PCH)	19,380	735	-	-	19,380	735	-	-	19,380	735	-	-
	Widen Warner Avenue	59,191	2,246	-	-	59,191	2,246	-	-	59,191	2,246	-	-
	Tide Gates	8,512	323	-	-	8,512	323	-	-	8,512	323	-	-
	Real Estate	20,000	759	-	-	20,000	759	-	-	20,000	759	-	-
	Mitigation	9,375	356	-	-	9,375	356	-	-	9,375	356	-	-
Total by Alternative		823,541	31,618	108,290	76,672	1,475,931	56,856	121,859	65,003	823,541	31,618	108,290	76,672

Note: IDC not included in the annual average cost

Table 21 shows reach by reach annual costs and benefits for the minimum and maximum improvement measures. Total first costs for the maximum channel improvements plan are the highest, at $1.4 billion. Annual net benefits for the maximum improvement measures are $121 million, annual net benefits for the minimum channel improvement measures are $108 million, and annual net benefits for the combination of these measures, also known as the NED, are $108 million. The minimum plan results in $76 million of annual net benefits, while the maximum plan results in $65 million of annual net benefits. For reaches 1, 2, and 23, the minimum plan is the maximum plan, and thus the maximum plan is the only option and becomes the NED. For all other reaches, the minimum plan becomes the NED. Thus the NED maximizes annual net benefits and is the TSP.

Table 22 shows the incremental analysis displayed in Table 21, by benefit categories and plan. Although benefits are higher for maximum improvement measures than for minimum improvement measures, net benefits are lower for the maximum improvement plan because the maximum measures costs are higher. Thus the NED benefits and costs reflect the same values as the minimum plan. It is important to note that benefits for structure and structure contents and other related categories for the minimum improvement plan reflect maximum improvement measures for Reaches 1, 2, and 23, and therefore will not match values shown in Table 12. IDC costs were excluded in annual cost values for the incremental analysis, due to the timing of construction period by increment, and are included in Section 7.3.

Table 20. Project Alternatives Benefit-Cost Comparison in FY 2019 Price Levels ($000)

	Plan		
Category	Minimum Improvement 2.875%	Maximum Improvement 2.875%	NED 2.875%
Annual Benefits	108,286	121,859	108,286
Structure and Structure Contents	75,985	76,553	75,985
Other Related Categories†	24,315	24,530	24,315
Bridge Replacement	1,188	13,101	1,188
Traffic Delay Benefits	5,805	6,345	5,805
Flood Insurance Program Benefits	992	1,330	992
Annual Costs*	31,618	56,856	31,618
Net Benefits	76,668	65,003	76,668

†Includes emergency, cleanup, and vehicle benefits

* Excludes IDC

Table 23 summarizes the measures used to formulate the NED, by reach and economic impact area. ‘Maximum’ indicates metrics from maximum channel improvement measures maximize net benefits in the reach, while ‘minimum’ indicates that minimum channel improvement measures maximize net benefits in the reach.

Table 21. NED Plan Measures

Reach	Impact Area	Measure
1 & 2	C05_5 & C05_6	Maximum
3	C05_4B	Minimum
4	C05_4A	Minimum
5	C05_2D & C05_3D	Minimum
6 & 7	C05_2C & C05_3C	Minimum
8	C05_2B & C05_3B	Minimum
9	C05_2A & C05_3A	Minimum
10, 11, 12	C05_1A	Minimum
13,14,15	C06_2	Minimum
16 &17	C06_1B	Minimum
18 & 19	C06_1A	Minimum
20	C04_4b & C04_4a	Minimum
21	C04_3	Minimum
22	C04_1 & C04_2	Minimum
23	C02_1	Maximum

7.3 Benefit-Cost Analysis with Incremental Construction Schedule

This section utilizes a 15-year incremental construction schedule to compute net benefits and the benefit-cost ratio for the NED, identified above, and the LPP (Locally Preferred Plan). The LPP is the maximum plan in all reaches. The following figure displays the construction schedule, by increment.

Table 22. Construction Increment Table

Construction Increment	Construction Duration	Construction Start	Construction End
Inc 1	4	2021	2024
Inc 2	3	2025	2027
Inc 3	3	2028	2030
Inc 4	3	2031	2033
Inc 5	2	2034	2035
Total	15	2021	2035

Under the current construction schedule, C02 would be completed in 2024, C04 would be complete in 2035, C05 would be complete in 2035, and C06 would be complete in 2035. Different portions for each of these channels are completed at different times.

For each construction increment, benefits and construction costs realized before the base year of 2035 were compounded to the base year. Interest during construction was calculated for the duration of the construction period of each increment shown in Table 28. Annual benefits and operation and maintenance costs for a 50-year period were discounted back to the base year. The sum of these benefits and costs is shown in Table 29. Benefits for each construction increment are calculated for the year immediately preceding the last year of construction since the majority of benefits will be realized incrementally, prior to the entire project being completed.

Using this 15-year construction schedule, the costs and benefits for the NED plan, formerly identified as the TSP, and the LPP (locally preferred plan) were analyzed. The measures for the NED plan are shown by reach above in Table 23. The LPP plan implements maximum channel improvements in all reaches.

Costs and benefits are shown in Table29 for the NED and LPP plans at 2.875 percent, taking into account the incremental 15-year construction schedule displayed in Table 28.

Table 23. Benefit-Cost Analysis, 15-year Construction Schedule, 2.875% ($000)

	NED Plan	LPP
Investment Cost		
Construction Cost	711,398	1,041,834
LERRDs	112,143	434,097
Subtotal First Cost	823,541	1,475,931
Interest During Construction	429,133	613,819
Total Gross Investment	1,252,674	2,089,750
Annual Cost		
Interest and Amortization	42,907	73,243
OMRR&R	617	1,166
Subtotal	43,524	74,409
Annual Benefits	145,295	160,511
Net Annual Benefits	101,771	86,102
Benefit to Cost Ratio	3.3	2.2

Note: Cost and benefits are displayed in FY2019 Price Levels and discounted at 2.875% over a 50 year period of analysis, with a base year of 2035

At the 2.875 percent discount rate, the average annual cost of the NED plan is $43 million, and the average annual cost of the LPP is $74 million. At 2.875 percent, the NED plan has annual net benefits of $101 million, and the LPP plan has annual net benefits of $86 million. These values include benefits compounded to the base year, and interest during construction, and are therefore different than the values shown in the incremental analysis in Table 21. The NED has a BCR of 3.3 and the LPP has a BCR of 2.2 at the 2.875 percent rate. The NED plan and LPP are both economically justified, and the NED maximizes net benefits.

7.4 Conclusion

The purpose of the study is to evaluate flood risk within the Westminster Watershed. Under the without project condition, it is estimated that nearly 400,000 people and 44,000 structures are at risk of inundation. It is estimated that average annual damages would be above $107 million, including structure and structure content, vehicle, emergency, cleanup, traffic delay damages, and bridge benefits. Implementing minimum channel improvement measures would result in estimated average annual benefits of $107 million, and implementing maximum channel improvement measures would result in average annual benefits of approximately$120 million.

This study assessed minimum and maximum channel improvement measures in the study area, and formulated a plan that incrementally maximizes net benefits by channel reach. This plan, known as the NED plan, was analyzed along with the LPP plan, based on a 15-yr construction schedule. Under this construction schedule, the NED plan would result in an estimated $145 million in average annual benefits and the LPP would result in average annual benefits of $160 million.

The study finds that at the 2.875 percent discount rate, the NED plan has annual net benefits of $101 million and a BCR of 3.3, and the LPP plan has annual net benefits of $86 million, and a BCR of 2.2.The LPP does not maximize annual net benefits, but is economically justified. The NED plan maximizes annual net benefits, and has a higher BCR than the LPP. The NED plan is a combination of minimum and maximum channel improvement measures and is economically justified at the current federal discount rate.

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1.0 Multi-Study Traffic Analysis

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MULTI-STUDY TRAFFIC ANALYSIS
LOS ANGELES REGIONAL DYNUST MODELING
BASE YEAR VALIDATION & INUNDATION SCENARIO ANALYSES

PREPARED BY:

METROPIA, INC.

PREPARED FOR:

U.S. ARMY CORPS OF ENGINEERS
CHICAGO AND LOS ANGELES DISTRICTS

OCTOBER 2018

metropia

CONTENTS

FIGURES AND TABLES

1. INTRODUCTION

The development of transportation planning and operation models has advanced due to the need to account for recurrent congestion in the planning process, to better analyze non-recurring congestion (e.g., incidents, construction, etc.) on a larger geographical scale and to assess a variety of ITS strategies among other. As a result, many transportation professionals are migrating traditional four-step (4-step) travel demand models to Activity-Based Models (ABM), such as the Southern California Association of Government (SCAG) travel demand model, to take advantage of the enhancements offered in modeling an individual's behavior. Regardless of the structure of travel demand models (ABM or 4-step), these models are developed to assess how changes in socio-economic and demographic characteristics impact the travel patterns and the transportation network in an aggregate manner over a selected time horizon. As such, they are better suited to model strategic planning decisions but the assumptions they rely on limit, in many ways, their applicability to operational analysis.

On the other hand, operational models are specifically developed to assess the dynamic conditions of congested environments, including the operations of special events (e.g., incidents, weather conditions, etc.) and have evolved in a number of areas over the past 30 years including their underlying principles (macroscopic to microscopic), their visualization capabilities (from none to incorporating 3D elements) and their scale of applications (corridor to sub-regional analysis.) Transportation professional are well versed in microscopic simulation models and they use them in a variety of projects including, but not limited to, corridor alternative design/analysis, incidents, work zones, traffic management strategies, and managed lanes. Nevertheless, the use of operational models for a large scale or regional application requires significantly more resources compared to travel demand models, in terms of underlying data, time, and funding. To bridge the gap between travel demand models and microscopic simulation models, transportation professionals began deploying, over the past 15 years or so, mesoscopic models as part of proposed modeling frameworks. Mesoscopic models, depending on the adopted approach, may simplify the demand, the supply or just the way they interact, compared to a microscopic model making them a useful tool for large scale operational analysis. Finally, mesoscopic models are often referred to or are interchangeable with Dynamic Traffic Assignment (DTA) models, but it is widely accepted that DTA models are mesoscopic models that deploy the Dynamic User Equilibrium (DUE) user route and/or departure time choice principal. As such, transportation professionals are deploying multi-resolution models to provide analysis at different levels. Multi-resolution models can be two tiered (meso/micro or macro/micro as initially the first generation of these platforms was developed) or three tiered (macro/meso/micro or macro/sub-area macro/micro as the first generation of these platforms was developed), depending on the specific needs of the assignment.

Metropia is utilizing a two-tier multi-resolution model comprised of SCAG's travel demand and DTA models to support the US Army Corps of Engineers (USACE) in performing traffic analyses pertaining to flood-induced road closures. This document provides a discussion on the validation of the base year model and its subsequent use for analyzing inundation scenarios, in support of the Westminster East Garden Grove Flood Risk Management Feasibility Study. This document will undergo technical and public review which may result in revisions to the findings prior to completion of the final Chief's Report.

2. STUDY AREA

The Southern California Association of Governments (SCAG) oversees the transportation planning process for the entire southern California region comprising six (6) counties, one-hundred ninety-one (191) cities and over eighteen (18) million residents. The region is home to several major airports, a myriad of transit agencies, independent City Departments of Transportation, and two world-class ports in Long Beach and Los Angeles, that together process over a third of all ocean-going freight into and from the United States. The transportation system service millions of residents as well as daily visitors, utilizing various means of transportation. SCAG's ABM model simulates daily activities and patterns in the SCAG region, illustrated in Figure 1.

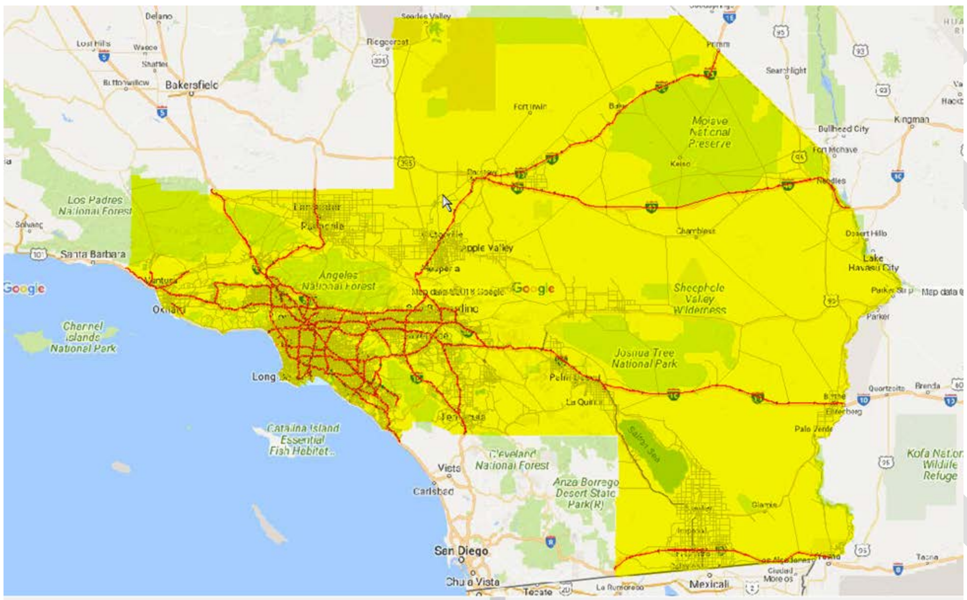

Figure 1: SCAG's Travel Demand Model Coverage Area

In 2014, SCAG contracted with Metropia, Inc. to develop a Dynamic Traffic Assignment (DTA) model based on the Dynamic Urban Systems for Transportation (DynusT) software, to investigate capacity improvements, congestion pricing, intelligent transportation system strategies, travel demand management, and other transportation matters. The existing SCAG DynusT model covers an extremely large geographic area and is one of the largest networks ever modeled. It covers over 20,000 centerline road miles, 31,000 nodes and 81,000 links and it tends to have a much finer resolution for areas within the Counties of Los Angeles and Orange. While the proposed inundation scenarios for the Westminster study are expected to have regional effects, their area of influence is envisioned to be significantly smaller than the SCAG coverage area and confined with a sub-area. Figure 2 illustrates the sub-area that was utilized to analyze the effects of the inundation scenarios (blue) as well as the area where flood-induced road closures are expected based on the flood conditions (yellow).

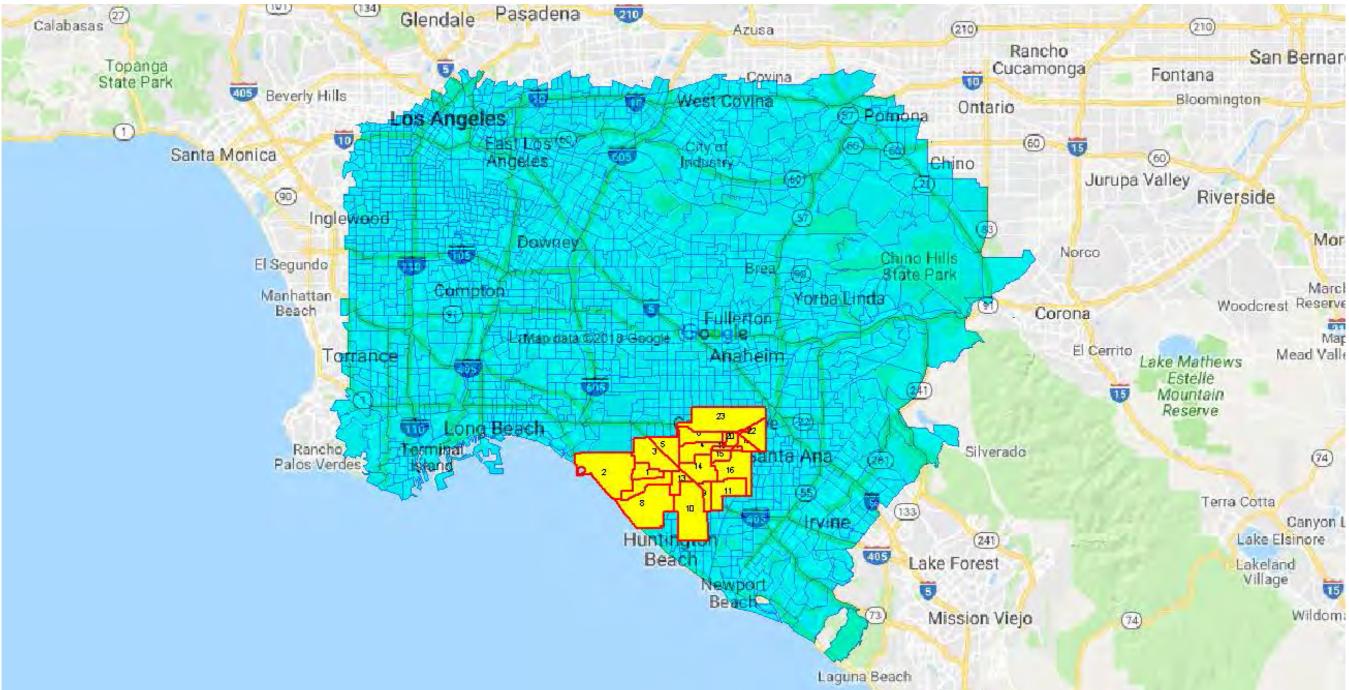

Figure 2: Westminster Study and Flood-Induced Road Closure Areas

3. DYNUST OVERVIEW

Balancing run time, data needs, geographic and temporal scales are key considerations when developing and implementing a DTA model. In literature, there are two major DTA model categories – analytical and simulation-based DTA. Most of the existing commercially available models are simulation-based because simulation-based DTA models are generally more flexible than analytical DTA models in accounting for various network traffic conditions such as traffic signals, incidents, or driver routing behaviors. A simulation-based DTA model typically consists of two principal model components: a simulation model and a traffic assignment model. The simulation model is aimed at evaluating the quality of the assignment solution and the assignment model takes the inputs from the simulation to further generate more paths and assign vehicles to different paths in order to get close to the equilibrium conditions as measured by the Relative GAP, over the iterations. While equilibrium is the state-of-practice for normal operating conditions, analyzing operating conditions related to incidents (e.g., construction zones, weather events, football games, etc.) does not generally require equilibration.

Dr. Yi-Chang Chiu, the founder of Metropia Inc. and a Professor at the University of Arizona, started the theoretical development of DynusT in 2002 and has been leading the DTA modeling innovation ever since. DynusT is currently licensed and supported by Metropia with a primary mission to facilitate real-world applications and enhance user's experience. DynusT is the outcome of more than a decade of rigorous research, as illustrated in Figure 3, and ushers in a new era of enhanced usability and advanced modeling features and capabilities. It is also in compliance with the DTA definitions and requirements specified in TRB's DTA Primer[1].

[1] Dr. Chiu, President of Metropia, was the main author and Dr. Papayannoulis, Vice president of Metropia, was one of the industry practitioner reviewers.

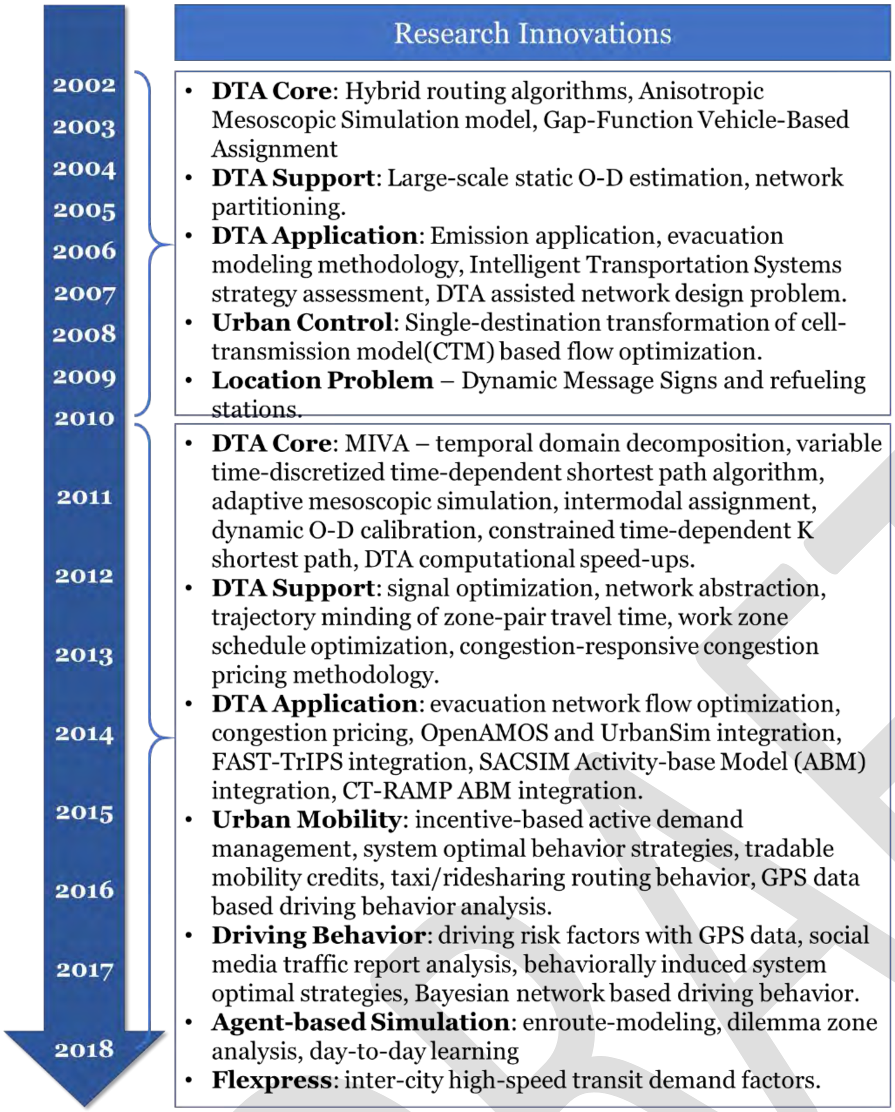

Figure 3: DynusT Research and Development History

Numerous DTA supporting functions have been developed to make DynusT a practical modeling tool for large-scale regional and corridor analyses, including the calibration of large-scale static and dynamic origin-destination matrices, based on both link counts (passing vehicles) and vehicle speed profiles. DynusT researchers developed a one-norm formulation with linear transformation as a Linear Programming (LP) problem (as opposed to the traditional computationally intractable quadratic formulation). This method opened the possibility of allowing the region-wide DTA model with thousands of zones (consequently millions of LP variables) to be calibrated in a computationally tractable manner. The O-D calibration and network partitioning capabilities were also built into the DynusT software and is available to the users.

The rigor and innovation incorporated in DynusT are reflected in the mesoscopic vehicular simulation logic, time-dependent shortest path algorithms and the vehicle assignment methods. These algorithmic advancements were implemented with the most efficient modern computing architecture. The hallmark accomplishment was the development of an empirically validated Anisotropic Mesoscopic Simulation (AMS) model that exhibits microscopic model like traffic flow properties with superb run-time performance (100 to 1000 times faster than a typical microscopic simulation model). Another significant advancement was the development of the Gap-Function Vehicle-based assignment algorithms that effectively identify and improve underperforming vehicles travel time so that dynamic user equilibrium convergence can be enhanced. In addition, the DynusT researchers developed the temporal domain decomposition method to allow large-scale problems to be solved in a computationally efficient manner model. This advancement was later integrated into DynusT and made DynusT arguably the most computationally efficient DTA model in the industry[2].

The algorithmic advances, supporting functions and DynusT's overall excellent traffic flow properties that are consistent with classical traffic flow theories are reasons for the high trust placed by practitioners who use the model to accurately depict traffic dynamics and congestion patterns, as evidenced by the accelerated number of citations and use of DynusT from 33 (2007-2010) to more than 240 from 2010 to 2017. Figure 4 identifies US markets where DynusT has been used to support projects, many of which have been implemented with FHWA's support and approval.

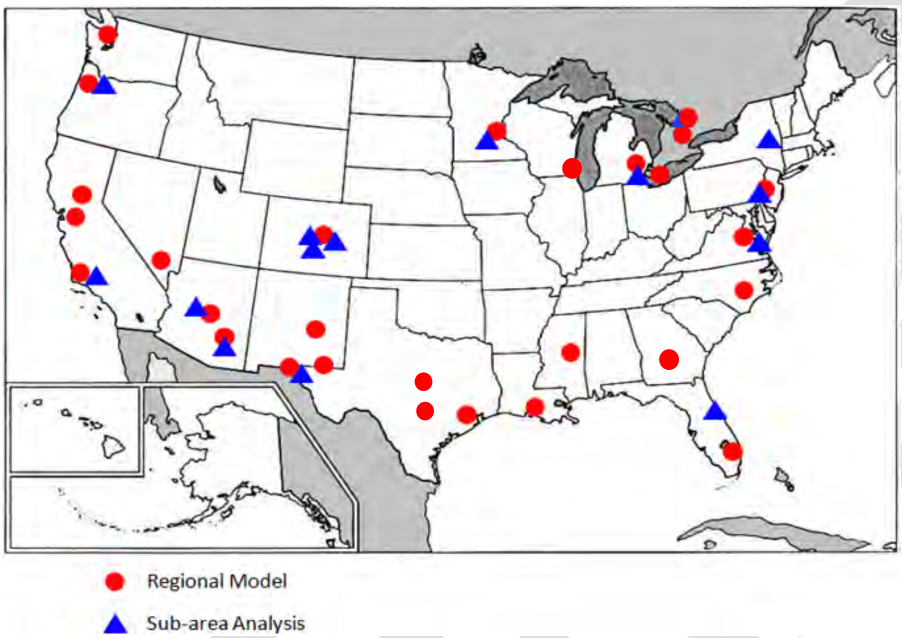

Figure 4: DynusT Deployment in the U.S.

DynusT also has a long track record of integrating with Activity-based Models (ABM) and was successfully utilized in both the recent ARC and ODOT SHRP C10 ABM-DTA integration projects. As early as 2010, it was selected as the primary DTA model by FHWA/TRB SHRP2 for several high-profile research projects including three SHRP2 C10 projects that pioneered the integration of ABM and DTA at the regional level. Between 2010 and 2017, DynusT was chosen to be integrated with several prominent ABM models such as SACSIM, OpenAMOS, and the land use model UrbanSim. One significant achievement was the collaboration with Prof. Mark. Hickman and his team on the development of the first simulation-based dynamic transit assignment model FAST-TrIPS. DynusT researchers guided and shaped FAST-TrIPS to achieve a seamless integration with DynusT and DTA in general. Furthermore, a new approach was proposed that exploited the DTA simulation vehicle trajectories to extract and store the zone-to-zone travel times without creating time-dependent skim

[2] The Southern California Associations of Governments (SCAG) conducted independent research on several prominent DTA models (DynusT, MATSIM, and TRANSIMS). DynusT was the only model capable of running the massive SCAG model with 20+M trips and 80k+ links.

tables (zone-to-zone travel time matrices) that typically take enormous amount of computer memory to store. This theoretical approach was successfully adopted in the 2017 FHWA C10 projects for the Atlanta Regional Commission (ARC) and Ohio Department of Transportation (ODOT) to attain significant computer memory savings.

Finally, DynusT is integrated with DynuStudio, the leading data management and visualization platform, to bring a unique experience to the user and facilitate a variety of tasks such as network coding, performance measures reporting, etc.

4. BASE YEAR MODEL CALIBRATION & VALIDATION

As with all transportation models it is critical that the Westminster DTA model to be calibrated and validated to reflect operations within the study area. While the terms calibration and validation are sometimes interchangeable, the calibration process entails the effort of adjusting model parameters, while the validation process entails the application of the calibrated model and the comparison of modeled values to observed data points (e.g., travel times, volumes, etc.). Generally, the initial calibration effort will produce model values that most probably will not much observed datasets. As such, an iterative process will initiate until the calibrated values produce model values that match observed datasets within acceptable ranges; i.e.; the model is validated. As a general rule, as the transportation models geographic area increases, the model fidelity may either decrease by area (e.g., the model may perform better in a core area where the model interest is focusing compared to a secondary area which simply is used to bring the demand properly to the boundaries of the core area) or by facility category (e.g., lower volume roadways are anticipated to have significant day-to-day variation compared to high volume roadways, thus the validation targets will have more flexibility). Validation criteria and associated target values for mesoscopic models have not been explored to the same degree as travel demand models or microscopic models have. For example, there are proposed criteria for travel demand models in FHWA's "Travel Model Validation and Reasonableness Checking Manual -2nd Edition" and the California Transportation Department (Caltrans) has issued criteria for microscopic models. For mesoscopic models though, the transportation modeling community is still exploring a variety of validation criteria and targets.

The calibration of DynusT is typically conducted in three steps - traffic flow model, time-dependent origin-destination matrices, and departure profiles.

4.1. Traffic Flow Model

Traffic flow models define fundamental relationships and are the basis for determining link delays. For freeway links, the traffic flow model is the sole source of delays. For arterial links, traffic flow models are applied to the mid-link section only, while approach delays due to intersection controls are added to link delays. The basic traffic flow characteristics can be depicted by the three fundamental diagrams illustrated in Figure 5 below:

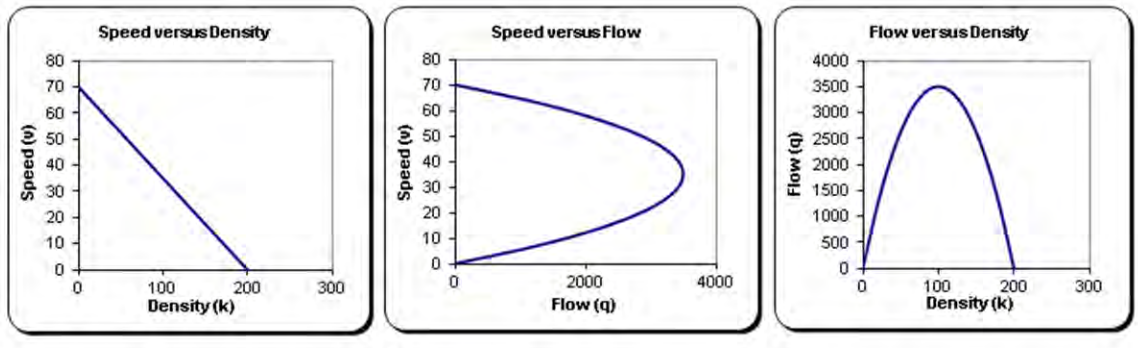

Figure 5: Traffic Fundamental Diagrams

There are two types of curves: 1-regime and 2-regime. Typically, 1-regime curve applies to arterials with interrupted traffic flows. On the other hand, 2-regime curve applies to freeways with uninterrupted traffic flows. The main difference between two curves is 2-regime curve has a distinct flat section when density is lower than a threshold and vehicles can travel at free flow speeds. In DynusT, the traffic flow model is formulated based on the speed-density curves illustrated in Figure 6 below:

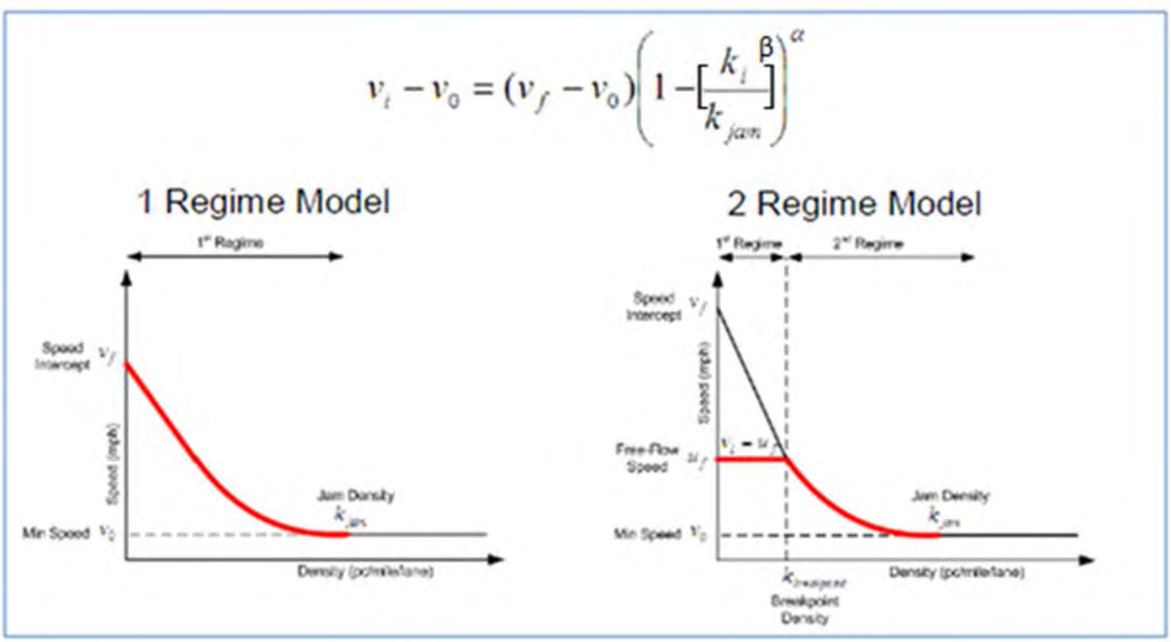

Figure 6 : DynusT Speed Density Curves

Besides the flat section, both curves are basically monotonic decreasing curves. The shape of the curve is determined by two parameters: alpha (α) and beta (β). Alpha determines the general slope of the curve and beta is used to augment the dropping rate of the slope. The alpha and beta parameters could be borrowed from previous models or estimated and calibrated using locally observed data such as speed and flow measurements collected at permanent loop counters throughout the network. The estimation method is based on an iterative approach that involves two steps. During the first step, the alpha value is estimated by keeping the beta value constant. Then the process is repeated using a new beta value. The process continues until a satisfying R-squared is reached. For this project the alpha and beta coefficients were borrowed and Figure 7 and Figure 8 illustrate the pertinent freeway and arterial traffic flow models, respectively.

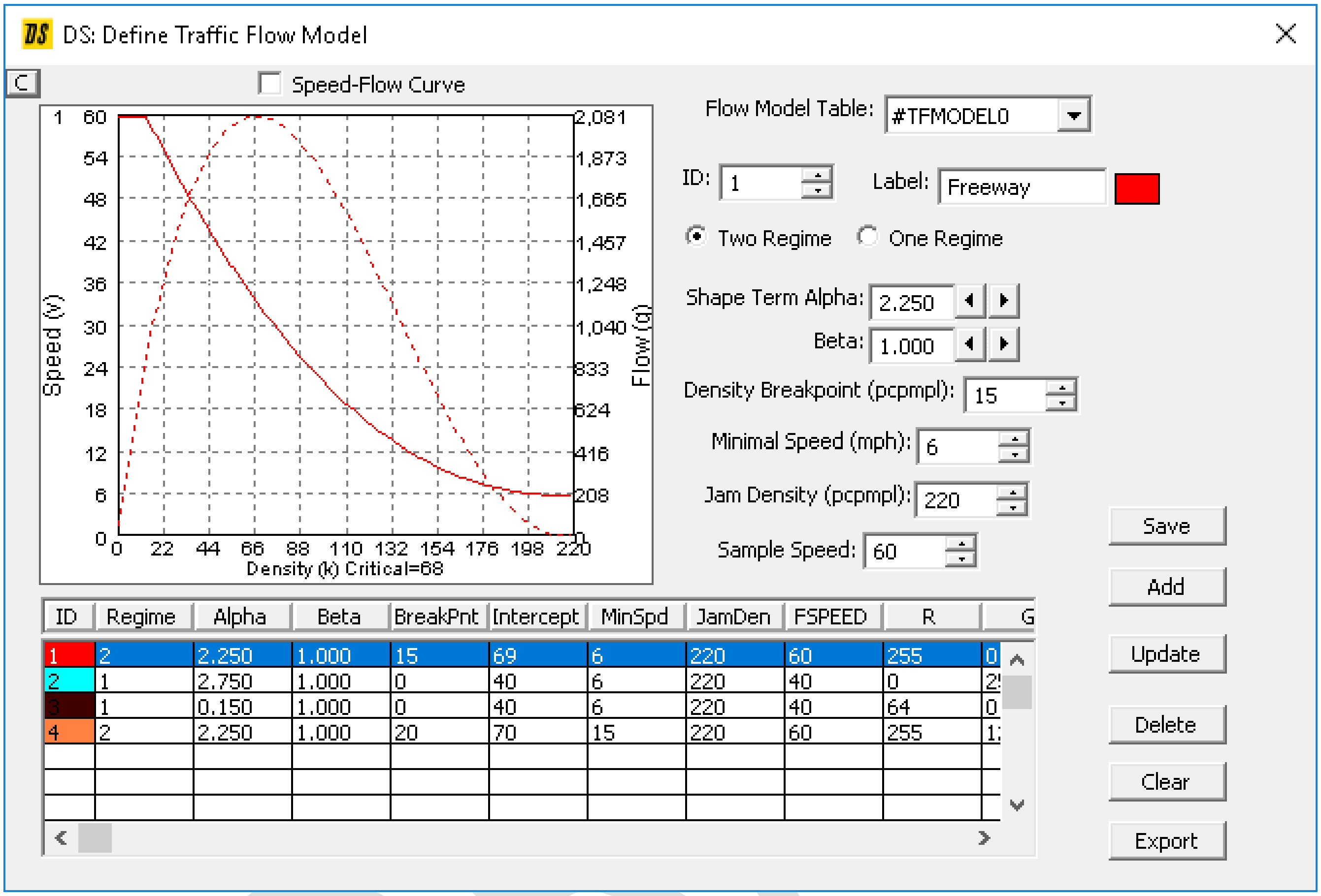

Figure 7: Freeway Traffic Flow Model

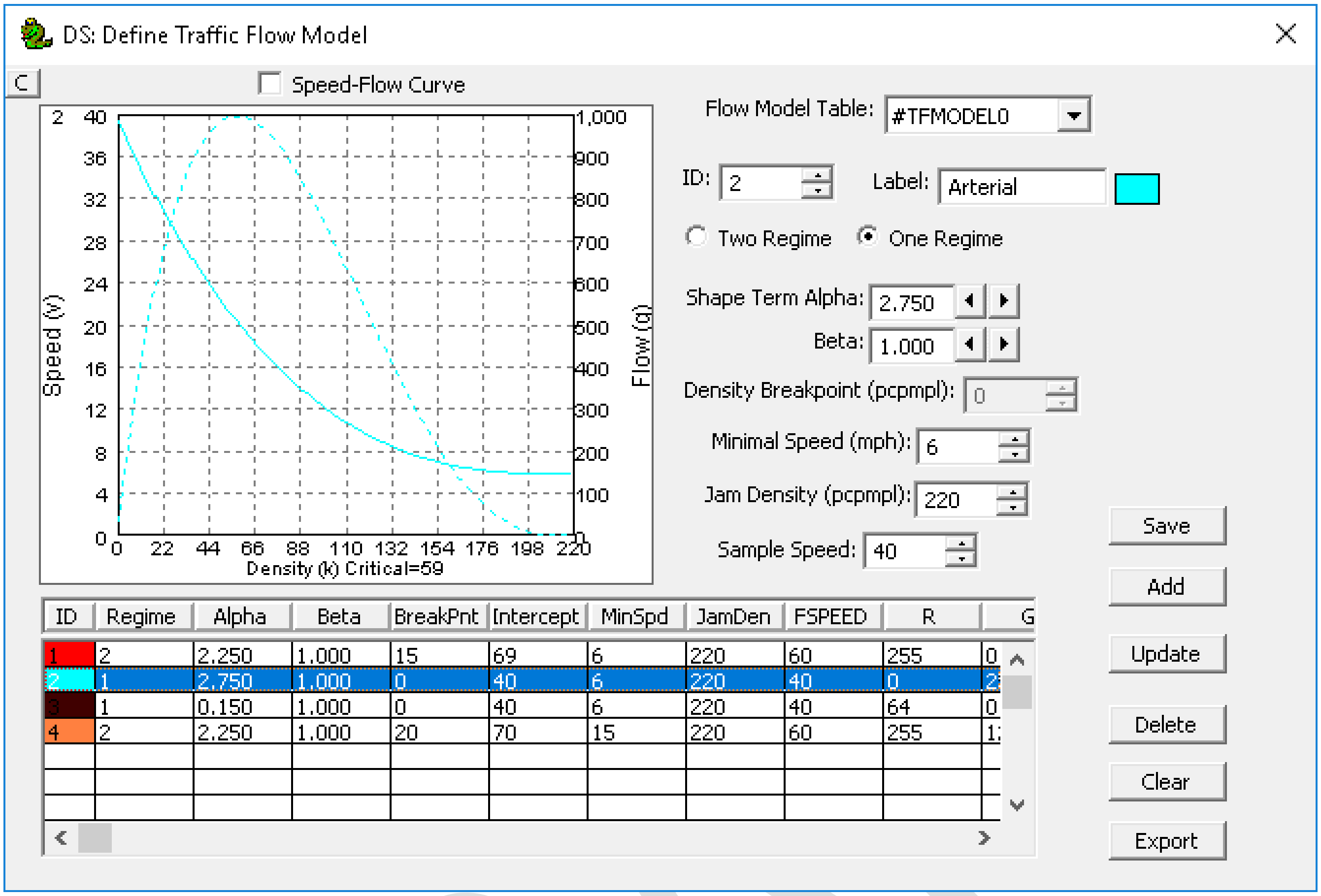

Figure 8: Arterial Traffic Flow Model

4.2. Time-Dependent Origin Destination Matrices

Since the Westminster study area reflects a sub-area of the regional travel demand model, a trip table consistent with the network representing the study area will need to be developed. The process involves the extraction of the relevant data and sub-area travel patterns from the SCAG/DynusT model and their further adjustment utilizing Origin Destination Matrix Estimation (ODME) techniques.

ODME techniques attempt to improve the accuracy of a “seed” trip table (in the case of mesoscopic models the one extracted from the travel demand model) based on information from fragmentary data (traffic counts, trip length distributions, trip ends and OD surveys) and range from simple proportional fitting to sophisticated Maximum Likelihood and Linear Optimization techniques. The end objective is to estimate the best trip table by mode, consistent with the observations available and the criteria selected. The “seed” table for the Westminster sub-area was developed from the SCAG regional DynusT model by performing an extract subarea procedure utilizing the available tools in DynuStudio/DynusT suite. The subarea has two-thousand (2000) zones and eighteen (18) million daily vehicles represented in three classes: SOV, truck and HOV. Table 1 provides statistics for the “seed” trip table. The departure time profiles for the subarea were compiled from the extracted trajectories in the subarea.

Table 1: Daily "Seed" Trip Table Statistics

Class	1	2	3	
TRIPS	SOV	TRK	HOV	ALL
I-I	11,527,727	334,550	350,915	**12,213,192**
I-X	2,536,766	206,644	121,863	**2,865,273**
X-I	2,440,751	198,283	112,122	**2,751,156**
X-X	536,871	78,266	41,644	**656,781**
ALL	**17,042,115**	**817,743**	**626,544**	**18,486,402**

Class	1	2	3	
TRIPS%	SOV	TRK	HOV	ALL
I-I	60.95	2.95	13.27	**94.74**
I-X	1.99	0.25	0.00	**2.38**
X-I	1.99	0.25	0.00	**2.38**
X-X	0.34	0.01	0.00	**0.49**
ALL	**65.26**	**3.46**	**13.27**	**100.00**

There are generally three issues that need to be addressed before an ODME process initiates: a) the sub-area zone structure, b) the intra-zonal trips, and c) the data consistency. Travel demand models are generally developed for strategic planning and their zone structures tend to be census tracks or combinations of census tracks. This structure may or may not be conducive to the objectives of the mesoscopic model, thus requiring a correspondence table to be developed for transferring information from the travel demand model to the mesoscopic model. Intra-zonal trips are generally the least well-estimated elements of a regional trip table. When the extracted trip table from the travel demand model is allocated to the mesoscopic model zone system, there is the potential for short-length trips to be overestimated. These estimates could be further exaggerated by the nature of the ODME process since OD tables are adjusted, among others, by the proportion the ODs contribute to pertinent counts, and thus an increase in short trips translates to a higher proportion of these trips to a specific link. Also, the ODME algorithm that a program uses may itself contribute to an increase of short trips. For example, if an algorithm adjust trips based on zone numbering and zones 1 and 2 are contiguous, then the trips between these zones may be overestimated. For the purposes of this project, the Traffic Analysis Zones (TAZ) internal to the sub-area are the same as the TAZ in the regional model while the external zones reflect locations were major regional corridors intersect with the boundary of the subarea.

Finally, since the ODME process is a mathematical one, it is important for the various datasets to be internally consistent and to inform the process in a unique way. For example, counts on consecutive freeway segments (when no access or egress is allowed) do not provide additional information to the ODME process and the one with the less reliable count should be dropped. The available volume data for this project was reviewed and any inconsistencies were rectified to the extent possible.

4.3. Validation System Performance Metrics

Regression analysis utilizing observed and model volumes was deployed to assess how well the DTA model replicates individual link volumes. A high value of R squared value would indicate that the DTA model is able to depict the network travel patterns and congestion realistically. Figure 9 Illustrates the regression results for all Average Daily Traffic (ADT) counts, indicating a strong correlation between modeled and observed value based on an R2 value of 0.98.

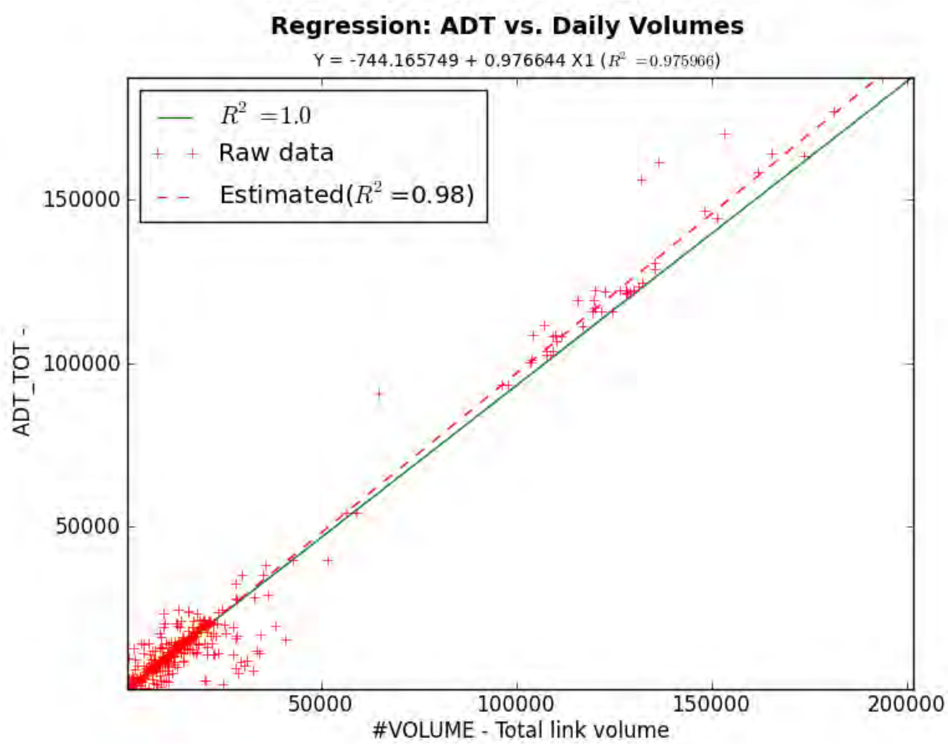

Figure 9: Regression of Daily Observed vs Modeled Volumes

In addition, modeled versus observed volume comparisons were performed across regional screen lines illustrated in Figure 10. The comparison summarized in Table 2 indicates that the DTA model performs well overall, with all screenlines below of a 10% error.

Figure 10: Regional Screenlines

Table 2: Screenline Comparison of Modeled versus Observed Daily Volumes

Screen Line	LINKS	ADT		VOL	GAP%	
2	54	1,348,885		1,343,299	-0.41%	
3	32	741,592		732,398	-1.24%	
4	46	1,694,126		1,642,344	-3.06%	
5	31	1,113,543		1,087,858	-2.31%	
6	6	290,863		309,902	6.55%	
8	16	728,677		751,016	3.07%	
16	32	1,056,370		1,060,110	0.35%	
24	10	316,272		298,914	-5.49%	
29	15	698,107		676,753	-3.06%	
30	2	108,200		115,278	6.54%	
OVERALL	**244**	**8,096,635**		**8,017,872**	**-0.97%**	

Finally, the Root Mean Square Errors (RMSE) by volume group were calculated and the results are presented in Table 3: Root Mean Square Errors (RMSE) by Daily Volume Group. The RMSE statistic reflects the average variation between observed and modeled volumes and could be calculated for all volume observations, by volume group and by time period. Another way that the statistic could be viewed is that represents the Standard Deviation of the dataset pertaining to the observed and model volume differences. For such a dataset, if there was a perfect fit the mean would have been equal to zero. Sometimes, the RMSE is divided by the average observed value for the observed dataset and is referred to as the Percent Root Mean Square Error.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}\left[(\mathrm{Count}_i - \mathrm{Model}_i)^2\right]}{N}}$$

Figure 11: Root Mean Square Errors (RMSE) Equation

where:

Count i = The observed traffic count for link i

Model i = The modeled traffic volume for link i

N = The number of links in the group of links including link i

Table 3: Root Mean Square Errors (RMSE) by Daily Volume Group

Volume Group (VPD)	Number of Counts	%RMSE
Less 40,000	177	18.8
40,000-80,000	2	2.6
80,000-120,000	35	5.3
120,000-160,000	7	6.5
160,000-200,000	4	5.2

5. INUNDATION SCENARIOS AND ANALYSIS

In support of the Westminster East Garden Grove Flood Risk Management Feasibility Study, a transportation analysis utilizing the Base Year DynusT model was undertaken, to estimate the impact of roadway flooding to the area transportation system over a range of flood severities. A total of six (6) scenarios were analyzed and they were determined based on their frequency and schedule of road closures (consisting of the starting time and duration when a given road link in the model is to be closed to traffic), provided by USACE. Table 4 summarizes statistics for each scenario, while Figure 12 through Figure 17 illustrate the road closures for each scenario.

Table 4: Inundation Scenario Summary

YEAR	NODES	LINKS	LANE MILES	START TIME	END TIME	DURATION
5	36	155	114.67	75	2160	2085
10	68	271	202.36	90	2115	2025
25	90	332	237.92	60	2160	2100
50	103	383	278.05	15	2160	2145
100	116	436	321.09	30	2160	2130
500	161	584	412.06	75	2160	2085

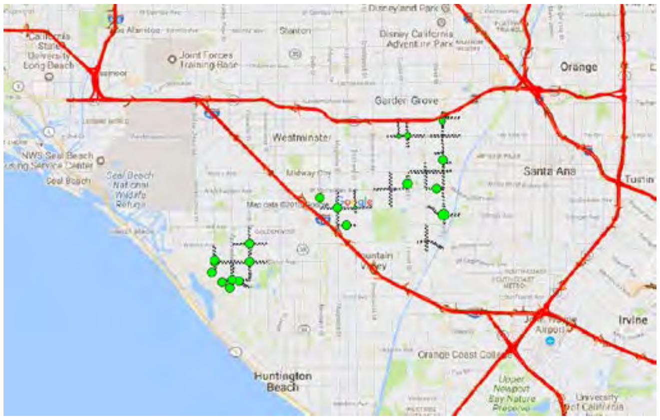

Figure 12: Inundated Links and Nodes for the 5-Year Frequency Scenario

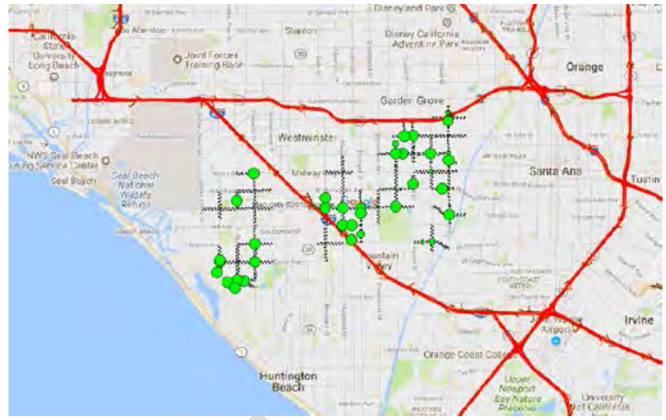

Figure 13: Inundated Links and Nodes for the 10-Year Frequency Scenario

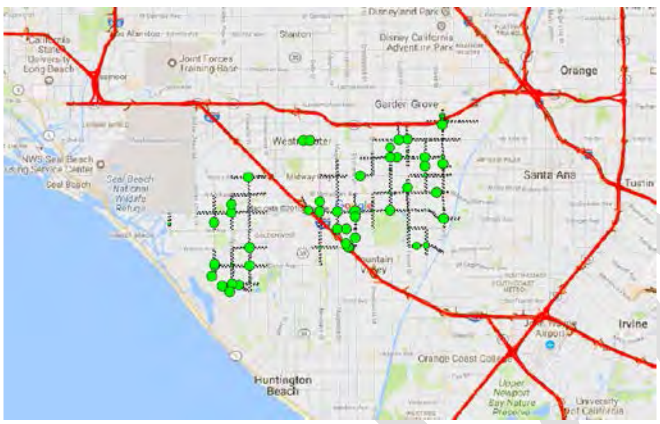

Figure 14: Inundated Links and Nodes for the 25-Year Frequency Scenario

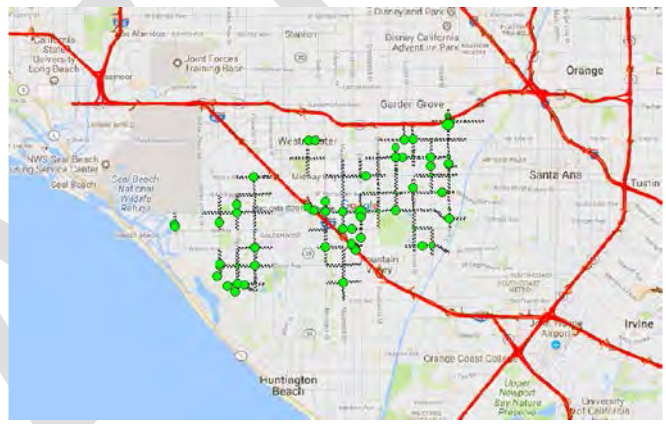

Figure 15: Inundated Links and Nodes for the 50-Year Frequency Scenario

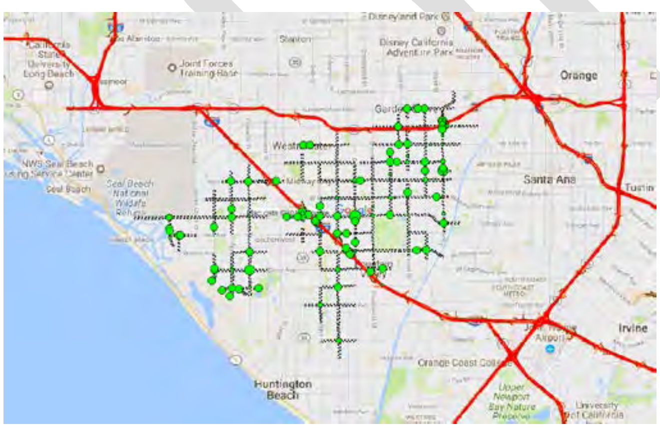

Figure 16: Inundated Links and Nodes for the 100-Year Frequency Scenario

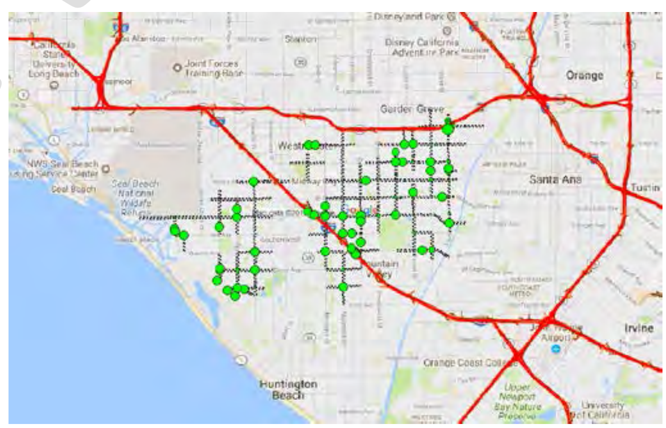

Figure 17: Inundated Links and Nodes for the 500-Year Frequency Scenario

The inundation scenario characteristics shown in Table 4 above, were coded in DynusT's workzone.dat file which was used an input for the subsequent model run (s). For the scenario analyses the following modeling assumptions were made:

- All links in/out inundated intersections will be closed for traffic
- All HOV/HOT lane restrictions were removed from the sub-area network, so all vehicles could use them
- Travel demand for the first day of closures will be equal to the daily demand for the base year
- Travel demand for the second day of closures is equal to first day demand minus the trips that were identified in the base year that traversed the closed links for the 500 years scenario, since these vehicles potentially did not complete their trip during the first day. For consistency purposes this second day demand was used for all the scenarios.
- One hundred (100) percent of the vehicles traversing the closed links for each scenario in the base year, are assumed to have en-route real-time routing information
- Eighty percent of all other vehicles in the network are assumed that follow their habitual paths (long-term routes established in the base year scenario) and only twenty (20) percent will have en-route real time routing information.
- Run simulation with an extended horizon of 3,000 min for all inundation scenarios, to allow simulation of operations past the most severe road closures.

A limited search for potential resources to inform the above assumptions provided little information that could be used to inform the inputs of the model. There are references pertaining to model developments and analysis, there references in terms of developing models to estimate potential demand before, during and after a flood event and there are references providing system statistics (e.g. roadway volumes). Given the budget and schedule constraints, it was decided to develop the above assumptions based on engineering judgement and consensus. For example, assuming en-route real time information for trips affected by the flood-induced road closures is a reasonably expected outcome given the proliferation of smartphone apps and in-vehicle navigation devices. In addition, the traveler population is composed of a mix route choices based on behavior and information accessibility. A 2005 Perception Tracking survey undertaken by Minnesota DOT indicated that twenty-nine (29) percent of drivers used an alternate route based on a travel sign information. While en-route real time routing provides continuous and dynamic compared to the static information of a sign and given the relative size of the inundation area compared to the sub-area, it was decided to utilize an 80/20 split of habitual routes versus en-route routing for trips not affected by flood-induced road closures.

Delay was the metric utilized for assessing the effect of the inundation scenarios and it was calculated by trip purpose based on information available in SCAG's travel demand model. Specifically trip purpose factors, by peak (AM & PM) and off-peak (MD, NI) periods, were derived from the daily person trip production/attraction (PA) tables based on the following calculation steps:

1. Combine PA trips into three designated trip types for analysis:
    - Work Trips = Home Based Work (HBW) + Home Based School/College (HBSC)
    - Social/Recreational Trips = Home Based Non-Work (HBNW)
    - Other Trips = Non-Home Based (NHB)
2. Calculate percentages of trip shares for each zone pair for peak and off-peak
3. Convert shares by regional zone into shares by sub-area zone

The resulting tables contained trip shares by type by period for each zone pair. Those shares were then applied to simulated vehicles by mode and by origin/destination zones to derive the final trips by type for delay and cost analysis. In addition, delays were monetized by trip length and trip purpose based on information on the Value of Time (VoT) provided by USACE. Table 5 summarizes the VoT details.

Table 5: Value of Time (VoT) by Trip Length and purpose

0-5 minutes	Occupancy	VOT/Hr
Work trips	1.1	1.92
Social/Recreation Trips	1	0.35
Other Trips	1	0.03
6-15 minutes		
Work trips	1.1	9.64
Social/Recreation Trips	1	6.29
Other Trips	1	3.95
Over 15 minutes		
Work trips	1.1	16.11
Social/Recreation Trips	1	16.33
Other Trips	1	17.56

In addition to the VoTs the following assumptions were made in the monetization of the delays and Table 6 summarizes the results by inundation frequency:

- For each scenario identify the vehicles that cleared the network and calculate delay. For each scenario also identify the number of vehicles that departed during the first day of the simulation and did not exit the network after 3000 min. Use an average delay based on the vehicles that cleared the system, to calculate the expected delay for these vehicles.
- Value of Time (VOT) varies by trip length (min) and reflects values approved by USACE.
- Based on the SCAG validation report, the average trip in Orange County is about 20 min. Given that the project study area reflects a subarea of the SCAG region, is assumed that all trips passing through the subarea, originating from the subarea but destined outside the subarea and originating outside the subarea and destined to our subarea have trip lengths more than 15 min, thus apply the higher VOT.
- All trips originating from and destined to within the subarea utilize the VOT values based on the trip length (min) calculated by DynusT.
- The delay cost calculated for unfinished trips is utilizing the highest VOT.

Table 6: Inundated Scenario Delays and Associated Costs

Scenario	Regional Trips	Inundation Area Trips	Regional Delays (hrs)	Inundation Area Delays (hrs)	Regional Delays ($$)	Inundation Area Delays ($$)
Base	17.75 M	876,340	270,680	13,470	4,608,490	228,500
5-year	17.75 M	876,340	781,960	312,600	7,368,480	2,518,365
10-year	17.75M	876,340	1,096,950	512,750	10,173,290	4,278,975
25-year	17.75M	876,340	1,397,890	687,535	12,791,380	5,773,700
50-year	17.75M	876,340	1,544,240	752,250	14,296,595	6,426,130
100-year	17.75M	876,340	1,674,870	786,778	15,671,165	6,834,280
500-year	17.75 M	876,340	2,769,110	1,207,975	26,802,510	10,801,175

Note: Delays for the Inundation Area reflect trips that originate from or destined to zones in the Inundation area, as defined by the boundary provided by USACE.