TETRA TECH

MEMO

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Date:	06/20/2022
Subject:	KC Levee Breach Analysis, Mapping, and Risk Assessment: Economic Approach Memo

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C – Final Economic Inventory Status Memo (Subtask 8.1)

1. INTRODUCTION

1.1. PURPOSE OF THIS MEMORANDUM

This memorandum is the deliverable associated with Subtask 8.2, Evaluation Approach, in the scope of work for King County Levee Breach Analysis, Mapping, and Risk Assessment, Contract Number E00670E20. The purpose of this memorandum is to document the economic evaluation approach that is proposed for the execution of Subtask 8.4, Conduct Economic Evaluation. Therefore, this memorandum presents the:

- Economic evaluation methodology, including the consideration of Equity and Social Justice, and the interface with ongoing geotechnical and hydraulic tasks as they pertain to the economic evaluation.
- Anticipated content and format of economic evaluation results.

Per the scope of work, this memorandum will be revised following King County review and a Team meeting (Subtask 8.3) to achieve concurrence on the final economic approach.

1.2. CONTEXT FOR THE ECONOMIC APPROACH SUBTASK

This *Economic Approach Memo* (Subtask 8.2) is intended to detail the proposed methodology and results of the economic evaluation being performed as part of the King County Levee Breach Analysis Mapping and Risk Assessment (LBAMRA) project and follows from the *Inventory Memo* (Subtask 8.1) which was previously prepared to document key inventory and damage function data sources (Attachment D). This *Economic Approach Memo* will build upon the information in the *Inventory Memo* to describe the proposed methodology to evaluate each impact category and describe how the results of the evaluation will be displayed. Following completion of this subtask, the agreed-upon approach will be executed in subsequent subtasks.

1.3. SCOPE OF WORK CROSSWALK

This memorandum provides the deliverable *Economic Evaluation Approach Memo*, addressing Subtask 8.2 as part of the economic evaluation of flood risk for the Lower Raging, Lower Tolt, and South Fork Snoqualmie River basins (Tasks 300, 400, and 500) of the LBAMRA. Table 1 summarizes the relevant scope and notes the sections of this memo which address each scope item.

Table 1 – Scope of Work Reference Table

Scope Item		*Document Reference*
A	Develop an economic evaluation approach best suited to the study area and describe in an economic approach memo.	This document is the deliverable that satisfies this scope item.
B	The approach shall include identification of risk categories and other considerations, assumptions and limitations appropriate to the study area.	Risk categories, termed impact categories in this memo, have been identified the basins in the scope of work. See Section 2.3. Considerations, assumptions, and limitations of the economic approach are discussed in Section 2.
C	The modeling approach shall use the data, information and modeling developed in previous subtasks.	The evaluation approach for each impact category builds upon the Inventory Status Memo developed as part of Subtask 8.1. Discussion of the interface between the economic approach and the ongoing geotechnical and hydraulic aspects of this study are summarized in Section 2.

1.4. ORGANIZATION OF THIS MEMORANDUM

This memo contains several sections that address economic methodology and results.

- Section 2 presents an overview of the economic evaluation methodology including the linkage between the geotechnical, hydraulic, and economic modeling.
- Section 3 describes the evaluation methodology for the impact categories.
- Section 4 describes the presentation of results, including both monetary and non-monetary results, and outputs resulting from the consideration of equity and social justice.
- Sections 5 and 6 document QA/QC and list of data sources, respectively.

In addition to the main sections of this memo, several Attachments are included that provide additional information:

- Attachment A provides a list of acronyms and a glossary for key terms.
- Attachment B provides a summary of socioeconomic and Equity and Social Justice (ESJ) data sources.
- Attachment C is the final *Inventory Memo* that was developed in Subtask 8.1.

2. ECONOMIC APPROACH OVERVIEW

The purpose of the economic component of the LBAMRA is to characterize flood risk by quantifying the impacts of flooding on people and property, including consideration of the possibility of levee breaches during a flood, and including consideration of the effects of climate change. This characterization will support future efforts to update capital project planning strategies and flood hazard management planning efforts. The following subsections present:

- The overall conceptual framework for the LBAMRA and the linkage between work being completed by the geotechnical, hydraulic, and economic elements of the team.
- A detailed description of the economic model that will be used to compute consequences (adverse impacts), including the model's approach to the incorporation of uncertainty and geotechnical failure risk.
- Key economic analysis variables (price level, period of analysis, and discount rate), as well as key modeling assumptions and limitations of the economic evaluation approach.

2.1. LBAMRA CONCEPTUAL FRAMEWORK

Risk is defined as the combination of the likelihood of the hazard occurring and the resulting undesirable outcome of that hazard, given by the equation shown below. This simple definition encompasses the technical effort being conducted as part of the LBAMRA.

$$\boldsymbol{Risk} = \boldsymbol{Probability} \times \boldsymbol{Consequences}$$

The geotechnical and hydraulic efforts of the LBAMRA are focused on quantifying the ***probability*** of flooding. Those analyses will incorporate many variables (and their uncertainties) to define several key relationships between river discharge, stage, levee failure, potential impacts of climate change, and resultant depth of inundation in the floodplain. These relationships are described further in Section 2.1.

The economic effort is focused on the estimation of ***consequences***, or the adverse impacts that arise from that floodplain inundation. The economic analysis also considers uncertainty in the development of the floodplain inventory, a database of the damageable assets that will be subject to adverse impacts in the economic model. The consideration of uncertainty is discussed in Section 2.2.2. Equity, social justice, safety and health impacts are also essential components of understanding flood risk in a community. In addition to monetary economic consequences, the analysis shall qualitatively consider other demographic and socio-economic considerations to inform and characterize flood risk.

Given the above definition of risk, Figure 1 illustrates the conceptual relationship between the geotechnical, hydraulic, and economic components of the LBAMRA. As shown in the figure, the geotechnical and hydraulic efforts generate the information necessary to understand the likelihood that a certain flood event occurs by defining key relationships between flow, stage, and levee fragility. Then, these key relationships are carried into the economic model. For the LBAMRA, the United States Army Corps of Engineers (USACE) Flood Damage Analysis (FDA) model will be used, which is discussed in detail in Section 2.2. What is not shown in Figure 1 is the added complexity of modeling multiple potential levee breach locations and combining these results into a single estimate of system-wide risk. This complication is discussed further in Section 2.2.4.

As presented in Figure 1, Equity and Social Justice (ESJ) evaluation will build upon and leverage the results of the consequence analysis. ESJ is a high priority within King County and its partners. This is echoed in the County's Equity and Social Justice Strategic Plan 2016-2022 (ESJ Strategic Plan or Strategic Plan; King County 2016), which provides a foundation for pro-equity investment decision-making. The plan describes that when there are disparities in the Determinants of Equity within a region, ESJ is not achieved. In addition, the County has developed the Equity Impact Review (EIR) tool, which is a process and a tool to identify, evaluate, and communicate the potential impact, both positive and negative, of a policy or program on equity. The Strategic Plan lists 8 key Determinants of Equity, including:

1) Access to child and youth development,
2) Economic development and jobs,
3) Environment and climate,
4) Health and human services,
5) Housing,
6) Information and technology,
7) Justice system, and
8) Transportation and mobility.

Characterization of non-monetary flood risk will include a focus on the potential for differential impacts of flooding on people and communities and will consider how these impacts are correlated to indicators of population vulnerability and/or determinants of equity and social justice. Demographic and economic data will facilitate identifying the locations of concentrated racial/ethnic groups and other communities of color (black, indigenous, and other people of color–BIPOC), low-income communities, senior populations, disabled populations, housing-related indicators, and other groups identified as vulnerable. In this memorandum, the term *ESJ populations* is used to refer generally to these potentially vulnerable groups. The analysis will consider ESJ through the lens of King County's Determinants of Equity and examine whether existing flood risk results in differential impacts within a community.

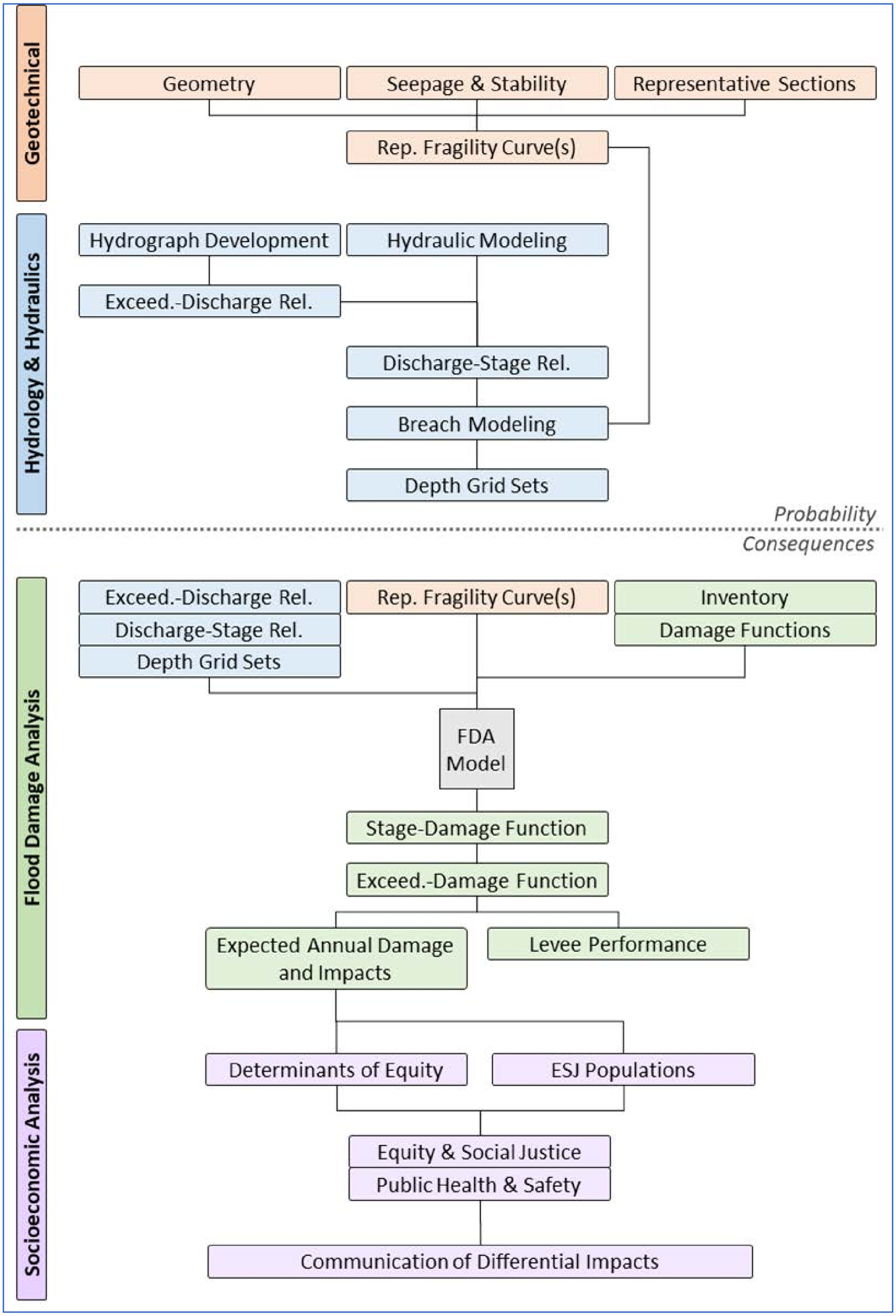

Figure 1 – LBAMRA Conceptual Framework

2.2. APPLICATION OF USACE FDA

The FDA software was developed by the USACE to support analysis of flood risk and levee performance consistent with USACE requirements for the inclusion of uncertainty in the estimation of flood risk. The model allows specification of parameters of uncertainty about the discharge-exceedance probability curve, stage-discharge curve, and stage-damage curves and implements Monte Carlo sampling to consider this uncertainty in the estimation of flood risk. The model also allows incorporation of a geotechnical fragility curve to consider geotechnical failure probability of a levee. The latest certified version of FDA (version 1.4.3) was used for the LBAMRA (USACE 2022).

The following subsections will describe how FDA computes flood risk, the implementation of FDA for the LBAMRA, and outputs from the model.

2.2.1. FDA Computational Summary

Characterization of flood risk relies on a spatial analysis that overlays the extent and depth of inundation on an inventory of floodplain assets that may experience adverse impacts when exposed to floodwaters. To estimate annualized flood risk, such an analysis must be performed for a series of flood events that define the full annual chance exceedance curve for the study area.

FDA facilitates this analysis by defining a set of functions, or curves, which relate hydrology, hydraulic, geotechnical, and economic inputs. FDA supports inclusion of uncertainty by specifying the parameters of the error about some of these curves. These relationships and curves are listed and described in Table 2. The table includes abbreviated names for the curves; these abbreviations are used throughout the remainder of this memorandum.

FDA incorporates uncertainty into the flood risk estimate via Monte Carlo simulation (discussed further in Section 2.2.2). Figure 2 summarizes the relationship between the input curves graphically. The red arrow on the figure illustrates how for a given exceedance probability, the relationships may be traced from discharge to adverse impact in the floodplain. Once Monte Carlo simulation is applied to sample these relationships many times, the result is the estimation of the damage-exceedance probability curve (bottom right in the figure). Integration of this curve yields the estimate of Expected Annual Damage (EAD), as shown by the blue-hatched area on the figure. EAD is therefore the mean estimated flood risk in any given year considering all possible flood magnitudes.

Table 2 – FDA Model Relationship Descriptions

Name	*Abbreviated Name*	*Description*	*Uncertainty Parameters*
Inputs			
Depth Grids by Flood Event	Depth grid set	Represents the floodplain as a set of grid cells and specifies the depth of flooding in each cell for 8 flood events, including the 50%, 20%, 10%, 4%, 2%, 1%, 0.4%, and 0.2% ACE floods, including 0.2% ACE future conditions (climate change).	None
Discharge–Exceedance Probability Curve	Q-EP curve	Relates stream discharge (cfs) and exceedance probability. May include transformation of flow to adjust for regulated systems.	5% and 95% confidence limits on discharge for a given exceedance probability
Stage–Discharge Curve	rating curve	Relates a given discharge to river stage at a specified location.	Standard deviation of error in stage for a given discharge.
Levee Failure Probability–Stage	fragility curve	Relates river stage to probability of levee geotechnical failure at that stage.	None
Stage–Damage Curve	S-D curve	Relates river stage to magnitude of impact in the floodplain based on the depth grids (irrespective of the fragility curve, which is considered only in the simulation process. See Section 2.2.2 for further discussion).	Accumulated uncertainty from economic parameters (value error, elevation error)
Output			
Damage – Exceedance Probability Curve	D-EP curve	Relates consequences (impacts) to exceedance probability to facilitate estimation of EAD by integration of this curve.	Uncertainty in output is based upon above parameters

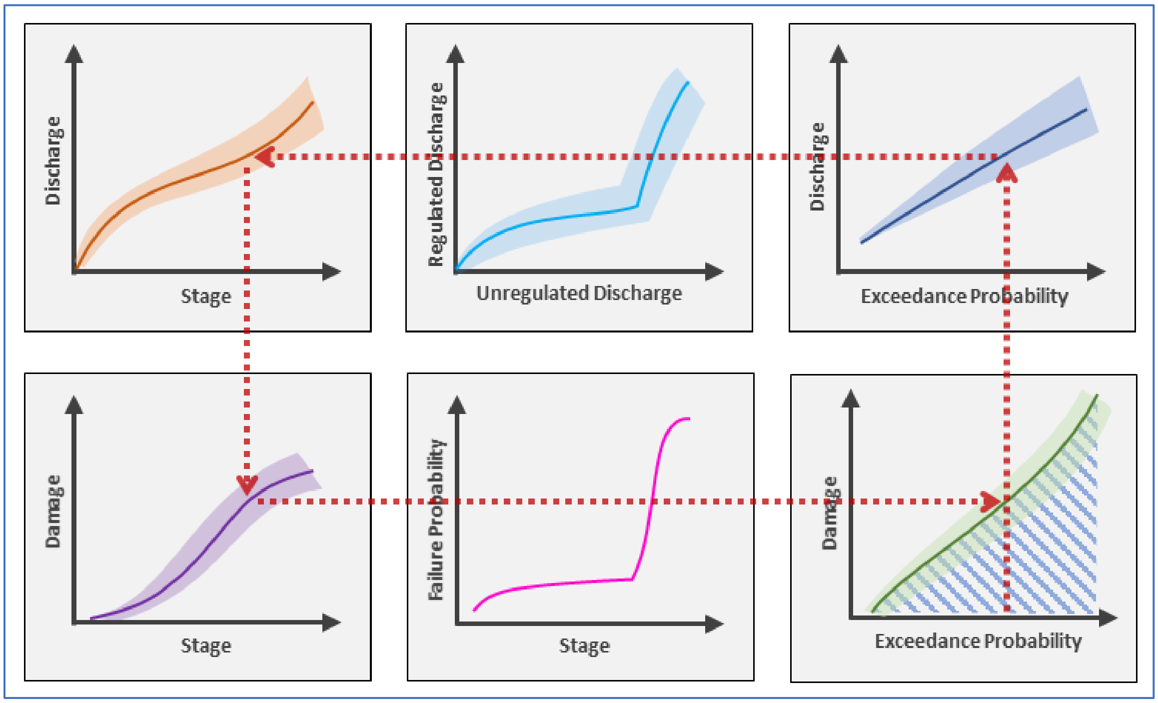

Figure 2 – FDA Relationships Visualization

2.2.2. Incorporation of Uncertainty

Parameters of uncertainty may be defined for several of the key input relationships in FDA, including the discharge–exceedance probability (Q-EP) curve (including the curve defining transformation between unregulated and regulated discharge if flood regulation is present on the basin), rating curve, and stage–damage (S-D) curve. Notably, FDA does not accommodate specification of uncertainty about the fragility curve. By including uncertainty in the inputs, FDA will use Monte Carlo simulation to sample the input distributions when computing the damage–exceedance probability (D-EP) curve and EAD, such that distribution of model outputs is also defined.

The parameters of uncertainty for each curve will be developed for the LBAMRA, as summarized below.

Q-EP Curve

- Defined in coordination with the hydraulic modeling team.
- For streams where the Q-EP curve may be fitted to a Log Pearson III distribution, FDA can compute synthetic statistics to generate the uncertainty distribution.
- For streams with regulated flow or that are otherwise not well-fitted to the Log Pearson III distribution, uncertainty is defined by FDA using order statistics, whose inputs are the ordinates of the Q-EP curve. FDA then computes the 5% and 95% error limit curves.
- For regulated systems, a transform flow relationship can be defined as ordered pairs of unregulated inflow and regulated outflow. Uncertainty in outflow for each ordinate may be entered with parameters of either a normal, log normal, or triangular distribution.

Rating Curve

- Defined in coordination with the hydraulic modeling team.
- Uncertainty in stage is specified by ordinate of the rating curve using the parameters of a normal, triangular, or log normal distribution.
- USACE provides guidance to assist in development of the minimum stage error for design-level discharge (e.g., the 1% AEP flow) in EM 1110-2-1619 (USACE 1996) based upon consideration of the hydraulic model input resolution (terrain) and modeling assumptions (Manning's n value).

S-D Curve

- Defined based upon the economic input datasets.
- There are three major sources of uncertainty from the economic perspective, including uncertainty in the value of the asset being impacted, uncertainty in the percent loss associated with a given depth of inundation, and uncertainty in the elevation of the first finished floor above ground (which is the reference point for depth-to-percent-damage curves).
    - For uncertainty in value, standard economic uncertainties include error in structure value, and error in content value (or error in the content-to-structure-value ratio). Uncertainty is defined by building occupancy type using the parameters of a normal, log normal, or triangular distribution. For the LBAMRA, triangular distributions will be developed based upon review of the inventory database. In general, parameters of the triangular distribution will be estimated based on the min, max, and mode of sampled or available values. However, data will be reviewed, and parameters may be manually modified to remove outliers in the sample data to ensure the uncertainty parameters are reasonable and representative of the variable being considered.
    - For uncertainty in percent loss, standardized uncertainty parameters are available for some occupancy types from the USACE, predominantly for the single-family home occupancy types. The LBAMRA FDA models will utilize available standardized functions. For building occupancy types without existing published uncertainty distributions, none will be specified.

  - The first-floor height/foundation height uncertainty will be specified by the standard deviation of the error, in feet. Based upon recent past studies, the standard deviation of error for windshield survey of foundation height was estimated at 0.5 feet (WSE 2014).

In the computational process, FDA incorporates uncertainty in two main steps. First, FDA computes the S-D curve with uncertainty. This requires assembling a table of the entire span of stages at the index location from the rating curve. Then, based upon the depth grid set, FDA computes the damages that would occur for each stage by transforming stage at the index to depths at each building in the floodplain based upon the depth grid sets. FDA incorporates uncertainty in the S-D curve by performing this calculation iteratively for each stage, sampling from the economic uncertainty distributions each time.

Once the S-D curve, Q-EP and rating curves have been developed, FDA can apply Monte Carlo simulation to estimate the D-EP curve and perform numerical integration to generate EAD. FDA applies a technique called curve sampling to make the Monte Carlo simulation more efficient. In short, each iteration of the Monte Carlo analysis will create a set of sample curves from the Q-EP, rating curve, and S-D curves, then compute EAD for that set of sample curves. It will then select a new set of sample curves, and compute EAD again. It will repeat this many times until the mean EAD and damage at the 1% ACE event have both stabilized (converged), such that performing more iterations does not significantly change the computed estimate of risk. Figure 3 illustrates this curve sampling graphically for two iterations of the Monte Carlo simulation (i.e., to sample EAD estimates).

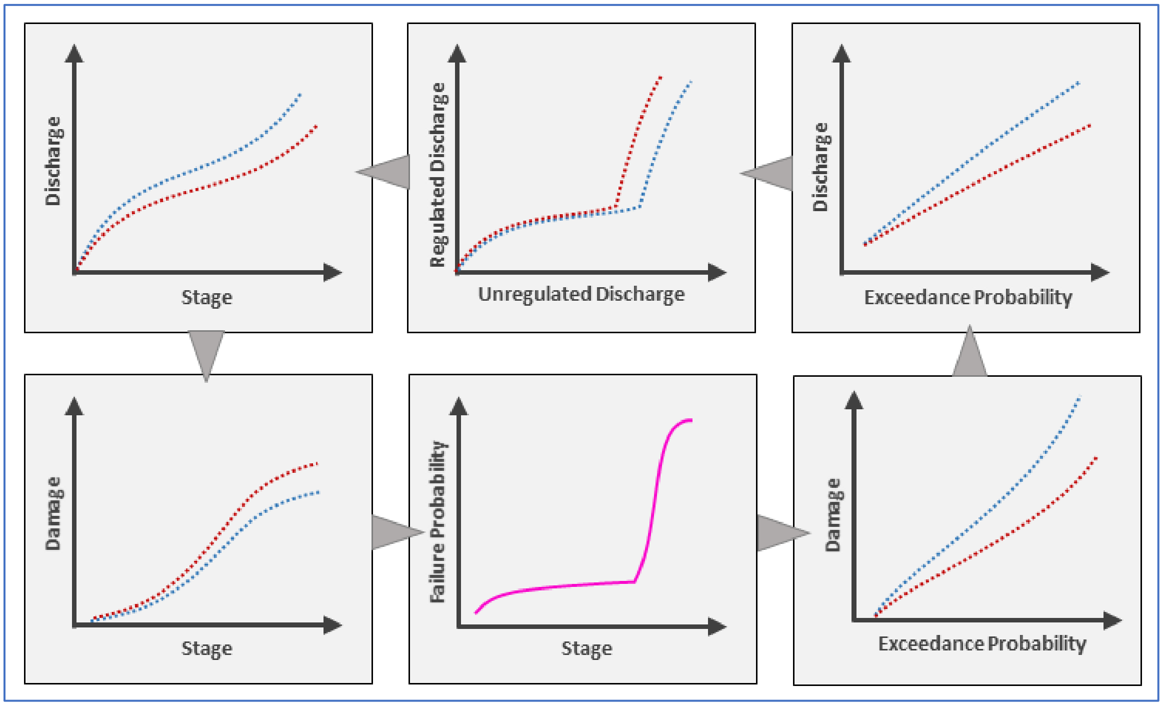

Figure 3 – FDA Monte Carlo Simulation, Two Iterations of Curve Sampling

The blue set of lines represent one set of sampled curves that FDA would use to compute EAD. The red set of lines represents a second iteration of the Monte Carlo process, using a new set of sample curve to compute a new estimate of EAD. This curve sampling is repeated thousands of times until convergence is achieved. Figure 4 illustrates convergence graphically, showing that as more iterations of the Monte Carlo simulation are completed (blue points), the mean EAD computed from those iterations begins to converge, and after a large number of iterations, further iterations would not significantly alter the estimated mean EAD. For example, in the first 5 iterations shown in Figure 4, the mean EAD is changing significantly between iterations. At around iteration 20, the mean EAD begins to stabilize (become a mostly flat line). By iteration 50, while the individual iteration results will continue to be distributed about the mean EAD line, the estimate of the mean EAD has stabilized, converging around the value of about $850K. In this example, adding more iteration data points will not significantly change the estimate of mean EAD.

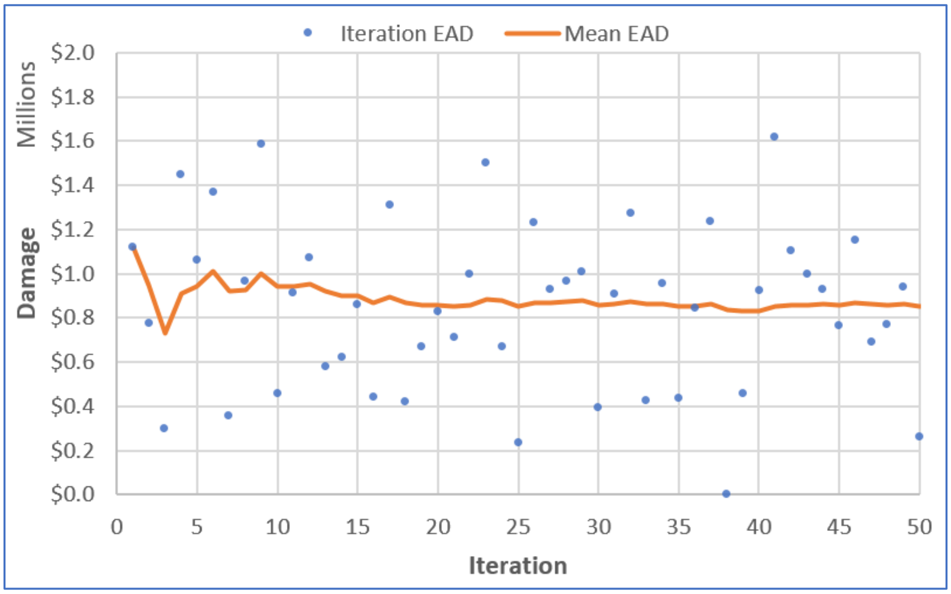

Figure 4 – Illustration of Model Convergence

As shown in Figure 3, FDA does not consider the effect of the fragility curve until the Monte Carlo simulation step that estimates the D-EP curve. The prior development of the S-D curve is based only on the index stages and the depth grid set. When performing the Monte Carlo analysis, FDA adds a step to check whether levee failure occurs based on the stage and fragility curve. Therefore, the resultant D-EP curve reflects the probability of levee failure.

2.2.3. Specification of FDA Damage Areas and Index Locations

The FDA model allows the floodplain to be divided into *damage areas*[1]. Damage areas are defined in the model as a set of floodplain grid cells all tied to the same *index location*. For each damage area, a point along the channel must be selected as the index location for the damage area. FDA performs the computation of flood risk for each damage area separately, and each damage area is assigned a Q-EP curve, rating curve, and fragility curve that corresponds to that damage area's index location. This means that each damage area will have its own S-D curve and resultant D-EP curve.

For the levee breach scenarios discussed in Section 2.2.4, the index location for a breach scenario is typically the location along the channel where the breach occurs in the hydraulic model. For a scenario without geotechnical breach, the index location is typically chosen where the best data is available to define a representative rating curve for the reach. In summary, an index location is usually chosen as a function of hydrologic, hydraulic, and geotechnical characteristics of the damage area; the index location does not drive selection of breach locations.

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[1] In the FDA software, these are termed *reaches*. Damage area is preferred here to better align with the application of FDA using a two-dimensional hydraulic model.

However, because each grid cell in the floodplain may only be assigned to one damage area and linked to one set of hydraulic outputs, FDA cannot accommodate multiple breach locations with potentially overlapping floodplains within one model.

Consider the hypothetical levee system and breach floodplains shown in Figure 5, where the inundation areas shown by the ovals represent the breach floodplain that would result if a breach occurred at that location during a large flood event.

- The left bank has one modeled breach location (Breach 4), thus a single damage area can be defined for the left bank, and all grid cells on the left bank floodplain will be tied to the index location for that damage area.
- However, the right bank has three modeled breach locations, resulting in some parts of the floodplain that may be impacted by more than one breach location (the overlap between the ovals). For these floodplain grid cells, there is more than one applicable damage area and index location, which FDA cannot accommodate in a single model.

To get around this limitation, separate FDA models must be created for each breach location. This allows estimation of flood risk from each breach separately. For the LBAMRA, each bank of the river will be defined as a damage area, and the index location for that damage area will shift depending on the breach location of relevance for that model.

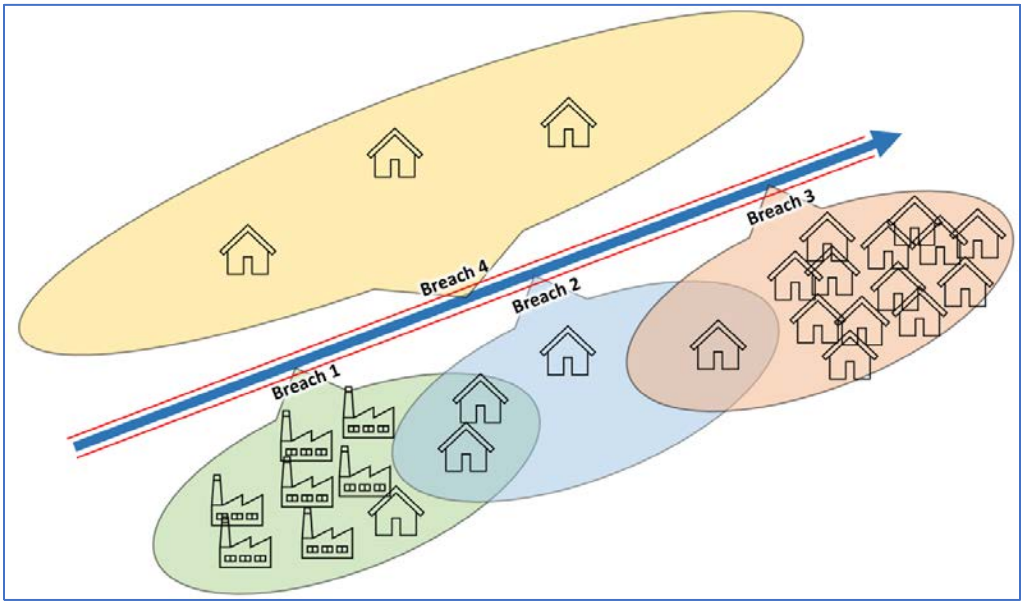

Figure 5 – Damage Area Definition – Hypothetical Breach Floodplains

2.2.4. Multiple Breach Locations and System-wide Risk

As described above, consideration of multiple breach locations in FDA requires separate models for each breach location when the breaches result in overlapping floodplains. By running separate models, the entire floodplain inventory can be included in each model, meaning that impacts associated with each breach location are evaluated over the entire inventory. This approach means that the computed flood risk for a given scenario will reflect the hydraulic attenuation effects of a breach in one location on other areas of the floodplain. Using Figure 5 as an example, the model which includes a breach at location 1 would likely show large impacts adjacent to the breach but might also show less impact to those farther downstream of the breach, such as near Breach Location 3.

Note that only one breach location is included in each FDA model, even when there are breach locations on opposite banks that could be modeled as separate damage areas. As noted above, only one breach is considered at a time to capture potential attenuation effects of the breach on other areas of the floodplain. A second reason for considering only one breach at a time is that having separate breach scenarios facilitates the generation of a system-wide risk estimate as described below.

Figure 6 (end of section) presents a graphic that illustrates how the results of multiple FDA models are weighted to estimate system-wide risk. On the map illustration at the upper right is a study area with three modeled breach locations on the right bank and one on the left bank. It shows the floodplain associated with each breach location for a large flood (e.g., the ACE 2% flood). This flood is large enough that it *could* result in levee breach, and there would likely be some overbank flooding at the downstream end of the study area without levee breach. Note that FDA accounts for all flood magnitudes in the estimation of EAD; one hypothetical flood is illustrated here for ease of interpretation.

The graphic steps through the following:

- **FDA Models:** Four breach scenarios are defined, requiring that four FDA models are developed. There is a model for each breach location, and a fifth *Overtop-then-Breach* model. These models would each have two damage areas, one for each bank. The four breach scenario models are intended to capture the potential for higher impacts due to geotechnical breach of the levees before they overtop. The overtop-then-breach scenario is intended to reflect flooding that occurs regardless of breach due to overbank flows. Considering that overtopping of levees would likely lead to breach, the floodplain depth grids for the overtop-then-breach model may be adjusted (composited from other model runs) in some areas to reflect how a breach after overtopping might increase flood depths.
- **Fragility Curves:** For each breach scenario model, the representative fragility curve developed as part of the geotechnical evaluation will be specified at the index location, and FDA will account for the occurrence of levee failure when tabulating impacts. For the overtop-then-breach scenario, there is no risk of failure before overtopping, and the bank height will control initiation of impacts at the index location. As shown on the figure, this results in a fragility curve that is a vertical line at the exceedance probability corresponding to the state that initiates overtopping.
- **Annual Probability of Failure:** Each fragility curve, which plots probability of failure against stage, will be translated to plot probability of failure against exceedance probability. The integral of these curves yields the annual probability of failure (APF) for each breach location.
- **Scenario Weights:** Because each FDA computes EAD for the entire floodplain and reflects the entire range of flood exceedance probabilities, the results of the models are not additive[2]. What the breach models capture is how geotechnical fragility exacerbates flood risk due to breach before overtopping, and each breach location is a representation of that risk for a different portion of the levee system and floodplain. Therefore, the APF computed from the fragility curves can be used to estimate the relative contribution of each model scenario to total system-wide risk. To do so, the APFs for each scenario are normalized. This normalized value will be used as the Scenario Weight for each model.
- **Damage-Exceedance Probability and EAD:** For each model, FDA will output an estimate of EAD. This estimate is derived from integration of the D-EP curve. This is referred to as the Scenario EAD in this framework.
- **Weighted EAD and System-wide EAD:** Multiplying the Scenario EAD by its Scenario Weight yields individual weighted EAD. Summation of the weighted EADs yields System-wide EAD. System-wide EAD is a representation of total flood risk that accounts for the possibility of breach

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[2] Consider that each FDA model includes the contribution of the 0.2% ACE flood to its computed EAD. The 0.2% ACE flood is likely large enough to overtop all banks regardless of levee fragility. As such, summation of the separate EAD results would quintuple-count (5 models) the impacts of the 0.2% ACE flood event.

before overtopping based upon the relative likelihood of breach occurring at any of the representative breach locations.

This same workflow would be adapted for systems with more or fewer modeled breach locations. As scoped the HEC-FDA modeling will include the following for the three levee systems:

- Lower Raging River: Two breach locations (i.e., two breach scenario), plus an overtopping-then-breach scenario
- Lower Tolt River: Four breach locations (i.e., four breach scenarios), plus an overtopping-then-breach scenario
- South Fork Snoqualmie: Six breach locations (i.e., six breach scenarios), plus an overtopping-then-breach scenario

Note that if geotechnical analysis finds that there is negligible risk of geotechnical failure for a chosen breach location, there are multiple ways that the economic analysis might address the situation. The chosen approach is likely to depend on what is behind the levee and the importance or desirability of having worst-case impact information for that area. For example, if a mobile home development were located landward of the levee, there may be value in being able to describe impacts if there were a breach, as those impacts may be quite severe.

As such, the first approach would be to simply include the low-fragility breach location as described above, knowing the relative probability of that scenario occurring would be very low and have a marginal effect on the system-wide risk. This approach would provide the most quantitative information about the breach scenario.

Another approach would be to ignore the risk of breach prior to overtopping for that location. If there were not important assets in the floodplain at that location, the breach location could be removed from the analysis, as the overtopping-then-breach scenario would be sufficient.

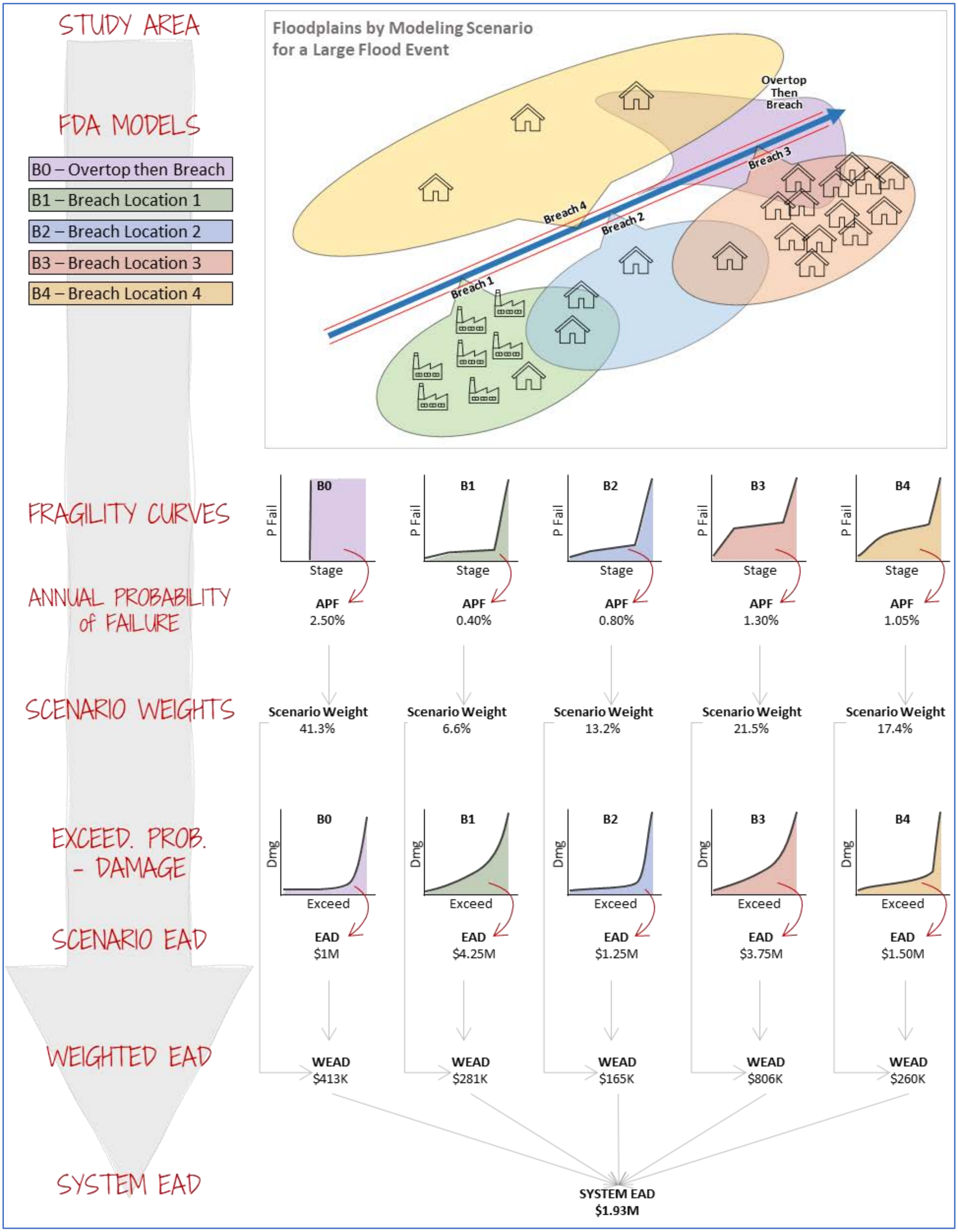

Figure 6 – Multiple Breaches and System-Wide Risk

2.2.5. Consideration of Climate Change

For the basins included in the LBAMRA, climate change is expected to exacerbate flood risk. Based upon research by the University of Washington Climate Impacts Group (Mauger, et al. 2020), climate change will result in future increases in peak flow and volume. For the LBAMRA, flood risk will be estimated given a future hydraulic condition scenario that includes climate change effects. To do so, the Q-EP curve will be revised to be representative of hydraulic conditions with climate change in approximately 2055, based on the climate change modeling being used by the hydraulics team. Changes in the Q-EP curve will be estimated by the hydraulic team per the approach developed by the hydraulics element of the King County LBAMRA team. These changes will be incorporated into a future conditions iteration of the FDA model for computing of EAD given the effects of climate change. After doing so, there will be two estimates of EAD, a baseline estimate that does not include climate change, and a future conditions estimate that does include climate change, that will be presented.

These two estimates of EAD may also be combined into a single metric, Average Annual Equivalent (AAE) impacts. To combine these estimates, the representative future year (2055) would be assigned to the with-climate-change results. In the example figure below, this representative future year is shown at 30 years into a 50-year analysis period. EAD is interpolated between year 0 and year 30 based upon the baseline and future conditions EAD estimates. EAD is then held constant at the level of the future conditions for all subsequent years of the period of analysis. AAE is then tabulated as the discounted and annualized impact from this curve, as summarized on Figure 7.

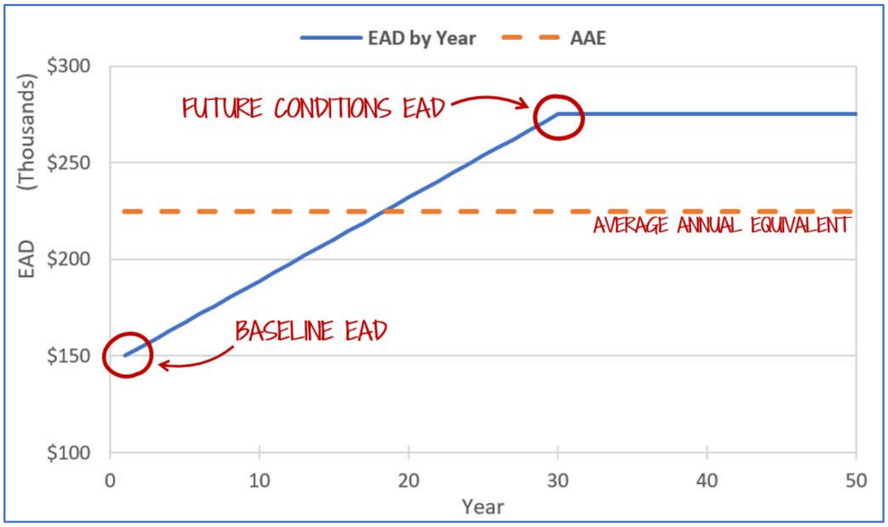

Figure 7 – Calculation of Average Annual Equivalent Impact

2.2.6. Levee Performance Statistics

In addition to EAD, FDA can report several levee performance statistics that describe the likelihood that a levee will contain (or not contain) certain flood events. For the LBAMRA, these statistics will be reported for each of the index locations used in the FDA modeling scenarios, including with and without climate change. The statistics reported by FDA include the following:

- Target Stage AEP: The median and expected AEP of the levee crest height or bank height. The reported median is computed from the FDA input functions. The expected value is the mean from the Monte Carlo simulations.
- Long-Term Risk: The probability of exceedance of the target stage over multiple years. Reported for 10-, 30-, and 50-year durations.

- Conditional Non-Exceedance Probability by Event: Reports the probability of the target stage containing the 10%, 4%, 2%, 1%, 0.4%, and 0.2% ACE floods.
- Assurance Statistic: The assurance statistic, per National Flood Insurance Program (NFIP) levee system accreditation requirements (USACE 2019) is the probability that the levee will prevent flooding of the leveed area for the 1% AEP event, considering geotechnical performance and uncertainty in flow and stage across the full range of possible annual floods.

2.3. ASSUMPTIONS AND LIMITATIONS

The following bullets list notable assumptions and limitations that should be considered when interpreting the results of the FDA evaluation:

- EAD is typically more sensitive to changes in hydrologic, hydraulic, and geotechnical inputs, and relatively less sensitive to changes in the value of the damageable assets in the floodplain (given reasonable magnitudes of change), because changes in engineering inputs that affect the probability of hazard occurrence can have a much greater impact on EAD than small changes in consequences for a given stage or flow.
- FDA includes no concept of time, which can tend to overestimate damages from frequent floods when considering EAD to represent risk over some planning period (e.g., 50 years). Effectively, the computed EAD reflects that all flooded buildings are restored to their pre-flood value before the next flood.
- FDA computes impacts based on inundation depth. There is no consideration in FDA for the effects of velocity on risk.
- FDA does not accommodate specification of uncertainty about the levee fragility curves.
- In the proposed framework for computing system-wide risk across multiple breach locations, each hydraulic breach is modeled independently. Therefore, this approach does not consider how concurrent loading of levees would affect breach risk.
- Due to the computations procedure of FDA, retrieval of building-level event damage or EAD reflects only the S-D function computed before the Monte Carlo simulation. As such, building-level information that reflects the effects of levee fragility or the uncertainty in the Q-EP and rating curves is not computed by the model.
- Data related to characteristics of ESJ populations is typically not readily available at the property level (i.e., the same level as the flood model results). The ESJ analysis will use best available data to draw conclusions about impacts at practicable levels of detail, but results will not be intended to describe vulnerability or ESJ impact at the specific property level.

3. IMPACT CATEGORY APPROACH DETAILS

The purpose of this section of the Economic Approach Memo is to summarize the approach that will be taken to evaluate each impact category and highlight any key considerations or assumptions. The section refines and builds upon the previously developed Inventory Data Memo (included in full as Attachment C), which developed a detailed list of impact categories relevant to the LBAMRA. Subsequent evaluation of these categories has confirmed that all 21 categories will be considered in each basin evaluation, though the relative significance of each impact category may vary by basin. Table 3 lists the impact categories and groups them into four summary categories for ease of summarization. For each impact category, a new *Evaluation Approach* subsection has been added to document the proposed approach for quantitative or qualitative incorporation of impact category into the modeling framework described in Section 2, and describe the outputs that would be generated for each impact category.

Table 3 – Impact Categories

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

3.1. DIRECT PHYSICAL DAMAGES

Direct physical damages include damages to buildings, vehicles, roads, bridges, other facilities, and agriculture. These are directly impacted due to flood waters and are distinct from other economic impacts such as response and restoration, business interruptions and other indirect impacts. Direct physical damages are also separate from ESJ impacts although equity considerations are highlighted for each of these subcategories.

3.1.1. Structure, Contents, and Inventory

3.1.1.1. Inventory Status Summary

This impact category describes the building-related losses associated with direct contact with floodwaters. The types of buildings included are based on occupancy and are outlined in Section 3.1.1.3. The impact category includes:

- *Structure damage* is an estimated dollar value of damage to structural components of the building, such as foundation, walls, and utilities.
- *Content damage* is an estimated dollar value of damage to non-structural components of the building, such as furniture, fixtures, cabinetry, and other personal property or commercial equipment.
- *Inventory damage* is applicable only to non-residential buildings that contain business inventory and is an estimated dollar value from loss of inventory that is ruined by floodwaters.

These impacts are estimated as a function of the depth of flooding at the building, relative to the building's first finished floor elevation. This depth of flooding is read against a depth-damage function (DDF), which provides the percent loss of structure, content, and inventory value at a given flood depth and a given total building replacement value[3]. Therefore, the economic inventory items needed for evaluation of this impact category include information regarding building attributes sufficient to allow identification and use of an appropriate DDF for each building.

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[3] Note that the database will support estimation of damages in terms of replacement cost or depreciated replacement value. For general risk characterization, reporting of depreciated values is recommended. This will be finalized in coordination with King County as part of Subtask 8.2, Evaluation Approach Memorandum.

3.1.1.2. Inventory Data

Best-available building information is available from the King County Department of Assessment. To capture the maximum potential extent of inundation based on future outputs from the geotechnical and hydraulic models, inventory extent was defined based on the hydraulic model domain for each basin. Based on this domain, a request was made for necessary data on 1,211 parcels for the Lower Tolt River, 1,276 parcels for the Lower Raging River, and 6,135 parcels for the South Fork Snoqualmie River. Based on coordination with the Assessor, all necessary building information is available, including attributes that will allow definition of building type/use, size, and replacement value, and is sufficient to assign the appropriate DDF for each building. First floor elevation information, will be sampled as necessary based on existing imagery, including Google Street View, or building imagery available on the King County website. First floor information has also been recently developed for a separate King County study on the Tolt, and it is expected that the data from that effort will be available for this study. The resultant building inventory and property characteristics database is also a key input to other impact categories discussed in this memorandum and provides a second data source to identify and describe critical facilities in the study area in addition to the Hazus model database (as discussed in Section 3.1.5).

3.1.1.3. Damage Function Data

The use of DDFs to estimate flood inundation impacts is the primary methodology employed by federal agencies such as the USACE and FEMA. Both of these agencies have published a variety of DDFs for many building types. Currently, there are two primary sources of standardized DDFs, one available from each agency. The USACE's Risk Management Center maintains the LifeSim model (USACE 2021), which supports event-based flood damage estimation. The LifeSim model contains a library of 40 standard building *occupancy types*, where each occupancy type has its own associated DDF. The second source is FEMA's Hazus model, which supports FEMA's multi-hazard damage estimation mission. Based on review of these sources, the LifeSim library of standard DDFs includes a complete and representative set of residential and non-residential DDFs, and no additions were identified from the Hazus library. USACE DDFs for residential structures are published in EGM 04-01, *Generic Depth-Damage Relationships for Residential Structures*, and are based on a USACE statistical analysis of past studies to generate standardized DDFs. The standard non-residential DDFs in LifeSim reflect a selection of riverine flooding damage curves from past USACE studies or from the FEMA HAZUS model default functions. As such, Table 4 presents the following preliminary list of occupancy types (and DDFs) that reflects the 40 standard occupancy types used in LifeSim and lists the content-to-structure value ratio for each occupancy, which is used to estimate a building's content value based upon its estimated structure value.

Table 4 – List of Occupancy Types and DDFs

Occupancy / DDF	*Description*	*Content to Structure Value Ratio*
AGR1	Agriculture facilities and offices	100%
COM1	Retail trade	100%
COM2	Wholesale trade	50%
COM3	Personal and repair services	100%
COM4	Professional and technical services	100%
COM5	Banks	100%
COM6	Hospitals	100%
COM7	Medical office and clinic	150%
COM8	Entertainment and recreation	150%
COM9	Theaters	100%
COM10	Parking garages	100%
IND1	Heavy industrial	150%
IND2	Light industrial	150%
IND3	Food/drugs/chemicals	150%
IND4	Metal/minerals processing	150%
IND5	High technology	150%
IND6	Construction facilities and offices	100%
EDU1	Grade schools and administrative offices	100%
EDU2	Colleges and universities	150%
GOV1	Government – general services	100%
GOV2	Government – emergency response	150%
REL1	Churches and non-profit organizations	100%
RES1-1SNB	Single family residential structure that is 1 story tall with no basement.	100%
RES1-1SWB	Single family residential structure that is 1 story tall and has a basement.	100%
RES1-2SNB	Single family residential structure that is 2 stories tall with no basement.	100%
RES1-2SWB	Single family residential structure that is 2 stories tall and has a basement.	100%
RES1-3SNB	Single family residential structure that is 3 stories tall with no basement.	100%
RES1-3SWB	Single family residential structure that is 3 stories tall and has a basement.	100%
RES1-SLNB	Single family residential structure that is a split-level structure with no basement.	100%
RES1-SLWB	Single family residential structure that is a split-level structure and has a basement.	100%
RES2	Manufactured housing	50%
RES3A	Multi Family Residence – Duplex	50%
RES3B	Multi Family Residence – 3 to 4 units	50%
RES3C	Multi Family Residence – 5 to 9 Units	50%
RES3D	Multi Family Residence – 10 to 19 Units	50%
RES3E	Multi Family Residence – 20 to 49 Units	50%
RES3F	Multi Family Residence – more than 50 Units	50%
RES4	Temporary lodging (e.g., Hotels, motels, or other buildings used for temporary lodging)	50%
RES5	Institutional dormitories	50%
RES6	Nursing Homes	50%

3.1.1.4. Preliminary Socioeconomic and ESJ Considerations

The structure inventory will serve as the smallest geographic unit of analysis for much of the ESJ analysis proposed for this study. The value and types of structures, as well as ownership rates, can give some insight into household incomes (e.g., mobile homes are lower value than permanent structures). Race and ethnic population data will be reviewed based upon King County American Community Survey (ACS) data and any other information from the King County Assessor's database (e.g., housing tenure as available). For non-residential properties, daytime/workday population will be reviewed based on the types of businesses and general income/race statistics for the industrial code. Also, a review of FEMA HAZUS methodology for selected non-residential occupancies will be completed and used if relevant.

3.1.1.5. Inventory Status Summary

At the time of writing, data from the Assessor has been received and is being processed. Based on preliminary review, the Assessor's data is complete and meets the needs identified in this memo. No inventory issues are anticipated in the use of the Assessor's data to support estimation of impacts to building structure, contents, and inventory.

3.1.1.6. Evaluation Approach

Economic Modeling

Completion of the building inventory for the study areas is a key component of the evaluation, requiring that property characteristics from the Assessor's database are appropriately related to building footprints being used in the hydraulic model. Given nuances of the data collected by the Assessor, and the approximate nature of the building footprints available for the study area, there are many instances where the number of buildings on a parcel in the hydraulic model differs from the number of buildings recorded in the Assessor's database. Therefore, a key component of the approach for this impact category is the careful definition of a standardized methodology for relating these two datasets. The following approach will be employed to fully integrate the building outline dataset with the Assessor's dataset.

- The building outlines present in the hydraulic model affect the modeled flow of water. As such, it is preferable to rely on the building outlines in the hydraulic model as representative of improvements on a parcel.
- Where the Assessor's dataset and building outlines differ in their representation of improvements on a parcel, this approach will use the building outlines to represent the location of the buildings but will ensure that the total reported value from the Assessor's database is maintained. For example, if there are only two buildings on a parcel in the hydraulic model, but three buildings in the Assessor's database, the value associated with the third building in the Assessor's database will be allocated to the two building outlines in proportion to building area. This will maintain the geospatial relationship to the hydraulic model while accounting for all the improvement value in the Assessor's database. For any cases where the Assessor's database reports an improvement that is not reflected in the building footprint dataset, the parcel will be manually reviewed and a building will be added using GIS tools, if appropriate.
- First floor elevations for buildings in the floodplain will be sampled using desktop tools. The sample will attempt to record first floor adjustments for 100% of non-residential buildings identified in the building outlines dataset, and at least 5% of residential buildings, stratified by occupancy type (e.g., single-family, mobile home, etc.). The sample data will be used to generate representative first floor adjustments for buildings not sampled, stratified by structure occupancy type.
- Once hydraulic model outputs are available, the building inventory will be overlaid on the depth grid sets in GIS to estimate the maximum depth of flooding above ground at the building for each modeled flood event and scenario. This step will rely on zonal statistics in GIS.

After assembling this dataset, it will be converted to a tabular file for import into the FDA software. The input files will specify the following:

- Definition of damage areas (reaches) in the economic model. At a minimum, separate impact areas will be defined for each bank of the river.
- Definition of base and future analysis years. The base year will be 2022, and the future year 2030 (subject to refinement in coordination with the H&H team). Future hydraulic conditions will be developed in coordination with the H&H team and will result in a second representative set of depth grids that is generated by revising the Q-EP curve associated with the original depth grid set. Future economic inventory conditions will be addressed by adjustment of the property characteristics applied to the baseline building inventory to reflect expected growth in the basins (King County 2021). This approach would not create any new or hypothetical future buildings in the floodplain and would instead focus on the increased value at risk and population at risk under future conditions.
- Depth grid set (depth of flooding at each building for each event). As noted above, zonal statistics around the building perimeter will be used in GIS will be used to estimate depth of flooding at each building.
- Q-EP curve for all index locations, and parameters of uncertainty for the Q-EP curve, which will be developed in coordination with the H&H team
- Rating curve at each index location, and parameters of uncertainty for the rating curve, which will be developed in coordination with the H&H team.
- Economic inventory, populated with building and content values, first floor adjustments, DDFs. Parameters of uncertainty in structure value and content value will be developed by review of the structure value and content value unit cost information, by structure occupancy type, which is obtained from the Assessor's database. Uncertainty in first floor elevation will be developed as previously discussed in Section 2.2.2.
- Specification of the levee fragility curve, as developed by the geotechnical team.

Once populated for all scenarios, up to three full FDA model runs will be conducted, to facilitate refinement of the model upon review of the initial results[4]. As described in Section 2, the FDA outputs will include estimation of the D-EP curve, EAD, and AAE damage. Once modeling is completed for all breach scenarios, system wide EAD will be computed. For each scenario, levee performance metrics such as assurance and long-term risk would be computed and reported.

ESJ Analysis

The ESJ analysis will focus on the differential effects of building-related losses associated with direct contact with floodwaters on ESJ populations. The socioeconomics and ESJ analysis will entail reviewing the structure-level information such as the value, type, and ownership rates of structures, to develop insights into household incomes and to identify low-income occupants and users of these structures. Census tract-level data from the American Community Survey (ACS) and information from the King County Assessor's database will be used to identify residents within the study area that are BIPOC (Black, Indigenous, and People of Color) and/or belong to other vulnerable groups. In addition to residential structures, the analysis will involve identifying differential effects on users of commercial, business, and other community structures, as well. For this, the analysis will include looking into the racial/ethnic make-up and income levels of the daytime/workday populations. This will be based on the types of businesses in the area and the income/race statistics for the associated industrial codes. Some data on racial/ethnic makeup of workers in different industries are compiled by the Bureau of Labor Statistics at the national level, which will be used along with qualitative information available for the study area. Section 3.4 provides additional discussion of how the building inventory will support the overall ESJ analysis.

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[4] The number of breach scenarios is separate from the number of model runs noted here. Up to three model runs was specified in the scope to limit the number of iterative revisions generated by review of the model results. The number of breach scenarios for each basin is defined by the scoped number of modeled breaches.

3.1.2. Direct Vehicle

This impact category estimates loss in vehicle value due to contact with floodwater. Vehicle impacts are modeled similar to building impacts, using a DDF that related depth of flooding to percent loss of vehicle value.

3.1.2.1. Inventory Data

A vehicle inventory is created as a function of the building inventory, where an average number of vehicles will be assigned to structures by occupancy type. For residential inventory, the average number of vehicles is obtained from U.S. Census Bureau datasets, such as the American Community Survey program and information from the Bureau of Transportation Statistics (BTS 2019). For non-residential inventory, sampling will be conducted on relevant occupancy types within the study area. Vehicle value will be based upon the latest published information from automotive industry sources, such as the Edmunds Used Vehicle Outlook (Edmunds 2020). For commercial vehicles, industry publications will be used to estimate average value for a typical commercial vehicle.

3.1.2.2. Damage Function Data

Based on past studies, the USACE has developed a standardized vehicle DDF for personal vehicles by vehicle type (USACE 2009). Recent work on the LifeSim model has resulted in a single aggregated DDF for personal vehicles as well. For commercial vehicles, an adjusted DDF will be developed based on the estimated difference in ground clearance between personal vehicles and a typical commercial vehicle (e.g., a semi-trailer truck).

3.1.2.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from flooded vehicles, the information may inform qualitative description of ESJ impacts to mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.1.2.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The population of the vehicle inventory is pending, as it will be informed primarily by the final building inventory. All necessary data is available, and no inventory issues are expected in the computation of these impacts.

3.1.2.5. Evaluation Approach

Economic Modeling

The approach for incorporation of vehicles damages into the modeling framework will be similar to that described for the building inventory. To represent vehicles in FDA, pseudo-buildings[5] will be included the model, where each building has as its value the total value of vehicles available to be flooded at that building, and a Vehicle occupancy type will be defined that reflects the vehicle DDF. Uncertainty in vehicle value will be incorporated by estimation of a triangular distribution. This approach will result in an estimate of EAD for vehicles.

ESJ Analysis

The socioeconomics and ESJ analysis will entail analyzing the differential effects on ESJ populations related to mobility due to vehicle losses. Vehicle losses due to flood damage can impact some ESJ populations disproportionately, especially those who need to work hourly and onsite. This will primarily be a qualitative analysis and will be considered within a broader transportation context given modeled flooding of roads, bridges, and related traffic and detour impacts, as discussed in other sections. The availability of alternative routes and modes of transportation for ESJ populations will also be considered.

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[5] *Pseudo-building* refers to using a building record in FDA to represent some other type of asset for damage tabulation purposes. Essentially, pseudo-buildings are additional points/assets in FDA that can be assigned a value and damage function.

3.1.3. Direct Road

Direct impacts to roads are typically difficult to quantify in a generalized manner for a large floodplain, as the susceptibility of a road to flood damage is largely a function of the road segment's susceptibility to erosion, which is in turn difficult to quantify in aggregate across all roads in a floodplain. As such, there are no standardized values available for road damage from flooding.

3.1.3.1. Inventory Data

A roadway inventory will be completed for each basin study area using the USACE LifeSim model, which facilitates generation of a road network based on the OpenStreetMap API (OSM 2021). The resultant GIS dataset will contain road centerlines and attribute information about the roads. This network will be cut into segments (e.g., ½-mile long segments) and a representative damage tabulation point will be assigned along each reach (e.g., the mean elevation along the segment).

3.1.3.2. Damage Function Data

Following Hurricane Katrina and its associated flooding, the USACE New Orleans District collected and elicited information about damage to roadways and used this information to develop depth-to-dollar damage functions for two types of roads, major/secondary highways, and other streets (USACE 2012). This function will be adjusted for geography and price level and applied to the study areas. Note that King County has provided historical damage information from four recent flood events that contains estimates of roadway damages for FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

3.1.3.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from road flooding, the information may inform qualitative description of ESJ impacts to transportation and mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.1.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The road network GIS layers for the entire model hydraulic domains have been generated and will be clipped to flood extents once hydraulic outputs become available. No inventory issues are expected in the computation of these impacts.

3.1.3.5. Evaluation Approach

Economic Modeling

The approach to estimate road damage will rely on depth and velocity from the hydraulic modeling results. A simplified flood severity raster will be developed by multiplying flood depth by velocity and mapped according to the simplified thresholds in FEMA Guidance Document 14 (FEMA 2020). It is expected that road segments in the Very High or Extreme categories (ft^2/s greater than 16) will be tagged as requiring inspection, cleanup, and/or repair. Unit costs will be based upon assimilation of historical damage information available from King County, and past federal flood risk studies. Uncertainty will be incorporated via estimation of a triangular distribution on road damage cost per segment.

To incorporate this damage into the FDA model, the relevant roads will be split into segments, converted to points, and incorporated into the model as pseudo-structures to extract depths at each location from the flood depth grids. A Roads occupancy type and DDF will be defined and linked to these road points. This approach will result in an estimate of EAD for road damage.

ESJ Analysis

The ESJ analysis will entail analyzing the differential effects on ESJ populations related to transportation and mobility due to road flooding and, consequently, road closures. Road flooding and closures can impact some ESJ populations disproportionately, especially those who need to work hourly and onsite. This will primarily be a qualitative analysis and will be considered within a broader transportation context given modeled flooding of vehicles, bridges, and related traffic and detour impacts, as discussed in other sections. The availability of alternative routes and modes of transportation for ESJ populations will also be considered.

3.1.4. Direct Bridge

This impact category addresses the potential for structural damage to bridges from flooding. Because damage to the bridge structure is dependent on velocities as well as depth, no standardized DDF is available for bridges. However, the FEMA Hazus model contains a bridge damage module that can estimate the percent damage on a bridge and the probability of the bridge being functional for a given flood event. This assessment in Hazus is based on failure risk for different magnitude flood events as a function of scour risk. Scour risk for bridges in the USFHWA National Bridge Inventory (FHWA 2021) are prepopulated in Hazus and may be leveraged in this analysis. If more recent or refined bridge risk data is available from King County or the hydraulic modeling team, in a format that can be readily applied to the HAZUS methodology, it will be incorporated in this analysis.

3.1.4.1. Inventory Data

The primary inventory data for this impact category is the National Bridge Inventory, which is prepopulated in the FEMA Hazus database and includes generalized bridge repair cost information for each bridge. The use of the HAZUS methodology to compute bridge risk will also rely on depth outputs from the hydraulic modeling for modeled flood events, which will be coordinated with the hydraulic modeling team.

3.1.4.2. Damage Function Data

The FEMA HAZUS methodology contains damage functions which estimate the percent damage to a bridge and the probability of the bridge being functional for a given flood event. In combination with a general estimate of total replacement cost, a frequency-damage function may be developed for each modeled bridge. Note that King County has provided historical damage information from four recent flood events that contains some information about damage to bridges for FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

3.1.4.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from bridge damage, the information may inform qualitative description of ESJ impacts to transportation and mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.1.4.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified and no inventory issues are expected in the computation of these impacts.

3.1.4.5. Evaluation Approach

Economic Modeling

To incorporate bridge damages into FDA, each bridge will be represented in the model as a pseudo-structure to extract depths at each location from the flood depth grids. The DDF developed will be a translation of the frequency-damage relationship developed for each bridge based upon the FEMA methodology. From the HAZUS methodology and dataset, bridge value and scour potential will be estimated for all bridges, and any data gaps will be filled by using representative data from other similar bridges. The methodology defines mean estimated repair cost for a failure (across all failure severities) to be 25% of replacement cost. The DDF included in FDA will reflect increasing probability of failure, and the value for each bridge will be the repair cost upon failure, such that FDA will compute damage as the probability-weighted repair cost. Uncertainty in damage will be incorporated by estimation of a triangular distribution on bridge repair cost generated from the FEMA methodology. This approach will result in an estimate of EAD for bridge damage.

ESJ Analysis

The ESJ analysis will entail analyzing the differential effects on ESJ populations related to transportation and mobility due to bridge damage and, consequently, bridge closures. Bridge damage and closures can impact some ESJ populations disproportionately, especially those who need to work hourly and onsite. This will primarily be a qualitative analysis and will be considered within a broader transportation context given modeled flooding of vehicles, roads, and related traffic and detour impacts, as discussed in other sections. The availability of alternative routes and modes of transportation for ESJ populations will also be considered.

3.1.5. Direct Critical Utilities

This impact category addresses direct impact to critical utility infrastructure not already addressed in Sections 3.1.1 (buildings), 3.1.3 (roads), and 3.1.4 (bridges). In each basin, there may be other utility infrastructure at risk of damage, such as water treatment plant or electrical substation infrastructure. There may also be utility infrastructure whose location in the floodplain will be mapped but damages will be not computed, such as buried arterial utility lines. In general, utility networks and connections to individual properties will not be inventoried or mapped.

Note that this impact category addresses direct damage to critical utility infrastructure. Loss of service impacts and equity and social justice impacts related to critical facilities are discussed in Section 3.4.4. The definition of critical facilities for the King County LBAMRA is presented in Section 3.4.3.

3.1.5.1. Inventory Data

The FEMA Hazus model contains a default database of critical utility infrastructure that provides facility type and value. This dataset will be cross-referenced with the inventory built from the Assessor's database and refined based on available data to ensure that the inventory of critical facilities is complete.

3.1.5.2. Damage Function Data

The FEMA Hazus model provides DDFs for critical utility infrastructure by facility type. These functions will be used to estimate impacts. Infrastructure valuation will be based upon local data from King County as available, with the option to use the generalized facility cost information available in Hazus where needed. The use of the Hazus methodology to compute impacts is dependent on the availability of hydraulic outputs to provide depths by flood event. Note that King County has provided historical damage information from four recent flood events as collected for FEMA Preliminary Damage Assessment reports (King County 2021a). Preliminary review of the data found that some damages to utility facilities was noted. This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

3.1.5.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from physical damage to critical utility infrastructure, the information may inform qualitative description of ESJ considerations and impacts related to access to critical facilities by providing the inventory of critical facilities for consideration in that evaluation. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.1.5.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified and no inventory issues are expected in the computation of these impacts.

3.1.5.5. Evaluation Approach

Economic Modeling
To incorporate utility facility damages into FDA, each asset will be represented in the model as a pseudo-structure to extract depths at each location from the flood depth grids. For utility features associated with a specific parcel, the feature will be assigned a parcel number from the Assessor's database for aggregation purposes. The DDF developed will relate depth to percent damage for each facility type per the DDFs available in the HAZUS model. Uncertainty in damage will be incorporated by estimation of a triangular distribution on facility value. This approach will result in an estimate of EAD for these critical utilities.

ESJ Analysis
The ESJ analysis will use the information developed about utility impacts to inform consideration of utility service loss impacts, as described in Section 3.4.4.

3.1.6. Agricultural Loss

Flood risk to agricultural production is typically estimated as a function of crop loss and the associated reduction in income due to flooding of crops and pasture. The USACE provides a standardized methodology (USACE 1987) for such an analysis in the LifeSim model. First, an inventory acreage by crop type is developed. Then, a production budget is entered for each crop. Based on the estimated seasonality of flooding that will be developed in coordination with the engineering team, the model computes the impacts to crops, the associated loss in yield and therefore sales, and adjusts for production expenditures that were never realized due to the flooding.

In addition to crop-related losses, there may be other farm-related losses that would need to be separately evaluated, including cost of restoring fields, farm roads, and equipment to regular operation. For example, some farms incur costs to drain fields or address sedimentation and may experience damage to specialized equipment or infrastructure, such as on-farm roads or irrigation equipment, or may experience adverse livestock impacts. Such losses will be estimated as supported by available historical information, stakeholder input about on-farm assets and risk, or application of an estimate per-acre cost for restoration activities.

3.1.6.1. Inventory Data

The crop loss approach in LifeSim requires identifying acreages of cropland in the floodplain, by crop type. This step is automated by LifeSim, allowing import of a GIS layer from the USDA Cropland Data Layer that covers the study area. The next requirement is the specification of enterprise crop budgets by crop type (planting and harvest dates, yield, price, monthly production expenditures, and optionally a substitute crop that might be planted if the field floods late in the season). This data is not provided in LifeSim, though is commonly available from previous studies or from the local agricultural extension. For this study, the database maintained by Washington State University (WSU 2021) will be used unless local budgets are available from stakeholders or King County.

3.1.6.2. Damage Function Data

In the LifeSim model, impacts are affected flood duration and flood timing (time of year). Specification of an assumed flood date affects how much production expenditure has occurred at the time of flooding for each crop type, the extent to which the planted crop can recover from the flood without impacting yield, and whether the farmer would have time to replant an alternate crop during the same year to recoup some losses. These adjustments are made by the model based on the monthly production budgets that are specified. A representative flood date will be selected in coordination with the H&H team based on engineering team judgment about the month that floods are most likely to occur.

Specification of duration-damage functions by crop may utilize one of three generalized curves in LifeSim, for 1-day, 3-day, and 7-day inundation durations. For this study, the hydraulic outputs will be reviewed to determine which of the generalized curves is most appropriate for the study area.

3.1.6.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary value loss from physical damage to agricultural properties, and as part of the ESJ analysis, the race/ethnicity of farmworkers will be reviewed (to the extent possible) for differential income impacts to farmworkers. The information may inform qualitative description of ESJ impacts related to economic opportunity and the importance of the King County agricultural economy. The analysis will also describe potential impacts to agricultural small-business enterprises, such as U-Pick berry farms or seasonal agrotourism (e.g., pumpkin patches). Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.1.6.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.1.6.5. Evaluation Approach

Economic Modeling

To incorporate crop and agriculture-related damages requires pre-calculating these damages to create a frequency-damage relationship, and then translation of that relationship to a depth-damage function for representative locations in the floodplain. Representative locations will be defined by placing a point within each parcel where agricultural damages are relevant. Relevant parcels will be identified based on GIS overlay of the Assessor's database, aerial imagery, and the National Cropland Data Layer.

The LifeSim methodology will be used to compute crop damage by event at each representative location. An appropriate representative flood date and appropriate duration-based damage curve will be determined in coordination with the H&H team based on review of the hydraulic model outputs and sensitivity analysis in LifeSim. For other related agricultural impacts, a per-acre unit cost will be estimated that reflects general costs incurred for restoring land and equipment to regular operation. These general costs will be estimated based upon consideration of national data from the USDA Risk Management Agency (USDA 2022), which publishes historical information about insurance-covered losses from natural disasters, as well as review of the historical damage information provided by King County. Uncertainty in the applied cost will be defined using a triangular distribution based upon the input data. This cost will be applied in proportion to inundated areas by flood event to build a frequency-damage relationship. This relationship will be translated to a depth-dollar loss function for incorporation into FDA. An agricultural occupancy type and DDF will be added to the FDA model. This approach will result in an estimate of EAD for agricultural loss.

ESJ Analysis

The ESJ analysis will revolve around analyzing the differential income effects on ESJ populations related to monetary value loss from physical damage to agricultural properties. Damage to agricultural properties due to flooding can impact some ESJ populations disproportionately, especially those working on farms or owning small farms or small agricultural enterprises. This will primarily be a qualitative analysis that characterizes impacts related to agriculture from an ESJ perspective. Agricultural workers can include low wage, marginalized, and sometimes undocumented immigrant employees. Public data sources will be used to characterize the race/ethnicity of farmworkers and farm owners within the study area. Small farms and small agricultural enterprises (such as U-Pick berry farms or seasonal agrotourism (e.g., pumpkin patches)) will also be a focus of the analysis to determine the effects on these. The analysis will describe the importance of these businesses and the extent to which ESJ populations are affected.

3.2. RESPONSE AND RESTORATION COSTS

3.2.1. Debris Removal

Following a major flood event there may be substantial debris requiring cleanup, such as building-related debris and natural debris (vegetation, sediment). The FEMA Hazus model contains a debris tonnage estimation methodology that addresses building debris as a function of building structural components (founding, structure, and finishes), but does not address content, inventory, or natural debris. However, this Hazus methodology represents the best-available debris estimation approach for large inventories. Consideration of building content and interior cleanup is considered separately in Section 3.2.2 Building Cleanup.

For this debris removal category, impact estimation relies on the depth grids that will be developed by the hydraulics element of the consultant team and the building inventory developed as part of this economics effort. The Hazus methodology will then be used to generate a frequency-to-debris-tonnage relationship. Tonnage may be converted to volume (cubic yards) based on published FEMA Debris Estimating Guides (FEMA 2010) typically employed for disaster recovery field operations. This information may then be converted to a frequency-damage relationship based on average debris removal costs per cubic yard.

3.2.1.1. Inventory Data

The inventory data required for estimation of these impacts will be finalized building inventory and hydraulic depth grids, both of which are required to implement the Hazus methodology to estimate debris tonnage. The building inventory is described in Section 3.1.1. Hydraulic depth grids are being developed by the hydraulic element of the project team under separate subtasks.

3.2.1.2. Damage Function Data

A 2020 study by the USACE Portland District published a range of costs from a minimum of $8 to a maximum of $46 per cubic yard, with an average of $28 for the cleanup, trucking, and disposal of flood debris (USACE 2020). This source will be adjusted for price level and provides the parameters of a triangular distribution for the estimation of debris removal impacts. Note that King County has provided historical damage information from four recent flood events, some of which contain estimates of damage related to debris removal (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source as appropriate.

3.2.1.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of structural debris cleanup following a flood. Recent research suggests that elsewhere in the country, the cleanup workers for these jobs include low wage, marginalized, and sometimes undocumented immigrant employees. Information on this topic will be reviewed and make up a qualitative discussion of this topic in the context of ESJ.

3.2.1.4. Inventory Status Summary

All of the inventory data needs are accounted for, and no inventory issues are expected in the computation of these impacts.

3.2.1.5. Evaluation Approach

Economic Modeling

To incorporate debris removal damages into FDA, the debris generation function from HAZUS will be applied by occupancy type, then multiplied by debris removal unit cost to estimate the maximum removal cost per structure. A pseudo-structure will be created for each building where the building value is the maximum debris removal cost, and the depth-damage function will relate depth to percent of debris removal cost assessed. Uncertainty in damage will be incorporated by estimation of a triangular distribution on maximum debris removal cost. This will result in EAD for debris removed computed by building.

ESJ Analysis

The ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to the monetary and health impact of structural debris cleanup following a flood. Research will be conducted regarding the characteristics of clean-up workers in the study area, especially given that elsewhere in the country, such workers include low wage, marginalized, and sometimes undocumented immigrant employees. Further research will look into the health hazards associated with flooding-related clean-ups, and the health effects of toxins on these frontline workers will be investigated. Any potential job creation associated with clean-ups following a flooding event will also be described. Additionally, the analysis will look into the incomes of frontline clean-up workers to understand the extent to which ESJ populations are affected. This will primarily be a qualitative analysis based on available literature and data.

3.2.2. Building Cleanup

The building cleanup impact category addresses the cleanup costs that would be incurred at residential buildings and some non-residential buildings for the extraction of floodwaters, drying out of the buildings and contents, and any necessary decontamination treatments such as mold and mildew abatement (these impacts are separate from the debris removal impacts discussed previously in Section 3.2.1). Building cleanup costs will be applied to those buildings whose occupancies indicate there would be a need for such cleanup activities, such as residential buildings, commercial buildings, and public buildings, where engagement with the public is generally expected. Building cleanup impacts will not be estimated for occupancies such as warehouses and industrial buildings, where such incremental cleanup costs may not be applicable due to differences in building materials, contents, and public accessibility.

3.2.2.1. Inventory Data

The inventory data necessary for cleanup costs is contained in the building inventory. Cleanup costs will be applied to buildings whose occupancies indicate there would be a need for such cleanup activities, such as residential, commercial retail, and public buildings. Cleanup costs will be calculated by structure based on a cleanup unit cost per square foot for the building's first floor square footage. Estimated cleanup unit costs are available from previous USACE studies, and generally are around $10 per square foot (USACE 2020a) of finished first floor area.

3.2.2.2. Damage Function Data

Recent studies by the USACE have developed a DDF for cleanup costs, assigning 100% of cleanup cost impacts for flood depths greater than 3 feet, and interpolating impacts at lesser depths. This function will be modified for application to study area occupancies and foundation types.

3.2.2.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of building cleanup following a flood. Recent research suggests that elsewhere in the country, the cleanup workforce for these jobs include low wage, marginalized, and sometimes undocumented immigrant employees. Information on this topic will be reviewed and make up a qualitative discussion of this topic in the context of ESJ.

3.2.2.4. Inventory Status Summary

All of the inventory data needs are accounted for, and no inventory issues are expected in the computation of these impacts.

3.2.2.5. Evaluation Approach

Economic Modeling

To incorporate building cleanup costs into FDA, the maximum cleanup cost by building will be estimated, and pseudo-structures will be created for each building where the building value is the maximum cleanup cost. The depth-damage function will relate depth to percent of debris removal cost assessed. Uncertainty in damage will be incorporated by estimation of a triangular distribution on maximum building cleanup cost. This will result in EAD for building cleanup by building.

ESJ Analysis
The ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to the monetary and health impact of building cleanup following a flood. This analysis will be performed in concert with the consideration of structural debris cleanup from an ESJ perspective, as described in the previous section.

3.2.3. Emergency Response

Emergency costs include those expenses resulting from a flood that would not otherwise be incurred. For example, the costs of flood fighting, increased costs of normal operations during the flood, and increased costs of police or fire service.

3.2.3.1. Inventory Data

The building inventory discussed in Section 3.1.1 will be used to calibrate estimated emergency costs from previous studies or other published information for use in the study areas.

3.2.3.2. Damage Function Data

Two USACE sources provide good information about estimating emergency costs associated with flooding.

The first is a report developed by the USACE New Orleans District (USACE 2012) which developed unit cost estimates and DDFs for several types of emergency costs, including emergency response roadway clearing, incremental hospital operating costs, police emergency operations per affected household, and fire emergency operations per affected household. The report also provides an estimate of relocation costs for stations that experienced substantial flooding.

The second is a recent USACE Portland District study on Columbia River (USACE 2020), which included elicitation of emergency operating costs for the Multnomah County Drainage District. This study provides activity-level cost information for flood fighting, inspections, road closures, and other operations in terms of labor, materials, and equipment. These costs will be leveraged to estimate local flood response costs for different size flood events to build a frequency-damage function.

Note that King County has provided historical damage information from four recent flood events that contains estimates of multiple types of damage for FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source as applicable.

3.2.3.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of emergency flood response. The methodology for this category relies on identification of affected properties, which is addressed by the building inventory in Section 3.1.1. In addition to property, ESJ considerations related to emergency response include health and safety risk to people experiencing homelessness that may be within the floodplain, which will be considered qualitatively.

3.2.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.2.3.5. Evaluation Approach

Economic Modeling
As noted above, there are several sources of emergency cost information, and as such, emergency costs will be incorporated in several ways:

- Emergency response costs as a function of the quantity and severity of buildings flooded will be incorporated based upon past USACE studies that estimated police, fire, and medical emergency services costs.
- Emergency response costs which are incremental costs of operating/inspecting flood protection systems, emergency warning systems, and other facility/infrastructure will be estimated based upon the information from King County and the recent USACE Portland District study.

For emergency costs tied to buildings, the approach will be similar to that described for vehicle damages. Pseudo-buildings will be included the model, where each building has as its value the total per-building emergency response cost for that building, and a DDF will be defined that related depth to percent of total emergency cost incurred. Uncertainty in emergency cost will be incorporated by estimation of a triangular distribution. This approach will result in an estimate of EAD for emergency costs tied to buildings.

For emergency costs tied to monitoring, inspection, and emergency operations, a pseudo-building will be included that allows definition of an occupancy type and function that captures total impact in the study area by event. These costs will be pre-calculated and inserted into FDA as a depth-to-dollar DDF. This will result in an estimate of EAD for these costs for the entire study area.

ESJ Analysis

The ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to the monetary impact of emergency flood response. Modeling results will be used to identify flooded properties, especially those belonging to lower-income groups (such as mobile homes, older houses, etc.). Next, ESJ considerations associated with emergency response activities will be qualitatively discussed. Emergency flood response can be slower for areas that have ESJ populations, thus affecting some groups disproportionately. In addition, many frontline workers associated with emergency response could potentially be lower income. The analysis will describe the incomes of frontline emergency response workers to understand the extent to which ESJ populations are affected. In addition, the health effects of toxins on these frontline workers will be described. Finally, the health and safety risk to people experiencing homelessness that may be within the floodplain will be investigated to the extent data are available.

3.2.4. Landscape Restoration

Landscaping impacts are estimated based on a repair/re-landscaping cost proxy, where flooded facilities, such as parks, golf courses, and schoolyards, would incur landscape restoration costs.

3.2.4.1. Inventory Data

GIS analysis will be used to identify properties requiring substantial landscape restoration. A point inventory of such areas will be developed and attributed with the ground elevation at the facility centroid and the total size of the area in acres.

3.2.4.2. Damage Function Data

A recent USACE Portland District study developed an average landscaping restoration cost per acre of $28,000 (USACE 2020) and developed an accompanying DDF. This source facilitates computation of landscape restoration impacts in the economic model in the same manner that building impacts are calculated. Note that King County has provided some historical flood damage information that included damages at parks and recreation facilities (2021a). This information will be reviewed in detail and used to adjust the standardized value from the USACE source as appropriate.

3.2.4.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of repairing landscaped areas following a flood. Because major landscaped areas include parks, golf courses, and potentially other public or community spaces, the results of this analysis may be leveraged in the ESJ evaluation to qualitatively describe impacts to access to parks and natural areas, consistent with the King County Determinants of Equity.

3.2.4.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The population of the landscape area inventory is pending, as it will be informed by the final building inventory and related Assessor's data to identify parcels with major landscaping requirements. All necessary data is available, and no inventory issues are expected in the computation of these impacts.

3.2.4.5. Evaluation Approach

Economic Modeling

To incorporate landscape restoration damages into FDA, each damageable asset will be represented in the model as a pseudo-structure to extract depths at each location from the flood depth grids. Because these points may represent parks or golf courses that cover a large geographic area, damages by event will be precalculated and the damage function used in FDA will be a depth-to-dollar damage function. Uncertainty in damage will be incorporated by estimation of a triangular distribution on dollar damage by event. This approach will result in an estimate of EAD for landscape restoration costs.

ESJ Analysis

The ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to the monetary impact of repairing landscaped areas following a flood. As a starting point, relevant affected areas will be identified, especially those possibly used by lower-income groups (such as parks and community spaces near low-income housing, mobile homes, older houses, etc.). Next, a qualitive analysis of related impacts on ESJ populations will be conducted. Information developed about flooded parks and natural areas will inform related ESJ impact analysis, as described in Section 3.4.

3.3. IMPLICIT COSTS

3.3.1. Transportation Detour and Delay

This impact category addresses impacts to users of roads, rail, and airport transportation.

When transportation routes are flooded and impassable, users experience health and safety risks, as well as adverse economic impacts in the form of lost time due to detours (applicable to passenger traffic), and added operating costs on those detours (applicable to both passenger and commercial traffic). By estimating the volume of traffic affected by flooding in a given event, and estimating the necessary detour, the adverse economic impact can be calculated. Health and safety risk from flooded roadways will be characterized through GIS mapping, showing the nature and extent of roadway flooding for various hydraulic scenarios.

3.3.1.1. Inventory Data

An inventory of roadways, rail, and airport infrastructure will be completed for each basin study area using the USACE LifeSim model, which facilitates generation of a transportation layer based on the OpenStreetMap API (OSM 2021). The resultant GIS dataset will contain road centerlines and attribute information about the roads, rail centerlines, and airport point features. Roadway traffic counts are available from King County (2021) as well as from WSDOT (2021) and will be used to attribute flooded roads with estimated traffic volume and affected population. Rail traffic and air traffic will be estimated based upon published industry and national statistics (BTS 2022). Necessary detours will be estimated based on a map analysis to identify reasonable detours along highways and major arterials[6], and alternate rail lines for key flood events. For air traffic, an assessment will be made to determine whether traffic is diverted to nearby airports or flights are cancelled.

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[6] Impacts to traffic on small local roads will not be analyzed, as it is typically assumed that trips experiencing significant detour and delay are accounted for by consideration of highways and major arterials.

3.3.1.2. Damage Function Data

The value of lost time for vehicle and train occupants can be estimated based on a USACE methodology for value of time saved. This methodology estimates an hourly value of time as a function of median hourly income, adjusted by the trip purpose (work trip versus recreation trip). This dollar value can be applied to the affected trip volume based on the duration of detour.

Increased vehicle operating costs are based on variable operating cost per mile, applied to the incremental mileage required for the detour. Variable operating costs per mile can be readily obtained from industry sources such as AAA (2020).

Increased operating cost for freight rail will be estimated based upon typical operating cost per mile for freight trains, which will be estimated based upon national statistics from the BTS (2022), and applied to the estimated detour route.

3.3.1.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of transportation detours and delays. Part of this analysis requires estimation of affected vehicle and passenger rail trips. This information may be leveraged in the ESJ analysis to describe the population whose access to transportation and mobility may be affected. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.3.1.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The GIS layers for the entire model hydraulic domains have been generated and will be clipped to flood extents once hydraulic outputs become available. No inventory issues are expected in the estimation of these impacts.

3.3.1.5. Evaluation Approach

Economic Modeling

Road, rail, and airport inventories will be used. Roads in the inventory will be categorized according to their size and general traffic volume, such as interstate, highway, arterial, and other. Detour and delay costs to drivers and passengers will be estimated as a function of detour length and added trip time. Detour length and added trip time by flood event will be manually estimated by review of inundation maps for each basin and use of online trip-planning tools such as Google Maps Directions. The same approach will be used for passenger rail traffic to tabulate detour and delay costs, however where detours via rail are impractical, passengers will be assumed to drive instead. For freight rail, only detour costs will be tabulated.

Based on the inundation maps, representative analysis points will be identified in GIS along relevant roadways. For both types of rail impacts, a single pseudo-building will be created at a representative point in the floodplain to capture the impact. Total detour and delay cost by event at each point will be converted to a frequency-damage relationship. This relationship will be translated to a depth-dollar function that is assigned to the analysis points in FDA by use of pseudo-buildings and a traffic occupancy type. Uncertainty will be incorporated by a triangular distribution on detour and delay cost. This will result in estimates of EAD for vehicle, rail, and air traffic detour and delay costs.

ESJ Analysis

The ESJ analysis will entail analyzing the differential effects on ESJ populations related to monetary impact of traffic detours and delays due to road, rail, and airport flooding and, consequently, road and bridge closures. This will primarily be a qualitative analysis and will be considered within a broader transportation context informed by the modeling or direct damage to roads and bridges as discussed in previous sections. Traffic detours and delays can result in disproportionate impacts to some ESJ populations, especially those who need to work hourly and onsite. To the extent practicable, the qualitative analysis will consider potential routes or roadways that, if flooded, might have disproportionate effects on ESJ populations. The availability of alternative routes and modes of transportation for ESJ populations will also be considered.

3.3.2. Business Disruption (Regional Economic Impacts)

Inundation of non-residential properties can result in temporary closure of businesses while owners restore the functionality of the property. During this period of closure, businesses would experience loss in sales and revenue. Estimates of these direct revenue losses will be based upon estimated annual revenue per square foot by occupancy type. In addition to these direct impacts, the IMPLAN input-output model will be used to estimate indirect and induced employment and income impacts on the regional economy[7].

3.3.2.1. Inventory Data

The non-residential inventory will be identified based on the building inventory dataset that is being developed and is discussed in Section 3.1.1. For relevant structures, estimated annual sales (revenue) will be estimated based on information provided by King County Assessor (as available), and supplemented as necessary with generalized values for major occupancy types which are contained in the FEMA Hazus model database.

3.3.2.2. Damage Function Data

The duration of business closure drives the potential magnitude of direct revenue losses. The closure period would include the period of inundation, as well as a restoration period after flood water has receded. The FEMA Hazus model provides estimates of restoration as a function of flood depth for common non-residential occupancy types. The direct loss estimates will be segregated by major industry for use as inputs to the IMPLAN model. This industry segregation will be based on information provided by the King County Assessor in the building inventory discussed in Section 3.1.1.

3.3.2.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses disruption of business activity from flooding. Results from the IMPLAN analysis will include job impacts. These job impact results may be used in the ESJ analysis to support characterization of ESJ impacts from flooding. Low-income workers may be more sensitive to even temporary income loss, and hence this could be more costly to those communities. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.3.2.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.3.2.5. Evaluation Approach

Economic Modeling

Incorporation of regional economic impacts requires a two-step modeling process. First, the IMPLAN model will be developed and run by basin to develop representative ratios of direct revenue loss to changes in employment, indirect sales, and induced sales. Once defined, these ratios will be applied to flooded businesses to include these impacts in the FDA model at the building level. More detail is provided below.

IMPLAN is an industry-standard input-output model, which is a type of model that measures the flow of commodities and services among industries, institutions, and final consumers within an economy. IMPLAN accomplishes this by capturing all monetary market transactions in an economy, accounting for inter-industry linkages and availability of regionally produced goods and services to predict the economic impacts of a change in one or several economic activities on an entire economy. These linkages are captured via multipliers which have been developed based on continual review and update

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[7] Direct revenue losses for flooded businesses are imported into IMPLAN to estimate the effects of sales and revenues loss on relationships with other industries and spending patterns in the economy (generating indirect and induced output losses).

of industry data. In the context of flood consequences, flooding of businesses may result in temporary business closures, during which the business cease operation. This results in direct adverse impacts on employment and business activity (i.e., impacts to the businesses that were flooded), as well as indirect adverse impacts on suppliers of flooded businesses, and induced impacts on many other businesses in the regional economy due to lost household income from employees of directly and indirectly affected businesses that is unavailable to be spent within the regional economy.

Based on review of the floodplains by event and basin, IMPLAN will be run for several representative industry mixes, such that the mix of the types of businesses experiencing revenue loss in the flood model are represented in specified IMPLAN industry mix. A minimum of three IMPLAN events will be processed for each basin, though five events may be used if necessary, to capture inflection points in the rating curve. Results of the IMPLAN model will be ratios of direct revenue loss to indirect impact, induced impact, job loss, and local tax impacts. These ratios will be applied to direct loss at the building level so that these impacts may be included in FDA at the building level.

Direct loss in sales (business revenue) by flood event will be estimated based on annual revenue for each flooded business. Revenue will be estimated based upon sales-per-square-foot unit costs available by occupancy type in the FEMA Hazus model. Total days of business closure will be estimated based on the FEMA standardized methodology which estimates business restoration time as a function of flood depth by occupancy type. Because FDA assumes buildings are present every year (see Section 2.3), business closure durations will be capped at 365 days. Closure durations will be multiplied by average daily revenue for each business and the IMPLAN ratios to estimate total direct revenue loss. Then the ratios will be used to tabulate other loss types by building.

To enter these impacts into FDA, pseudo-structures will be inserted, and depth-to-dollar damage functions will be entered for these structures. Uncertainty will be considered via a triangular distribution, developed based upon the uncertainty in total annual revenue for each business. The output of this category will be regional economic impacts of business disruption reported on an EAD basis.

ESJ Analysis

The socioeconomics and ESJ analysis will focus on the differential income effects of business disruption on ESJ populations from flooding and the related job losses. Disruption of business activity due to flooding can impact some ESJ populations disproportionately, especially those working on hourly wages or owning small businesses. Such workers are generally more sensitive to income losses, including temporary losses of income and livelihoods. Hourly wage workers can include low wage, marginalized, and sometimes undocumented immigrant employees. As a starting point, various public data sources will be used to identify the race/ethnicity of low-wage and hourly workers, as well as small business owners (especially micro business enterprises) within the study area. Publicly available inventories of small businesses, along with any ownership information will be obtained and analyzed. The analysis will also look into the incomes of small businesses to understand the extent to which ESJ populations are affected. This demographic and business characterization will be cross-referenced with the quantitative regional economic impact analysis to identify and describe notable ESJ concerns arising from business disruptions.

3.3.3. Recreation and Natural Lands Access Losses

This impact category estimates the economic impact of flooding on affected recreation, and other natural land resources. For this impact category, the quantitative focus is on public outdoor recreation resources. Impacts associated with private or fee-based recreation facilities (e.g., museums, golf courses) are considered to be addressed by the business interruption analysis discussed in Section 3.3.2. For public recreation resources, the recreation value being evaluated is user willingness to pay for the resource, regardless of whether use fees are actually charged. For this purpose, the USACE provides the Unit Day Value methodology (USACE 2020b) which uses a scoring rubric to estimate the willingness to pay for recreation resources in the floodplain based on the context of other resources available locally and regionally. The methodology provides annually updated unit costs that can be applied to visitation counts to estimate resource value.

In addition to use value, there may be impacts from physical damage to recreation trails or related facilities.

3.3.3.1. Inventory Data

Recreation visitation data for public and free recreation areas, such as trails and parks, is not often available. However, if representative data is available from King County, it will be used to develop generalized use rates for different recreation areas or facility types. If local site-specific data is not available, existing published information from past studies or based on other existing published data for outdoor recreation within the study areas will be used to estimate use density, such as based on published visitation volumes for State parks (WSP 2021).

3.3.3.2. Damage Function Data

Losses will be estimated based on an estimated duration of closure for recreational facilities following flooding. The basis for these estimates will be inundation duration information that will be available from the hydraulic modeling and will be adjusted to account for reasonable inspection and restoration of facilities. Note that King County has provided some historical flood damage information that included damages at parks and recreation facilities (2021a). This information will be reviewed in detail and used to adjust the standardized value from the USACE source as appropriate.

3.3.3.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary economic impact from reduction in quality and/or quantity of available recreation resources. Information about the type and location of recreation resources in the study area may inform characterization of ESJ conditions with regard to access to parks and natural areas. For example, different cultural groups might be more or less dependent on such resources. Also, subsistence fishing and hunting curtailments may be relevant to low-income as well as racial and ethnic populations. Finally, homeless populations could be more affected by loss of access to parks and other natural public properties. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 3.4.

3.3.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.3.3.5. Evaluation Approach

Economic Modeling

Loss of recreation value will be included in the FDA model by created pseudo-structures, where structure value corresponds to maximum annual recreation value loss for the facility, and the corresponding damage function relates percent of that loss as function of depth. After review of the damage data provided by King County (2021a), it was determined that the Unit Day Value (UDV) methodology would provide the best estimate of the value of recreation opportunity loss to local residents. The UDV methodology estimates the value of recreation through approximation of visitors' willingness to pay for the recreation resource. Willingness-to-pay is assumed to represent the economic value, in dollars, that a visitor places on a recreation resource. The UDV method for estimating recreation benefits relies on informed opinion and judgment to approximate the average willingness to pay of users. By applying a unit day value per visitor, an approximation of recreation value is obtained.

Execution of the UDV process will include scoring of recreation areas using the USACE UDV rubric to yield a point score for the groups of recreation activities at the site. The point score is converted to dollars per visit using tables provided in the UDV guidance. The final dollars-per-visit value is the UDV. The UDV is then multiplied by the number of annual visitors to generate an estimate of the annual recreation value at the site.

Annual visitation to each site will be estimated based on typical recreation use density that is available from Washington State Parks. Judgement will be used to extrapolate these estimates to describe use levels in neighborhood and community parks within the study area. Uncertainty parameters will be based upon a triangular distribution about the visitation density assigned to each facility to generate a triangular distribution of visitation and value for each facility.

Recreation value loss will be estimated by facility and event, and inserted into FDA using pseudo-structures, and a depth-to-dollar damage function is defined. This will yield estimated recreation loss on an EAD basis.

ESJ Analysis

The ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to the economic impact from reduction in quality and/or quantity of available recreation resources following a flood. A qualitive analysis of related impacts on ESJ populations will be conducted based upon the modeled flooding of parks and other recreation areas. Relevant affected areas will be identified, especially those possibly used by lower-income and diverse racial/ethnic and cultural groups (such as parks and community spaces near low-income housing, mobile homes, and older houses, as well as natural areas used for subsistence fishing and hunting). A qualitative assessment of the importance of these facilities within the study area will be made, and potential adverse impacts on recreation opportunity for ESJ populations described. For some of these communities, public parks and facilities provide the main recreation opportunities, while for others, some natural areas are important sources of livelihoods through fishing or hunting. Rebuilding natural areas can be slower for areas and facilities that are used by ESJ populations, thus affecting some groups disproportionately. Access to alternative sources of recreation and subsistence fishing and hunting for ESJ populations will also be considered. Some of these parks and facilities may also be used by people experiencing homelessness, and the effects of damage and subsequent restoration on communities will be considered and described.

3.3.4. Lost worker Productivity

This impact category is intended to characterize worker productivity impacts that may arise due to adverse human health impacts following a flood, such as from extreme stress and anxiety. The FEMA BCA Methodology for the Hazard Mitigation Assistance grant program establishes a standardized dollar value per affected resident of the floodplain that represents the long-term decrease in productivity (i.e., employee income) associated with the aforementioned mental health impacts (FEMA 2016). Because these effects are a function of individual trauma and are an estimate of cumulative effects up to 30 months after the flood event, they are not considered duplicative of the business disruption impacts addressed in Section 3.3.2.

3.3.4.1. Inventory Data

This impact category is applicable to the affected residential building inventory. The relevant population will be identified for each flood event based upon hydraulic modeling outputs, the residential building inventory discussed in Section 3.1.1, and the average household size for King County from the best available U.S. Census data.

3.3.4.2. Damage Function Data

The FEMA BCA Toolkit version 6.0 contains the most recent standard values per affected resident. Based upon the FEMA literature, the standard values already incorporate a distribution of flood impact severity. As such, the standard loss value may be applied to all residences experiencing flood damage. Note, however, that the monetary results of this analysis are secondary to the qualitative characterization of human health impacts as it relates to the ESJ analysis.

3.3.4.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.3.4.4. Evaluation Approach

Economic Modeling

To incorporate lost worker productivity costs into FDA, pseudo-structures will be created for each residential building, and the value of the building will correspond to the maximum lost productivity for the building, as a function of the estimated number of employed people living in the building, and the unit cost for worker wage loss. The number of employed people will be estimated as a percent of the total building population based upon age and employment statistics from the U.S. Census. A simple damage function will be included in FDA that triggers when flooding exceeds 1 foot above the first floor. Uncertainty in damage will be incorporated by estimation of a triangular distribution on maximum productivity loss cost. This will result in EAD for lost productivity.

ESJ Analysis

The socioeconomics and ESJ analysis will revolve around analyzing the differential effects on ESJ populations related to worker productivity impacts that may arise due to adverse human health impacts following a flood, such as from extreme stress and anxiety. This will primarily be a qualitative analysis that describes the affected population from quantitative modeling of lost worker productivity through an ESJ lens. Socially and economically vulnerable ESJ populations can be affected more by mental health and anxiety issues due to the more direct and immediate effects of job losses, loss of homes, loss of access to resources, transportation disruptions, etc. ESJ populations may also have reduced access to mental health resources, and the potential for such disparities based on the flooded population will be described.

3.4. EQUITY, SOCIAL JUSTICE, PUBLIC HEALTH AND SAFETY

Equity, social justice, and health impacts are an essential component of understanding flood risk in a community. In addition to monetary expected annual damage, the analysis shall qualitatively consider other demographic and socio-economic considerations to inform and characterize flood risk. This shall include identification of critical facilities, populations at risk, and ESJ populations. For the following categories, impacts will be generally qualitative, and will include a spatial analysis of indicators of equity, social, and health within the study area population, overlaid with results of the flood risk modeling outputs.

3.4.1. Equity and Social Justice Impact Indicators

King County's Equity[8] and Social Justice[9] (ESJ) Strategic Plan provides a foundation for pro-equity investment decision making. Where there are disparities in the Determinants of Equity[10] within a region, equity and social justice is not achieved. The Strategic Plan includes a Pro-Equity Policy Agenda focused on eight key Determinants of Equity, including 1) child and youth development, 2) economic development and jobs, 3) environment and climate, 4) health and human services, 5) housing, 6) information and technology, 7) justice system, and 8) transportation and mobility. Within the context of the LBAMRA study, the goal of the ESJ analysis is to understand the extent to which socially and economically vulnerable ESJ populations in floodplains are at a higher risk of being disproportionately negatively impacted by levee breaches. Such risk can be related to several of the Determinants of Equity through impacts to educational and park facilities, impacts to businesses providing local jobs, impacts to medical facilities, and impacts to transportation systems which enable access to the aforementioned community resources.

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[8] "Equity is the full and equal access to opportunities, power and resources so that all people achieve their full potential and thrive. Equity is an ardent journey toward well-being as defined by those most negatively affected." (King County 2016)

[9] "All aspects of justice—including legal, political, economic and environmental—and requires the fair distribution of and access to public goods, institutional resources and life opportunities for all people." (King County 2016)

[10] "The social, economic, geographic, political and physical environments and conditions in which people live. Full and equal access to the Determinants of Equity is necessary to have equity for all people regardless of race, class, gender, language spoken and geography." (King County 2016)

This impact category identifies the socially and economically vulnerable ESJ populations in the affected areas. Demographic and economic data will facilitate identifying the locations of concentrated racial/ethnic groups and other communities of color (black, indigenous, and other people of color–BIPOC), low-income communities, senior populations, disabled populations, housing-related indicators, and other groups identified as ESJ populations. This characterization of population will be based upon existing published information from the U.S. Census Bureau, King County, and other local and state agencies, as described in the next section.

Overlays with other socioeconomic and geographic factors, and the outputs of the hydraulic modeling will serve to inform the analysis. The analysis will use GIS tools and maps to provide a clearer visual interpretation of risks and impacts. Comparison with other nearby locations, such as adjacent census units, will also help demonstrate how populations differ.

3.4.1.1. Inventory Data

Data from the U.S. Census Bureau, such as the Census 2020 and American Community Survey (ACS) 5-Year estimates will provide the necessary inventory data for this impact category. The U.S. Census Bureau continues to publish additional datasets from the 2020 Census. Best available geographic resolution will be obtained and utilized following the finalization of the Evaluation Approach Memorandum (Subtask 8.2). Other sources of demographic and economic data to supplement the analysis include Washington State Office of Financial Management (OFM), King County Office of Economic and Financial Analysis, and Washington Employment Security Department (ESD). In addition, the analysis will be informed by the Washington Environmental Health Disparities Mapping Tool (WEHD), the EPA Social Vulnerability Index (SVI), and other vulnerability indices. These published indices will provide tract-level information that may be used to generate more detailed estimates at the block group or block level. Specifics of the approach will be detailed in Subtask 8.2, Evaluation Approach Memorandum.

While the U.S. Census Bureau does not provide population projections, it is considered the best source of latest population estimates/data at the census tract level broken down by race, ethnicity, sex, and age groups. If needed, population growth rates for racial and ethnic groups (including BIPOC), gender identity, and different age groups may be estimated based on State-level projections by OFM and applied to ACS population estimates to develop population projections for relevant areas.

Population and demographic information will be compiled and integrated with the final building inventory discussed previously in Section 3.1.1. This will support estimation of population exposed to flooding as well as support this ESJ evaluation.

3.4.1.2. Damage Function Data

The identification of ESJ populations will provide information on geographic pockets where such communities are concentrated. Impacts from the other categories (e.g., structure impacts, roads, utilities, agriculture) will be evaluated for the ESJ populations and compared with impacts for the less vulnerable populations.

3.4.1.3. Inventory Status Summary

For this impact category, inventory and data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4.1.4. Evaluation Approach

Economic Modeling

This impact category does not require new quantitative modeling. The results of the previously discussed modeling will be summarized and organized such that it can be attributed with ESJ-specific data and analyzed in GIS to support the various components of the ESJ analysis, including qualitative analyses that will rely on mapping of ESJ populations and flood impacts, and well as the use of the ESJ index being proposed to help communicate where there are significant intersections of flood impacts and ESJ populations.

ESJ Analysis

Identifying and analyzing ESJ aspects and impacts of a project requires a multi-pronged approach. The approach and methodology to be used will entail three key steps:

Review of Data and Socioeconomic Characterization

To ensure that the analysis upholds the Strategic Plan vision of "A King County where all people have equitable opportunities to thrive," the information collected in the geospatial database will contain data that assists the County in planning for ESJ populations. Such communities are described as groups that are traditionally underserved and overburdened, including:

- Black/African American and other people of color (BIPOC)
- Indigenous/First Nations/Alaskan Native
- Non-dominant, marginalized ethnicity and cultural background
- King County identified first- and second-tier language speakers and descendants
- Refugees or immigrants
- People subjected to poverty or low incomes (including those experiencing homelessness where reliable data are available)
- Businesses and farms (especially small ones) whose owners or employees are predominantly in these groups
- People who are more vulnerable due to age, pregnancy, or other physical and mental health factors

The analysis will include characterization of socioeconomics and ESJ populations. Examples of some of the broad categories of analysis include:

- **The numbers of households and the population by location.** This will be used to evaluate flood risk geographically, and to analyze service need and provision by geography.
- **Characteristics of households by location.** The socioeconomic characteristics of households will be explored for geographic resolutions supported by available data (e.g., census tract, census block-group). For example, income information will be reviewed to identify low-income communities. Other examples include the numbers and concentrations of people who have difficulty speaking English in a region and the number of children living near the levee. These data will support the next step.
- **Identification of ESJ populations.** This step will provide the basis for comparing monetary flood risk to population vulnerability. It will include identification of places with higher concentrations of different racial and ethnic groups, low-income populations, etc. Also, focus on areas with low access to transportation, culturally unique characteristics, pre-existing health burdens, etc.
- **Trends in housing, populations, and businesses.** This will include gathering forecasts for population by census tract. These forecasts will be increasingly valuable for ongoing planning and understanding which locations will have increasing, and which decreasing needs in the future. In addition, planning with the racial equity lens will help the design of future programs and services and may also be informed by the socioeconomic information in the system.

Identify Equity Issues and Causes in Basin

To provide a more accurate analysis for individual basins, ESJ issues will be identified for each basin separately. This will be primarily based on review of publicly available data and information for that basin, including socioeconomic data, other studies done in the area, published news reports, etc. Information gathered here will allow the ESJ analysis for each basin to target the most important issues in the community.

Develop Key Indicators Addressing Issues

For some of the items above, the demographic and socioeconomic data identified in the preceding paragraphs will facilitate the identification of ESJ populations. Examples of these items are race/ethnicity, language, immigrant status, poverty levels, and age. The remaining items address health status (underlying conditions and vulnerability) and non-dominant, marginalized ethnicity, and cultural background. For some of these areas, there are existing data sources for King County that have been compiled and that may be useful to include in the analysis. Two of these are described in greater detail in Attachment B. These are the Washington Environmental Health Disparities (WEHD) mapping system, and the Social Vulnerability Index (SVI) measurement designed through support from the EPA at the national level.

Both the SVI and the WEHD system produces an overall index of vulnerability at the census tract level, based on a number of data inputs. The SVI was developed by the Center for Disease Control (CDC) and a measure for each census tract in the country has been developed. The SVI focuses on the vulnerability of the population and does not include metrics for the pollution burden in the tract like the WEHD does. However, there are 15 socioeconomic metrics, and so the SVI may be considered a more comprehensive index of population vulnerability. The metrics used to develop both the SVI and WEHD are shown in Attachment B.

After considering these options, the team determined that there is value in inclusion of both the environmental health variables as well as socioeconomic variables. Given these considerations, the recommended approach is to develop a new index for this project that combined considerations and variables unique to the WEHD with Census-based variables common to both the WEHD and the SVI. The purpose of generating a new index will be to achieve higher spatial resolution (e.g., block or block group) by leveraging the building-level characteristics and modeled flood damages being developed for this study.

This would be accomplished by combining U.S. Census Bureau data at the block group level with WEHD data at the tract level and attributing the building inventory in the economic model with representative data. This would provide an index of vulnerability at a higher geographic resolution than available from the WEHD or SVI, providing more resolution in the comparison of the spatial distribution of ESJ populations and the spatial distribution of flood impacts.

3.4.2. Residential Evacuation, Subsistence, and Reoccupation

This impact category addresses the potential need for residents to evacuate their homes, subsist following evacuation (food, lodging, etc.), and reoccupation[11]. Relevant population at risk will be identified based upon flood modeling results and the inventory data identified in Section 3.1.1. This will include identification of total population at risk, as well as the population in buildings with sufficient depth that evacuation is required. This population will be characterized according to the equity and social justice indicators discussed in Section 3.4.1. To the extent possible, potentially affected homeless populations will also be identified in terms of temporary public outdoor spaces. This category will also qualitatively characterize the flooding of arterial roadways that may affect the viability of

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[11] Following Hurricane Katrina and its associated flooding, the USACE New Orleans District collected and elicited information for this impact category and developed an estimate of up to $5,500 (2010 prices) per affected household (USACE 2012).

evacuation and may result in public safety impacts based on the nature and extent of roadway flooding for various hydraulic scenarios.

3.4.2.1. Inventory Data

The residential building inventory discussed in Section 3.1.1 will provide the necessary inventory data for this impact category.

3.4.2.2. Damage Function Data

Based upon past USACE studies (USACE 2012), evacuation is likely to begin where flood depths exceed 2 feet of water. This criterion will be applied to the flood model results to identify relevant properties and populations.

3.4.2.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4.2.4. Evaluation Approach

Economic Modeling

For this impact category, the quantitative component of the analysis is the estimation of the residential population in buildings that will experience sufficient depth of flooding to warrant evacuation. This will be accommodated in FDA by creating a custom damage function that relates depth to the number of people affected in the building. This will yield build-level estimates of affected population by event. Similarly, a custom damage function will be created that related depth to an estimated time period that residents would be in temporary lodging. These estimates of affected buildings, population, and evacuation duration will support several components of the ESJ analysis. This information will also be discussed in consideration of arterial roadway flooding to characterize the viability of evacuation for various hydraulic scenarios.

ESJ Analysis

Using the information from the economic modeling for affected population, in combination with ESJ population information developed in previous sections, the spatial distribution of flooding requiring evacuation will be compared to the spatial distribution of ESJ populations. Affected population information and roadway flooding information will also be used to characterize the potential use and accessibility of evacuation routes. The qualitative analysis will also consider the availability of, and access to, alternative sources housing for ESJ populations that may need to evacuate. The duration of evacuation for affected households will be used to describe the potential financial burden on ESJ populations when a home must be evacuated and then repaired before the residents returning.

3.4.3. Public Services and Critical Facilities

There are many public services and critical facilities that benefit the community and may be subject to impact from flooding, such as schools, libraries, and community centers. In addition to the direct damage to these buildings or cost of emergency response, adverse impacts may additionally include loss of service impacts to local residents (e.g., school closures). This impact category considers the extent to which loss of critical facility services would differentially affect local ESJ populations and the King County Determinants of Equity.

For this study, critical facilities will be defined consistent with the 2020-2025 King County Regional Hazard Mitigation Plan (King County 2020), which lists the following critical facilities: schools, hospitals, nursing homes, hazardous materials storage facilities, wastewater and stormwater management facilities, animal waste storage facilities. Additional facilities that will be considered critical include assisted living facilities, police and fire stations, facilities with designated emergency management purposes (storage, operations center, shelter, etc.), major sports venues (i.e., stadiums), and jail/correctional facilities. Buildings identified as critical facilities will be flagged in the database. Identification of critical facilities will be based upon existing published data from King County, including GIS datasets and the Regional Hazard Mitigation Plan. Designation as a critical facility will not affect computed structure, content, or inventory damages, but the presence and type of critical facilities in the floodplain may inform the evaluation for other impact categories.

3.4.3.1. Inventory Data

The building inventory discussed in Section 3.1.1 and the critical utility facilities analysis discussed in Section 3.4 will provide the necessary inventory data for this impact category. Relevant critical facilities will be mapped in combination with inundation information from the hydraulic modeling outputs.

3.4.3.2. Damage Function Data

Relevant public buildings experiencing loss of service will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012). It is anticipated that these outage probabilities will be used to adjust the FEMA standard values such that they can be applied to all relevant damaged buildings. Based on these sources, the potential duration of service loss can be characterized and used to describe the magnitude of this impact in a qualitative manner.

3.4.3.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4.3.4. Evaluation Approach

Economic Modeling

The economic modeling required for this impact category is accomplished through other impact categories, such as the evaluation of damage to buildings discussed in Section 3.1.1 and Section 3.4. Those outputs will be used to identify affected critical facilities.

ESJ Analysis

The ESJ analysis will analyze the differential effects on ESJ populations related to loss of access to or services provided by critical facilities. This will primarily be a qualitative analysis intended to characterize the critical facilities that are at risk in the study area and describe the extent to which affected facilities are important to identified ESJ populations.

3.4.4. Utility Loss of Service Impacts (Electric, Water, Wastewater)

Reliable utility service is critical to the daily lives of floodplain residents. This impact category evaluates the potential for interruption of utility service. Risk of utility outage will be used to characterize the potential affected population for each flood event.

3.4.4.1. Inventory Data

The building inventory discussed in Section 3.1.1 will serve as the inventory for this impact category. Buildings experiencing outage will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012).

3.4.4.2. Damage Function Data

Buildings experiencing outage will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012). Affected buildings will be used in conjunction with population information to characterize the potential for utility service disruption and the affected population. Duration of disruption will be estimated based upon the FEMA benefit-cost analysis methodology, which estimates the need for approximately 45 days of restoration time per foot of flood depth relative to the first floor.

3.4.4.3. Inventory Status Summary
For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4.4.4. Evaluation Approach

Economic Modeling
The quantified modeling required for this impact category is the number of affected buildings and people that may experience utility service outages. To compute this by event, depth of flooding at each building will be converted to an estimate of the total days required for restoration of building function, which FEMA estimates at about 45 days per foot of water above the first floor. Population in affected buildings will be obtained from the analyses performed for other impact categories. Outputs will be characterization of utility outage potential by building that will facilitate the ESJ analysis.

ESJ Analysis
The ESJ analysis will analyze the differential effects on ESJ populations related to loss of access to or services provided by critical facilities. Loss of power, water, and wastewater utility service may occur following substantial flooding. This will primarily be a qualitative analysis that considers the potential for utility service loss from flooding and examines the spatial relationship between ESJ populations and areas with sufficient flooding to probably have utility service disruptions. Availability and cost of alternative sources of power, water, gas, etc. for ESJ populations will also be qualitatively considered and described.

3.4.5. Mental Health, Stress, and Anxiety

This impact category is intended to characterize human health impacts following a flood that may result in a decreased quality of life through adverse impacts on mental health. For example, the FEMA BCA Methodology for the Hazard Mitigation Assistance grant program establishes a standardized dollar value per affected resident of the floodplain that represents the costs of mental health treatment following a flood. For this analysis, this risk of human health impact will be considered in the ESJ evaluation to understand whether there would likely be differential human health impacts from flooding that may affect the evaluation of flood risk.

3.4.5.1. Inventory Data
This impact category is applicable to the affected residential building inventory. The relevant population will be identified for each flood event based upon hydraulic modeling outputs, the residential building inventory discussed in Section 3.1.1, and the average household size for King County from the best available U.S. Census data.

3.4.5.2. Damage Function Data
The FEMA BCA Toolkit version 6.0 contains the most recent standard values per affected resident. Based upon the FEMA literature, the standard values already incorporate a distribution of flood impact severity. As such, the standard loss value may be applied to all residences experiencing flood damage. Note, however, that the monetary results of this analysis are secondary to the qualitative characterization of human health impacts as it relates to the ESJ analysis.

3.4.5.3. Inventory Status Summary
For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4.5.4. Evaluation Approach

Economic Modeling
For this impact category, the quantitative component of the analysis is the estimation of the population that will be affected by flooding. This is readily accommodated by the affected population estimates completed for previous impact categories. FEMA standard values are available to generate a

distribution of mental health effect severity and cumulative long-term mental health costs that would be borne by the affected population.

ESJ Analysis

The ESJ analysis will assess the differential effects on ESJ populations related to adverse mental health effects of flooding on affected population. This will primarily be a qualitative analysis that describes the affected population based upon analysis completed for other impact categories. Based upon the FEMA research and standard values cited above, and given the affected population that will be modeled, the number of residents experiencing mild/moderate and severe adverse mental health, stress, and anxiety effects may be estimated. The spatial distribution of these estimates will be compared to the distribution of ESJ populations in the study area. Socially and economically ESJ populations can be affected more by mental health and anxiety issues due to the more direct and immediate effects of job losses, loss of homes, loss of access to resources, transportation disruptions, etc. ESJ populations may also have reduced access to mental health resources, and the potential for such disparities based on the flooded population will be described. In addition to population counts, additional healthcare costs that will be borne by the affected population will be estimated and discussed.

4. COMMUNCATION OF RESULTS

The LBAMRA will produce a range of monetary and quantitative outputs and metrics that characterize flood risk. This section describes the presentation of these outputs with the intent that the results of the LBAMRA may be communicated clearly and consistently across basins.

The two main methods of communicating results will be presentation of tabular data (as in the technical documentation) and summary of results in graphical form (e.g., maps). Each is discussed in more detail in Sections 4.2 and 4.3. First, Section 4.1 summarizes the key flood risk outputs that have been identified for use in both the tabular and graphical presentation of results.

4.1. KEY FLOOD RISK OUTPUTS, INDICATORS, AND METRICS

The following list of outputs, indicators, and metrics are intended to address the monetary, quantitative, and qualitative impacts being considered in the King County LBAMRA.

Monetary Impacts

- EAD and AAE damage
    - By scenario
    - System-wide
    - With uncertainty in EAD based upon the FDA Monte Carlo results
    - Results will be summarized per the four impact category groups described in Section 3, as well as presented by category.

Levee Performance

- Levee Performance
    - NFIP Assurance statistic for existing levees
    - Long-term exceedance probability

Event-Based Characterization of Impacts

- Summary of impacts for a key breach event (e.g., the 1% ACE flood with breach).
    - Count of buildings impacted (water at the building) and inundated (sufficient water to result in damage)
    - Population associated with impacted and inundated buildings

  - Length of flooded roads
  - Average depth of flooding for damaged inventory
  - Summary of impacts for other categories will be similarly developed
- To consider ESJ, the same items identified in the previous bullet will be developed specific to identified ESJ populations, or areas with higher concentrations of ESJ populations that could be disproportionately affected.
  - Identification of areas of significant vulnerability based on ESJ considerations
  - Identification of locations where there is an intersection of significant flood risk and ESJ population
  - Identification of locations where significant flood risk may have an indirect adverse impact on ESJ populations (e.g., flooding of businesses, affecting employees' ability to work)
  - Identification of other flooded assets that may have a disproportionate effect on ESJ populations, such as public and community facilities (e.g., schools and transportation facilities).

4.2. TABULAR RESULTS

The primary location for presentation of tabular results will be as a component of the Subtask 8.6 technical memorandum. That memorandum will document the application of the economic approach and present the results of the approach for each basin with a focus on the outputs, indicators, and metrics described in Section 4.1. Narrative will be included in the memo that highlights key findings of the analysis.

4.3. MAPS AND GRAPHICS

A series of maps will be developed and included as an attachment to the technical memorandum. These maps will present high-level findings from the analysis across several themes for each basin. To limit the total number of maps produced, it is anticipated that maps would be generated that summarized annualized impact as well as for the 1% ACE flood event, but not for all individual flood events. A database of outputs will be provided that would support generation of additional custom maps. The themes are summarized in the bullets below.

- **Monetary Impact:** The theme will summarize monetary impacts, including both direct and indirect economic loss, such as building damage, business disruption, and other costs.
- **Public Health and Safety Impact:** The theme will summarize impacts to human health and safety, including direct impact (population flooded), evacuation potential, public service impacts, and critical facilities.
- **Equity and Social Justice:** The theme will build upon the previous two to map the spatial distribution and intersection of flood risk and a characterization of the study area through an ESJ lens. This will include areas where ESJ populations are concentrated and where flood risk intersects these concentrations.

Consideration will be given to the appropriate geographic resolution of mapped flood risk estimates. For maps intended for public risk communication, map format will be coordinated with King County to ensure that appropriate measures are taken to preserve sensitive property or population information.

One approach would be to present information using *feature bins*. Rather than mapping outputs tabulated for individual properties, statistics would be aggregated to larger areas, such as hexagonal grids drawn on top of the study area. This approach provides flexibility in the geographic resolution of the results (by specifying the size of the hexagons) and facilitates visual comparison of risk across the floodplain. A similar approach would be the generation of a heatmap. Figure 8 shows an example of a hexagonal bin map and a heatmap for the same hypothetical dataset, where darker colors indicate larger magnitudes.

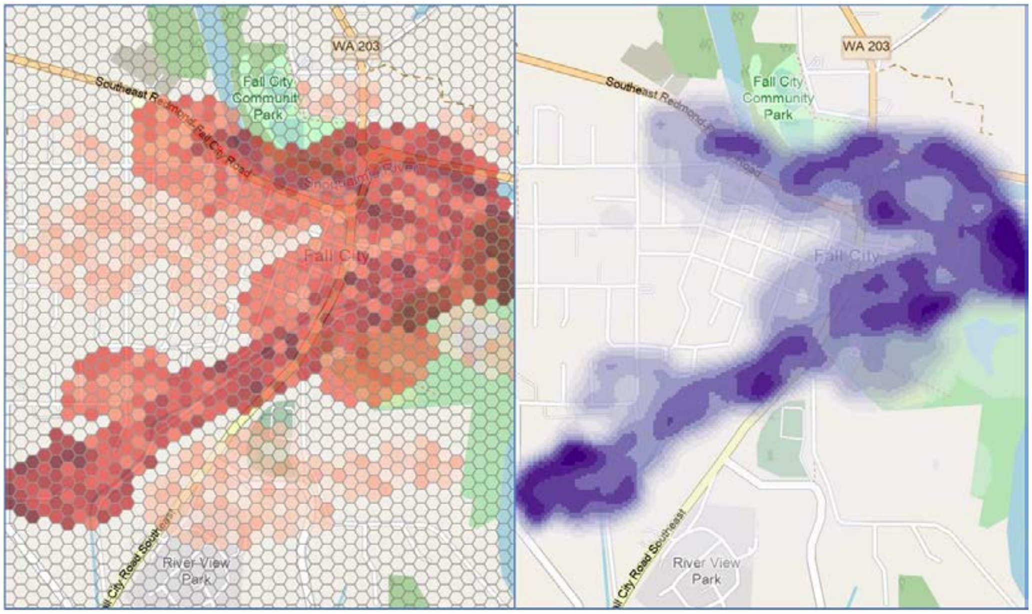

Figure 8 – Hexagonal Grid Bin and Raster Heat Map Examples

5. QUALITY CONTROL

A quality control review of this memorandum was completed by staff not directly involved with the development of the memorandum.

6. LIST OF DATA SOURCES

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ATTACHMENT A – ACRONYMS AND GLOSSARY

List of Acronyms and Abbreviations

Item	Description
AAA	Automobile Association of America
AAE	Average Annual Equivalent impacts
ACE	Annual Chance Exceedance Probability
ACS	U.S. Census Bureau American Community Survey program
AEP	Annual exceedance probability
EP	Exceedance probability
API	Application Programming Interface
BCA	Benefit-cost analysis
BIPOC	Black, Indigenous and People of Color
BTS	U.S. Bureau of Transportation Statistics
Census	U.S. Census Bureau
cfs	Discharge in cubic feet per second
DDF	Depth-to-Percent-Damage Function
D-EP	Damage–exceedance probability curve
DoE	Determinants of Equity
EAD	Expected Annual Damage
EGM	USACE Economic Guidance Memorandum
EPA	U.S. Environmental Protection Agency
ESD	Washington Employment Security Department
ESJ	Equity and Social Justice
FDA	U.S. Army Corps of Engineers Hydrologic Engineering Center Flood Damage Analysis model
FEMA	Federal Emergency Management Agency
Fragility curve	Levee failure probability–stage curve
FY	Fiscal Year
GIS	Geographic Information System
HAZUS	FEMA Hazards U.S. model
IMPLAN	Impact Analysis for Planning model
LBAMRA	Levee Breach Analysis Mapping and Risk Assessment
LifeSim	USACE LifeSim model
LTEP	Long-Term Exceedance Probability
OFM	Washington State Office of Financial Management
PV	Present Value
Q	Discharge in cubic feet per second
QA/QC	Quality Assurance and Quality Control
Q-EP curve	Discharge–exceedance probability curve
Rating curve	Stage–discharge curve
S	Stage, or water surface elevation, in feet
S-D curve	Stage–damage curve
SVI	EPA Social Vulnerability Index
UDV	Unit Day Value
USACE	U.S. Army Corps of Engineers
USFHWA	U.S. Federal Highway Administration
WEHD	Washington Environmental Health Disparities Mapping Tool
WSDOT	Washington State Department of Transportation
WSP	Washington State Parks
WSU	Washington State University

Economic Approach Glossary

The following terms, definitions, and related assumptions for the LBAMRA are provided to support the Approach Memo. Many of the hydrologic, hydraulic, and economic definitions have been adapted from the *USACE Key USACE Flood Risk Management Terms* publication from the USACE Hydrologic Engineering Center (USACE 2015). Others have been adapted from the King County Regional Hazard Mitigation Plan (2020) and King County Equity and Social Justice Strategic Plan (2016).

Term and Description
Annual Chance Exceedance: When referring to flood events with a certain likelihood of occurrence, the events are specified by their annual chance exceedance probability (ACE) as a percent, which indicates the flood level's chance of being exceeded in any year. For example, the 1% ACE flood has a 1-in-100 chance of being equaled or exceeded in any year. The standard set of ACE floods typically considered in the development of an FDA model are the 50%, 20%, 10%, 4%, 2%, 1%, 0.4% and 0.2% ACE floods.
Annual Exceedance Probability: Annual exceedance probability (AEP), generally refers to the probability that an event of specified magnitude will be exceeded in any year.
Annual Probability of Failure: When considering the potential for levee breach, annual probability of failure (APF) is the annual chance of levee breach given expected hydraulic loading. APF may be obtained by integration of the *probability-of-failure-to-exceedance-probability* curve.
Critical Facilities: Consistent with the *2020-2025 King County Regional Hazard Mitigation Plan* (2020), critical facilities include: schools, hospitals, nursing homes, hazardous materials storage facilities, wastewater and stormwater management facilities, and animal waste storage facilities. Additional facilities that are considered critical for the LBAMRA include assisted living facilities, police and fire stations, facilities with designated emergency management purposes (storage, operations center, shelter, etc.), major sports venues (i.e., stadiums), and jail/correctional facilities.
Determinants of Equity: "The social, economic, geographic, political and physical environments and conditions in which people live. Full and equal access to the determinants of equity is necessary to have equity for all people regardless of race, class, gender, language spoken and geography." – *King County Equity and Social Justice Strategic Plan, 2016*
Discharge: The volume of water passing a specific point in a given period of time, usually measured in cubic feet per second (cfs). Sometimes referred to as "flow" and abbreviated by "Q", denoting a volumetric flow rate.
Discount Rate: Conceptually, the time value of money is the rate at which society is willing to trade current consumption for future consumption, a discount rate. Definition of an appropriate social discount rate is a matter of economic research, and for practical purposes, Federal agencies specify an interest rate in policy that is used across the agency to perform consistent analyses across projects. The USACE, for example, annually sets the discount rate to be used for BCA based upon the average market yields on Treasury securities (i.e., the cost of government borrowing). The current (FY22) rate is 2.25% (USACE 2021a). Other agencies, such as FEMA, require BCA's use a 7% discount rate based upon guidance from the Office of Management and Budget that this rate approximate the marginal pretax rate of return on private sector investments and is a better reflection of the opportunity cost of capital for Federal investment (USACE 1993). For the LBAMRA, results will be presented in FY22 prices over a 50-year period of analysis using the current USACE discount rate of 2.25%.

Term and Description
Discounting: The discounting of costs and benefits places all costs and benefits at a common point in time (the present) for purposes of comparison, regardless of when during the planning period the costs and benefits occur. For example, consider the choice between receiving $100 today, or $100 in one year. Most would agree that $100 received now is more attractive. Discounting is the quantification of this preference. Assuming an interest rate of 10%, the present value of $100 received in one year is $90.91, given by [$100/ (1+10%) ^2]. Therefore, receiving $100 in one year would be equivalent to receiving $90.9 today, due to the time value of money. Alternatively stated, given an interest rate of 10%, an investment of $90.91 today would grow to $100 after one year.
Equity and Social Justice: Equity is “the full and equal access to opportunities, power and resources so that all people achieve their full potential and thrive. Equity is an ardent journey toward well-being as defined by those most negatively affected.” Social Justice refers to “All aspects of justice—including legal, political, economic and environmental—and requires the fair distribution of and access to public goods, institutional resources and life opportunities for all people.” – *King County Equity and Social Justice Strategic Plan, 2016*
Average Annual Equivalent impact: Average Annual Equivalent impacts (AAE) is a measure of economic risk that considers the impacts of future conditions on hydrology, hydraulics, and flood damage over the period of analysis. The LBAMRA will consider the effects of climate change on flood damages. As such, the model will compute EAD for each condition (existing, and with climate change), then compute AAE impacts to provide a single risk estimate that reflects current conditions and climate change.
ESJ Populations: Groups of people that may have historically experienced unequal treatment, unequal access to opportunities, or disproportionate negative impacts from government activities. These groups include racial minorities and other communities of color (black, indigenous, and other people of color–BIPOC), low-income communities, senior populations, disabled populations, populations with common housing-related indicators, and other groups identified as vulnerable. In this memorandum, the term *ESJ populations* is used to refer generally to these potentially vulnerable groups.
Exceedance Probability: Exceedance probability generally refers to the probability that an event of specified magnitude will be exceeded over some period of time. Unless otherwise stated, usually refers to an annual exceedance probability.
Expected Annual Damage: Expected Annual Damage (EAD) is a measure of economic risk that considers all possible flood magnitudes. EAD is calculated as the integral of the D-EP curve. In the context of the FDA model, EAD represents the predicted mean of the distribution of flood damage, as determined by the Monte Carlo sampling of the Q-EP curve, rating curve, and S-D curve.
Flood Risk: Measure of the probability and severity of adverse impacts (consequences) from flooding.
Flood Stage or Water Surface Elevation: Water height measured as the vertical distance in feet above a local or national datum. Given stage and a ground elevation, depth of flooding above ground may be computed.
Geotechnical Fragility Curve: A fragility curve is a function that defines a levee’s probability of failure as a function of an applied loading. For the LBAMRA, fragility curves were developed based on flood loading to estimate the probability of breach due to flooding. Therefore, fragility curves will specify the probability of levee breach as a function of river stage.
Impacted Building: Per convention and preference of King County, a building (or other asset) is *impacted* when there is floodwater at the building, even if depths are not sufficient to cause damage. In the context of the hydraulic modeling, *impacts* are identified anywhere the depth of flooding above ground is greater than zero.
Index Location: In the FDA model, an index location is a river station that is linked to each damage area. The index location is the point where the discharge and stage relationships are defined for each damage area.

Term and Description
Inundated Building: Per convention and preference of King County, a building (or other asset) is *inundated* when there is sufficient depth of flooding to cause damage.
Levee Assurance: Assurance, formerly Conditional Non-Exceedance Probability, is the probability that a target stage will not be exceeded during the occurrence of a flood of a specified ACE. Note that before 2019, assurance was calculated relative to the median 1% stage. However, assurance calculations for the NFIP must now consider the 1% ACE, which includes the full range of events, rather than a single event stage. The assurance statistic may be computed in FDA.
Long-Term Exceedance Probability: Generally, the probability of exceedance over some specific period of time (usually greater than one year). When considering levee performance, long-term exceedance probability is often reported for several periods, such as 10-, 30-, and 50-year periods of time. Sometimes referred to as long-term risk.
Monte Carlo: A sampling technique used to propagate uncertainty in a model. Given model inputs with defined uncertainty distributions, a Monte Carlo analysis will randomly sample input values and perform the desired deterministic calculation, yielding a single random sample of possible model output. This is repeated many times until the sample of model outputs is sufficient to define the probability distribution of the output.
Period of Analysis: For benefit-cost analysis of capital improvement or civil infrastructure projects, the period of analysis is the length of time (in years) over which costs and benefits are tracked and tabulated to compare benefits to costs. The period of analysis for flood risk analyses typically considers the expected life of potential mitigation projects. For structures such as levees and floodwalls, the default period of analysis generally used by Federal agencies is 50 years. For the LBAMRA, a 50-year period of analysis was assumed when converting annualized damages to present value.
Present Value: When presenting monetary results of a flood risk analysis, it is common to present both annualized and present value results. Present value is the current value of a stream of future costs or benefits considering the time value of money, whereby future costs or benefits are discounted to their present worth.
Price Level: Federal policy and planning procedure for flood risk evaluation present all costs and benefits at a constant price level (USACE 1993). For the LBAMRA's presentation of existing condition flood risk, an FY2022 price level will be utilized.
Uncertainty: Uncertainty is the measure of imprecision in the characterization of hydraulic, hydrologic, geotechnical, and economic inputs to a flood risk analysis. Uncertainty in risk estimates arises from natural variability (aleatory uncertainty) and from imperfect scientific knowledge about a phenomenon or population (epistemic uncertainty). A risk-based analysis acknowledges both types of uncertainty and their contribution to the total uncertainty in resulting risk estimates. FDA allows representation of the natural variability of streamflow in the Q-EP and rating curves. It allows representation of some key knowledge uncertainties in the economic inventory, such as for structure value and first floor elevation uncertainty. These uncertainties are accumulated and reflected in the estimate of EAD produced by FDA's Monte Carlo sampling process.
Vulnerable Population: See ESJ population.

ATTACHMENT B – DATA FOR SOCIOECONIMCS AND ESJ ANALYSIS

Introduction

This attachment is a supplement to the information presented in the main Approach Memorandum. It describes data sources key social and demographic indictors that will be used in the analysis.

Equity and Social Justice

Equity and Social Justice (ESJ) is a high priority within King County and its partners. This is echoed in the County's Equity and Social Justice (ESJ) Strategic Plan 2016-2022 (ESJ Strategic Plan or Strategic Plan), which provides a foundation for pro-equity investment decision-making. Where there are disparities in the Determinants of Equity within a region, equity and social justice is not achieved. The Strategic Plan lists 8 key Determinants of Equity, including 1) access to child and youth development, 2) economic development and jobs, 3) environment and climate, 4) health and human services, 5) housing, 6) information and technology, 7) justice system, and 8) transportation and mobility. In addition, the County has developed the Equity Impact Review (EIR) tool, which is a process and a tool to identify, evaluate, and communicate the potential impact, both positive and negative, of a policy or program on equity.

Given the focus on equity, this Attachment presents some of the key inventory data available to perform a social and environmental justice analysis for the King County Levee Breach Study.

Available Data

Prior to identifying available demographic and economic data, it is important to understand why such data are needed. Data are need to supporting identification of ESJ populations and to conduct related equity and social justice analysis.

- **Identifying/Verifying Communities of Color and Other ESJ Populations.** Demographic and economic data will facilitate identifying the locations of concentrated racial/ethnic groups, senior populations, other communities of color, and groups identified as vulnerable.
- **Conducting analyses relevant to equity and social justice.** Overlays of information about flooding, in a GIS platform, with demographic, social, and economic data, will serve to inform the analysis of equity and social justice impacts.

The fundamental data available for the equity and social justice analysis covers:

- Socioeconomic Data (Income, Wealth, Health, Race, Age, Children)
- Demographics – race, ethnicity, age by census tract
- Socioeconomics – employment, income, poverty,
- Economics – businesses, commercial properties, zoning, by municipality, location, tract
- Forecasts – population forecasts by census tract
- Parcel Data
- General Geographic Data – municipalities, streets and transportation routes, waterways, parks, other public infrastructure (libraries, schools, sidewalks, hospitals, etc.)

The following table summarizes identified repositories of this data.

TABLE 1 – AVAILABLE SOCIOECONOMICS DATA

Type of Data	Potential Source(s)
Demographics	U.S. Census Bureau – most recent American Community Survey data (ACS)
Socioeconomics	U.S. Census Bureau – most recent ACS data
Economic	ACS, Sales Genie, BLS (maybe), other federal and local sources
Project Information	King County
General Geographic Data	King County GIS
Demographic Forecasts	Can be conducted by Project Team; Washington State Office of Financial Management; Puget Sound Regional Council's (PSRC) Land Use Vision (LUV); King County Office of Economic and Financial Analysis
Economic Forecasts	Washington Employment Security Department; King County Office of Economic and Financial Analysis
Other health burden and health characteristics data	Washington Environmental Health Disparities Mapping Tool

Recommended specific data from the U.S. Census Bureau are found in Table 2.

TABLE 2 – ACS DATA POTENTIALLY RELEVANT FOR GEOSPATIAL DATABASE

Population Data
Sex by Age
Race
Hispanic or Latino Origin
Citizenship Status
Nativity of Parent
Place of Birth
Ancestry
Household Data
Household Size
Housing Units
Household Tenure
Units in Structure
Ability to Speak English
Disability Status
Educational Attainment
Health Insurance Coverage
Language Spoken at Home
Computer and Internet Use
Vehicles Available
Monthly Housing Costs
School Enrollment and Type of School
Housing Costs as a Percent of HH Income
Employment and Income Data
Supplemental Nutrition Assistance Program (SNAP)
Poverty Status
Employment Status
Income in the past 12 months
Industry
Journey to Work
Means of Transportation to Work
Occupation

Washington Environmental Health Disparities (WEHD) mapping system and the Social Vulnerability Index (SVI)

There are existing data sources for King County that have been compiled and that may be useful to include in the analysis. Two of these are described in greater detail. These are the Washington Environmental Health Disparities (WEHD) mapping system, and the Social Vulnerability Index (SVI) measurement designed through support from the EPA at the national level.

Both the SVI and the WEHD system produces an overall index of vulnerability at the census tract level, based on a number of data inputs. For the purposes of this analysis, either one of these indices might be useful. Either one could be used to identify geographic areas with higher and lower vulnerability and health disparity. For this project, the study team considered several options for use of these existing indices.

- Include the census tract-level SVI and WEHD index scores and use each according to where and how it might be relevant, such as in display of the intersection of modeled flood impact and the spatial distribution of ESJ populations.
- Focus on just one of these indices following further review of the component variables of the index, and then use the index in a similar manner, to compare spatial distribution of vulnerability to spatial distribution of flood impacts.
- Include all of the input variables to each index along with the indices thereby preserving all options, at the risk of introducing additional complication by including many variables.
- Develop a wholly new index unique to King County using a select group of input variables used in the SVI and WEHD and any other data.

Some background information on each index will support the decision about incorporating these data into the analysis. Beginning with the WEHD, it is intended to evaluate community risk by combining measures of exposure to hazards and community vulnerability using 19 indicators. Exposure hazards, or threats, include measures of traffic density, while socioeconomics captures factors such as linguistic isolation, education, and health measures such as cardiovascular disease. Overall risk is ranked from 1 to 10 with 10 indicating the highest impact. These rankings reflect the risk each community faces from multiple environmental hazards and the degree to which a community is more vulnerable to those hazards because of sociodemographic factors.

The SVI was developed by the Center for Disease Control (CDC) and a measure for each census tract in the country has been developed. The SVI focuses on the vulnerability of the population and does not include metrics for the pollution burden in the tract like the WEHD does. However, there are 15 socioeconomic metrics, and so the SVI may be considered a more comprehensive index of population vulnerability.

The metrics used to develop both the SVI and WEHD are shown below in summary format below (Table 3). A more comprehensive list of these data and the sources for each is provided in Tables 4 and 5 and Figures 1 and 2.

The source data for the SVI are all from the U.S. Census Bureau ACS. The advantage of this is that is a nationally uniform measurement and is created for the census tract geography. The same data source is used for five of the seven Socioeconomic Factors used in the WEHD Index, and the other two Socioeconomic Factors, as well as the other 12 metrics used are gathered from a variety of different statewide and national data sources including the Washington State Department of Health, Office of Financial Management, and the national EJScreen.

After considering these options and the component variables of the indices, the team noted that approximately five of the socioeconomic descriptors in the WEHD Index are essentially the same as five of the socioeconomic factors used in the SVI. Because the other indicators in the SVI are all from the ACS data, data for these variables is available from the U.S. Census Bureau and some variables may be quantified at the block group level in addition to the census tract level. The remaining indicators from the WEHD are recommended for inclusion in this analysis in addition to the actual WEHD index result. Details about the sources of these exposure indicators are available in Table 5.

Given these considerations, the recommended approach is to develop a new index for this project that combined considerations and variables unique to the WEHD with Census-based variables common to both the WEHD and the SVI. The purpose of generating a new index will be to achieve higher spatial resolution (e.g., block or block group) by leveraging the building-level characteristics and modeled flood damages being developed for this study.

TABLE 3 – INPUT DATA USED IN CALCULATING SVI AND WEHD INDICES

SVI Indicators	WEHD Indicators
Socioeconomic Status	**Environmental Exposures**
• **Below Poverty**	• Diesel emissions
• **Unemployment**	• Ozone
• Income	• Particulate Matter 2.5 (PM2.5)
• **No High School Diploma**	• Toxic releases from facilities
Household Composition and Disability	• Traffic density
• Aged 65 or Older	**Environmental Effects**
• Aged 17 or Younger	• Lead risk and exposure
• Civilian with Disability	• Proximity to hazardous waste generators and facilities
• Single-Parent Households	• Proximity to Superfund sites
Minority Status and Language	• Proximity to facilities with highly toxic substances
• **Minority**	• Wastewater discharge
• **Speak English "Less than Well"**	**Sensitive Populations**
Housing and Transportation	• Cardiovascular disease
• Multi-Unit Structures	• Low birth weight infants
• Mobile Homes	**Socioeconomic Factors**
• Crowding	• **Poor educational attainment**
• No Vehicle	• Housing burden
• Group Quarters	• **Linguistic isolation**
	• **Poverty**
	• **Race (People of color)**
	• Transportation expense
	• **Unemployment**

FIGURE 1 – SOCIAL VULNERABILITY INDEX GRAPHIC

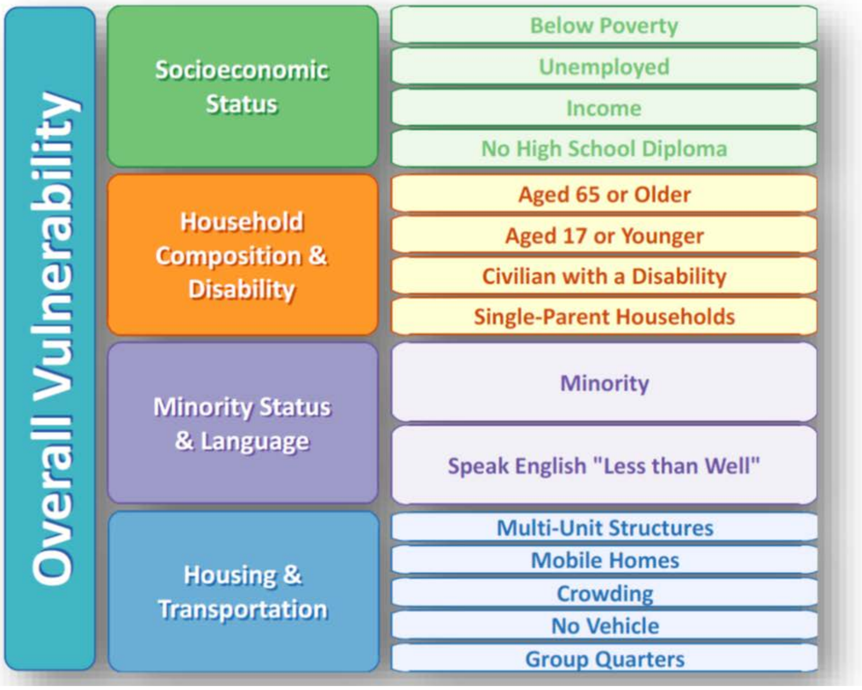

FIGURE 2 – INDICATOR LIST FOR WASHINGTON ENVIRONMENTAL HEALTH DISPARITY INDEX

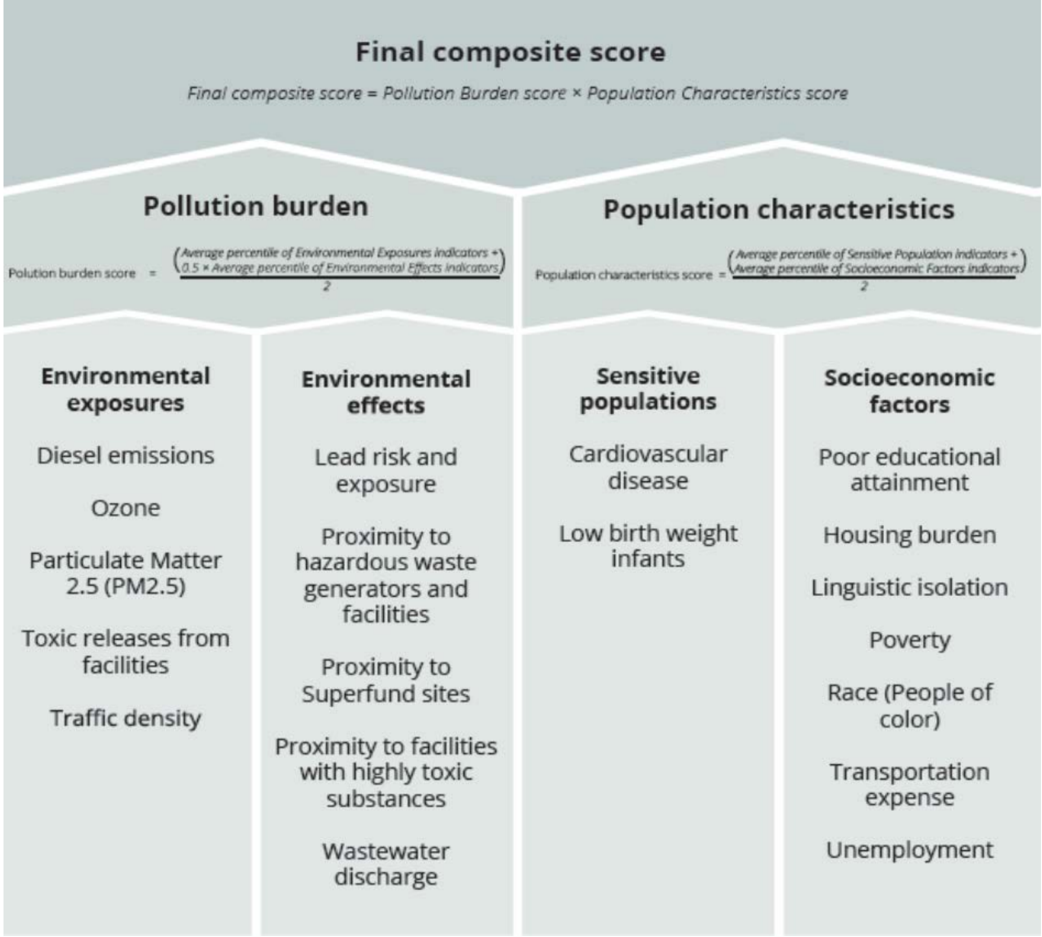

TABLE 4 – INDICATOR LIST FOR SOCIAL VULNERABILITY INDEX

Indicator	Explanation of Indicator	Source(s)
Socioeconomic Status		
Below Poverty	Persons below poverty estimate	U.S. Census Bureau ACS for 2012–2016
Unemployment	Civilian (age 16+) unemployed estimate	U.S. Census Bureau ACS for 2012–2016
Income	Per capita income estimate	U.S. Census Bureau ACS for 2012–2016
No High School Diploma	Persons (age 25+) with no high school diploma estimate	U.S. Census Bureau ACS for 2012–2016
Household Composition & Disability		
Aged 65 or Older	Persons aged 65 and older estimate	U.S. Census Bureau ACS for 2012–2016
Aged 17 or Younger	Persons aged 17 and younger estimate	U.S. Census Bureau ACS for 2012–2016
Civilian with Disability	Civilian noninstitutionalized population with a disability estimate	U.S. Census Bureau ACS for 2012–2016
Single-Parent Households	Single parent household with children under 18 estimate	U.S. Census Bureau ACS for 2012–2016
Minority Status & Language		
Minority	Minority (all persons except white, non-Hispanic) estimate	U.S. Census Bureau ACS for 2012–2016
Speak English "Less than Well"	Persons (age 5+) who speak English "less than well" estimate	U.S. Census Bureau ACS for 2012–2016
Housing & Transportation		
Multi-Unit Structures	Housing in structures with 10 or more units estimate	U.S. Census Bureau ACS for 2012–2016
Mobile Homes	Mobile homes estimate	U.S. Census Bureau ACS for 2012–2016
Crowding	At household level (occupied housing units), more people than rooms estimate	U.S. Census Bureau ACS for 2012–2016
No Vehicle	Households with no vehicle available estimate	U.S. Census Bureau ACS for 2012–2016
Group Quarters	Persons in institutionalized group quarters estimate	U.S. Census Bureau ACS for 2012–2016

TABLE 5 – INDICATOR LIST FOR WASHINGTON ENVIRONMENTAL HEALTH DISPARITY INDEX

Indicator	Explanation of Indicator	Source(s)	Details on Data
POPULATION BURDEN			
Environmental Exposures			
Diesel emissions	Human exposure to diesel emissions	Washington State Department of Ecology's 2014 Comprehensive Emissions Inventory	Gridded emissions were allocated to census tracts using area-weighted spatial interpolation
Ozone	Exposure to ozone pollution	AIRPACT - provides data that averages daily max ozone level for three years within 12km x 12km grid cells	3-Year mean concentration of daily maximum 8-hour rolling averaged ozone for 2009-2011 from AIRPACT; block-level ozone concentrations were averaged for all blocks within a census tract.
Particulate Matter 2.5 (PM2.5)	Human exposure to PM2.5	AIRPACT - provides data that data that averages daily mean concentration of PM2.5 over three years within 12km x 12km grid cells.	3-Year mean concentration of annual PM2.5 for 2009-2011 from AIRPACT; block-level concentrations were averaged to the census tract level.
Toxic releases from facilities	Toxicity-weighted concentrations of chemical releases to air from facility emissions and off-site incineration	Risk Screening Environmental Indicators (RSEI); TRI program (2014–2016)	Data was downloaded from Risk Screening Environmental Indicators (RSEI) where air releases are modeled by the TRI program (2014–2016)
Traffic density	Census block population estimates; estimated annual average daily traffic volumes (AADT)	Washington State Office of Financial Management; Washington State Department of Transportation	2017 census block population estimates from the Washington State Office of Financial Management and 2017 roadway traffic density data from the Washington State Department of Transportation
Environmental Effects			
Lead risk and exposure	Total number of houses and proportion of houses by year of construction; national estimates of the proportion of housing from each era with lead risks	U.S. Census Bureau ACS for 2012–2016	Provides the total number of houses and proportion of houses by year of construction from the U.S. Census Bureau ACS for 2012–2016. These data were used in conjunction with national estimates of the proportion of housing from each era with lead risks.

Indicator	Explanation of Indicator	Source(s)	Details on Data
Proximity to hazardous waste generators and facilities	Count of all commercial Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) facilities within 5 km, divided by distance, presented as population-weighted averages of blocks in each census tract	Data downloaded from EJSCREEN in 2017	The data used to calculate this indicator were downloaded from EJSCREEN in 2017.
Proximity to Superfund sites	Count of sites proposed and listed on the National Priorities List (NPL) within 5 km of the average resident in a block group, divided by distance and calculated as the population-weighted average of blocks in each census tract	Data downloaded from EJSCREEN in 2017	Sites proposed and listed on the National Priorities List (NPL), directly downloaded from EJSCREEN in 2017.
Proximity to facilities with highly toxic substances	Count of RMP facilities within 5 km, divided by distance, presented as population-weighted averages of blocks in each census tract	Data downloaded from EJSCREEN in 2017	The data were downloaded from EJSCREEN in 2017.
Wastewater discharge	Toxicity-weighted concentration in stream reach segments within 500 meters of a block centroid, divided by distance in meters, presented as the population-weighted average of blocks in each block group	Data downloaded from EJSCREEN in 2017	The data were downloaded from EJSCREEN in 2017.
POPULATION CHARACTERISTICS			
Sensitive Populations			
Cardiovascular disease	Mortality rate from cardiovascular diseases for 2012–2016 per 100,000 population. This rate represents the proportion of deaths in a population due to cardiovascular disease. This indicator uses an age-adjusted rate per 100,000 population.	Washington State DOH Center for Health Statistics	Cardiovascular disease mortality data from the Washington State DOH Center for Health Statistics. The Center for Health Statistics collects information on the deaths of Washington state residents from their death certificates, including the deaths of Washington state residents that died in other states or in Canada.
Low birth weight infants	Number of live born singleton (one baby) infants born at term (at or above 37 completed weeks of gestation) with a birth weight of less than 2,500 grams (about 5.5 lbs.) for 2012–2016. The rate represents the count of low-birthweight, live-born singleton infants divided by the total number of live-born singleton infants born at term to Washington state resident mothers.	Washington State DOH Center for Health Statistics	Data collected by the Washington State DOH Center for Health Statistics from birth certificates.
Socioeconomic Factors			
Poor educational attainment	Percent of population over age 25 with less than a high school education	U.S. Census Bureau ACS 5-year estimates for 2012–2016	Data collected from the U.S. Census Bureau ACS 5-year estimates for 2012–2016.

Indicator	Explanation of Indicator	Source(s)	Details on Data
Housing burden	Modeled percent of income spent on housing for a four-person household making the median household income	U.S. Census Bureau ACS 5-year estimates for 2012–2016	U.S. Census Bureau ACS 5-year estimates for 2012–2016
Linguistic isolation	Census tract-level data on the percent of limited English-speaking households	U.S. Census Bureau ACS 5-year estimates for 2012–2016	Indicator was developed using census tract-level data on the percent of limited English-speaking households from the U.S. Census Bureau ACS for 2012–2016
Poverty	Percent of the population living below 185 percent of the federal poverty level	U.S. Census Bureau ACS 5-year estimates for 2012–2016	Indicator uses data on the percent of the population living below 185 percent of the federal poverty level from the U.S. Census Bureau ACS for 2012–2016.
Race (People of color)	Sum of all race/ethnicity categories except White/Non-Hispanic. It includes Black, American Indian/Alaskan Native, Asian, Native Hawaiian-Other Pacific Islander and two or more races.	Washington State Office of Financial Management (OFM)	The data for this indicator is derived from the 2015 population estimates dataset at the Washington State Office of Financial Management (OFM). The OFM uses models of birth, death, and migration in to make forecasts based on numbers obtained from the U.S. Census Bureau.
Transportation expense	Transportation costs based on percentage of income for the regional moderate household	Center for Neighborhood Technology (CNT)	The Center for Neighborhood Technology (CNT) defines regional moderate household income as a household income of 80 percent of the area median, the regional average household size and the regional average commuters per household.
Unemployment	Percent of the population over the age of 16 that is unemployed and eligible for the labor force. Excludes retirees, students, homemakers, institutionalized persons except prisoners, those not looking for work and military personnel on active duty.	U.S. Census Bureau ACS 5-year estimates for 2012–2016	U.S. Census Bureau ACS 5-year estimates for 2012–2016

ATTACHMENT C – FINAL ECONOMIC INVENTORY STATUS MEMO (SUBTASK 8.1)

TETRA TECH

MEMO

To:	Judi Radloff (King County)
Cc:	Patty Robinson (King County), Brian Reznick (S&W), Project File
From:	James Carney (Tt), Ridge Robinson (Tt), Gretchen Greene (GE)
Date:	2/1/2022
Subject:	KC Levee Breach Analysis, Mapping, and Risk Assessment: Economic Inventory Status Memo

1. INTRODUCTION

1.1. PURPOSE

The purpose of this memorandum is to document the status of inventory data gathering and to describe the major datasets, information sources, and references that will be used in components of Subtask 8, Economic Evaluation of Flood Risk. Therefore, this memorandum achieves concurrence among the consultant team and King County, providing the data and information sources that will be relied upon for the risk evaluation. The information documented in this memorandum will provide the basis for development of the economic evaluation approach for each basin that will be documented in a technical memorandum as part of Subtask 8.2, Evaluation Approach.

1.2. CONTEXT FOR INVENTORY DATA COLLECTION

Inventory data in support of the economic analysis includes information that describes the people, property, and infrastructure which are at risk of impacts from flooding. These assets or resources that are at risk are grouped into *impact categories*, with the intent that a specific *evaluation methodology* will be developed for each impact category in future Subtask 8.2 that will detail the modeling methods. As scoped, inventory data is limited to existing and publicly available information. As such, agreement upon the breadth and depth of inventory data that will be relied upon, and manner in which any data gaps will be filled based on publicly available information, will inform the development of the evaluation methodology.

1.3. SCOPE OF WORK

This memorandum provides the deliverable *Inventory Status Memo*, addressing Subtask 8.1 as part of the economic evaluation of flood risk for the Lower Raging, Lower Tolt, and South Fork Snoqualmie River basins (Tasks 300, 400, and 500) of the King County Levee Breach Analysis Mapping and Risk Assessment study (LBAMRA). Table 1 summarizes the relevant scope and notes the sections of this memo which address each scope item.

Table 1 – Scope of Work Reference Table

	Scope Item	*Document Reference*
A	Inventory the floodplain and compile land use information to differentiate land use types and identify roads, utilities, and critical facilities.	Sections 2.0, 3.0, and 4.0 discuss impact categories which characterize land use and the built environment.
B	Compile demographic information and develop estimates of population at risk, vulnerable populations, and identification of other ESJ considerations to supplement the quantitative economic evaluation of flood risk.	Each impact category discussion includes a subsection that describes how that category will be considered in the ESJ analysis. Section 5.0 discusses the ESJ analysis directly.

	Scope Item	*Document Reference*
C	Collect and verify damage function data for specified risk categories. Default damage functions and inventory data obtained from the FEMA Hazus database shall be checked for suitability and used in the analysis if appropriate. Data sources shall be limited to the existing Hazus Level 2 database, publicly available and published industry, and agency reports, previous USACE studies, data provided by King County, and Hazus data.	Each impact category subsection describes damage function data that was collected and verified.
D	Extent of inventory should allow for maximum extent of inundation based upon input from geotechnical and hydraulic elements of the project.	The inventory information for the built environment has been assembled according to the hydraulic model domain for each basin. Relevant sections include 2.0, 3.0, 4.0. Extents will be refined when model outputs are available.
E	The deliverable will be a simple memorandum noting the status of inventory development and bulleting the major datasets that will be incorporated into the Economic evaluation approach memorandum.	This document is the deliverable that satisfies this scope item.

The following impact categories address scope items A through D, from Table 1. Note that not all impact categories may be applicable in all basins. The Evaluation Approach Memo will include inventory data summarization for each basin which identified the final proposed list of impact categories for each basin, selected from that list of impact categories identified in this memorandum.

A total of 19 potential impact categories are discussed in this memorandum. As shown in Table 2, these categories are grouped into 4 summary categories according to the nature of the impact.

Table 2 – Summary of Impact Categories

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

* Other modes such as rail and air were excluded following preliminary review of the basins, which determined there were not rail or air transportation assets in the floodplain. Should other basins added to the scope through modification, the addition of detour and delay impacts for other transportation modes may occur.

1.4. ORGANIZATION OF THIS MEMORANDUM

This memorandum is organized according to the potential[1] impact categories that will be modeled in the economic evaluation of flood risk. Each of the summary impact categories shown in Table 2 (Direct Physical Damages; Response and Restoration Costs; Other Economic Disruptions; and Equity, Social Justice and Health) is addressed in terms of the data inventory status and the proposed use of the data is summarized. For each summary impact category, the following topics are addressed:

- Definition of the proposed impact category;
- Summary of the inventory data proposed for use;
- Summary of the damage functions proposed for use; and
- Summary of overall inventory status.

Following the impact category summaries, Section 6 documents the QA/QC for the development of this deliverable, and Section 7 lists the proposed data sources.

2. DIRECT PHYSICAL DAMAGES

Direct physical damages include damages to buildings, vehicles, roads, bridges, other facilities, and agriculture. These are directly impacted due to flood waters and are distinct from other economic impacts such as response and restoration, business interruptions and other indirect impacts, and also

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[1] The final list of impact categories to be included in the modeling will be defined and coordinated with King County as part of Subtask 8.2, Evaluation Approach Memorandum.

separate from environmental justice impacts although equity considerations are highlighted for each of these subcategories.

2.1. STRUCTURE, CONTENTS, AND INVENTORY

This impact category describes the building-related losses associated with direct contact with floodwaters. The types of buildings included are based on occupancy and are outlined in Section 2.1.2. The impact category includes:

- *Structure damage* is an estimated dollar value of damage to structural components of the building, such as foundation, walls, and utilities.
- *Content damage* is an estimated dollar value of damage to non-structural components of the building, such as furniture, fixtures, cabinetry, and other personal property or commercial equipment.
- *Inventory damage* is applicable only to non-residential buildings that contain business inventory and is an estimated dollar value from loss of inventory that is ruined by floodwaters.

These impacts are estimated as a function of the depth of flooding at the building, relative to the building's first finished floor elevation. This depth of flooding is read against a depth-damage function (DDF), which provides the percent loss of structure, content, and inventory value at a given flood depth and a given total building replacement value[2]. Therefore, the economic inventory items needed for evaluation of this impact category include information regarding building attributes sufficient to allow identification and use of an appropriate DDF for each building.

2.1.1. Inventory Data

Best available building information is available from the King County Department of Assessment. In order to capture the maximum potential extent of inundation based on future outputs from the geotechnical and hydraulic models, inventory extent was defined based on the hydraulic model domain for each basin. Based on this domain, a request was made for necessary data on 1,211 parcels for the Lower Tolt River, 1,276 parcels for the Lower Raging River, and 6,135 parcels for the South Fork Snoqualmie River. Based on coordination with the Assessor, all necessary building information is available, including attributes that will allow definition of building type/use, size, and replacement value, and is sufficient to assign the appropriate DDF for each building. First floor elevation information, will be sampled as necessary based on existing imagery, including Google Street View, or building imagery available on the King County website. First floor information has also been recently developed for a separate King County study on the Tolt, and it is expected that data from that effort will be available for this study. The resultant building inventory and property characteristics database is also a key input to other impact categories discussed in this memorandum and provides a second data source to identify and describe critical facilities in the study area in addition to the Hazus model database (as discussed in Section 2.5).

2.1.2. Damage Function Data

The use of DDFs to estimate flood inundation impacts is the primary methodology employed by federal agencies such as the USACE and FEMA. Both of these agencies have published a variety of DDFs for many building types. Currently, there are two primary sources of standardized DDFs, one available from each agency. The USACE's Risk Management Center maintains the LifeSim model (USACE 2021), which supports event-based flood damage estimation. The LifeSim model contains a library of 40 standard building *occupancy types*, where each occupancy type has its own associated DDF. The second source is FEMA's Hazus model, which supports FEMA's multi-hazard damage estimation mission. Based on review of these sources, the LifeSim library of standard DDFs includes a complete

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[2] Note that the database will support estimation of damages in terms of replacement cost or depreciated replacement value. For general risk characterization, reporting of depreciated values is recommended. This will be finalized in coordination with King County as part of Subtask 8.2, Evaluation Approach Memorandum.

and representative set of residential and non-residential DDFs, and no additions were identified from the Hazus library. USACE DDFs for residential structures are published in EGM 04-01, *Generic Depth-Damage Relationships for Residential Structures*, and are based on a USACE statistical analysis of past studies to generate standardized DDFs. The standard non-residential DDFs in LifeSim reflect a selection of riverine flooding damage curves from past USACE studies or from the FEMA HAZUS model default functions. As such, Table 3 presents the following preliminary list of occupancy types (and DDFs) that reflects the 40 standard occupancy types used in LifeSim.

Table 3 – List of Occupancy Types and DDFs

Occupancy / DDF	*Description*
AGR1	Agriculture facilities and offices
COM1	Retail trade
COM2	Wholesale trade
COM3	Personal and repair services
COM4	Professional and technical services
COM5	Banks
COM6	Hospitals
COM7	Medical office and clinic
COM8	Entertainment and recreation
COM9	Theaters
COM10	Parking garages
IND1	Heavy industrial
IND2	Light industrial
IND3	Food/drugs/chemicals
IND4	Metal/minerals processing
IND5	High technology
IND6	Construction facilities and offices
EDU1	Grade schools and administrative offices
EDU2	Colleges and universities
GOV1	Government – general services
GOV2	Government – emergency response
REL1	Churches and non-profit organizations
RES1-1SNB	Single family residential structure that is 1 story tall with no basement.
RES1-1SWB	Single family residential structure that is 1 story tall and has a basement.
RES1-2SNB	Single family residential structure that is 2 stories tall with no basement.
RES1-2SWB	Single family residential structure that is 2 stories tall and has a basement.
RES1-3SNB	Single family residential structure that is 3 stories tall with no basement.
RES1-3SWB	Single family residential structure that is 3 stories tall and has a basement.
RES1-SLNB	Single family residential structure that is a split-level structure with no basement.
RES1-SLWB	Single family residential structure that is a split-level structure and has a basement.
RES2	Manufactured housing
RES3A	Multi Family Residence – Duplex

Occupancy / DDF	*Description*
RES3B	Multi Family Residence – 3 to 4 units
RES3C	Multi Family Residence – 5 to 9 Units
RES3D	Multi Family Residence – 10 to 19 Units
RES3E	Multi Family Residence – 20 to 49 Units
RES3F	Multi Family Residence – more than 50 Units
RES4	Temporary lodging (e.g., Hotels, motels, or other buildings used for temporary lodging)
RES5	Institutional dormitories
RES6	Nursing Homes

2.1.3. Preliminary Socioeconomic and ESJ Considerations

The structure inventory will serve as the smallest geographic unit of analysis for much of the ESJ analysis proposed for this study. The value and types of structures, as well as ownership rates, can give some insight into household incomes (e.g., mobile homes are lower value than permanent structures). Race and ethnic population data will be reviewed based upon King County American Community Survey (ACS) data and any other information from the King County Assessor's database (e.g., housing tenure as available). For non-residential properties, daytime/workday population will be reviewed based on the types of businesses and general income/race statistics for the industrial code. Also, FEMA HAZUS methodology for selected non-residential occupancies will be reviewed and used if relevant.

2.1.4. Inventory Status Summary

At the time of writing, data from the Assessor has been received and is being processed. Based on preliminary review, the Assessor's data is complete and meets the needs identified in this memo. No inventory issues are anticipated in the use of the Assessor's data to support estimation of impacts to building structure, contents, and inventory.

2.2. DIRECT VEHICLE

This impact category estimates loss in vehicle value due to contact with floodwater. Vehicle impacts are modeled similar to building impacts, using a DDF that related depth of flooding to percent loss of vehicle value.

2.2.1. Inventory Data

A vehicle inventory is created as a function of the building inventory, where an average number of vehicles will be assigned to structures by occupancy type. For residential inventory, the average number of vehicles is obtained from U.S. Census Bureau datasets, such as the American Community Survey program and information from the Bureau of Transportation Statistics (BTS 2019). For non-residential inventory, sampling will be conducted on relevant occupancy types within the study area. Vehicle value will be based upon the latest published information from automotive industry sources, such as the Edmunds Used Vehicle Outlook (Edmunds 2020). For commercial vehicles, industry publications will be used to estimate average value for a typical commercial vehicle.

2.2.2. Damage Function Data

Based on past studies, the USACE has developed a standardized vehicle DDF for personal vehicles by vehicle type (USACE 2009). Recent work on the LifeSim model has resulted in a single aggregated DDF for personal vehicles as well. For commercial vehicles, an adjusted DDF will be developed based on the estimated difference in ground clearance between personal vehicles and a typical commercial vehicle (e.g., a semi-trailer truck).

2.2.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from flooded vehicles, the information may inform qualitative description of ESJ impacts to mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

2.2.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The population of the vehicle inventory is pending, as it will be informed primarily by the final building inventory. All necessary data is available, and no inventory issues are expected in the computation of these impacts.

2.3. DIRECT ROAD

Direct impacts to roads are typically difficult to quantify in a generalized manner for a large floodplain, as the susceptibility of a road to flood damage is largely a function of the road segment's susceptibility to erosion, which is in turn difficult to quantify in aggregate across all roads in a floodplain. As such, there are no standardized values available for road damage from flooding.

For this study, the expected recommended approach in the Evaluation Approach memo (future Subtask 8.2) will be to use the hydraulic modeling results to identify a threshold, based on depth and/or velocity, which is reasonably likely to induce roadway damage. With this approach, the identification of damaged roads would be directly tied to the flood modeling results. The addition of this step acknowledges that not every road segment experiences damage when inundated. To assess the reasonableness of the resultant frequency-damage function, it will be compared to historical damage information available from King County, and/or past federal flood risk studies, as available.

2.3.1. Inventory Data

A roadway inventory will be competed for each basin study area using the USACE LifeSim model, which facilitates generation of a road network based on the OpenStreetMap API (OSM 2021). The resultant GIS dataset will contain road centerlines and attribute information about the roads. This network will be cut into segments (e.g., ½-mile long segments) and a representative damage tabulation point will be assigned along each reach (e.g., the mean elevation along the segment).

2.3.2. Damage Function Data

Following Hurricane Katrina and its associated flooding, the USACE New Orleans District collected and elicited information about damage to roadways and used this information to develop depth-to-dollar damage functions for two types of roads, major/secondary highways, and other streets (USACE 2012). This function will be adjusted for geography and price level and applied to the study areas. Note that King County has provided historical damage information from four recent flood events that contains estimates of roadway damages for the purpose of FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

2.3.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from road flooding, the information may inform qualitative description of ESJ impacts to transportation and mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

2.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The road network GIS layers for the entire model hydraulic domains have been generated and will be clipped to flood extents once hydraulic outputs become available. The specifics of the depth/velocity thresholds for identification of damaged roads will be coordinated with the hydraulic element of the consultant team and documented in the Evaluation Approach memo (subsequent Subtask 8.2). No inventory issues are expected in the computation of these impacts.

2.4. DIRECT BRIDGE

This impact category addresses the potential for structural damage to bridges from flooding. Because damage to the bridge structure is dependent on velocities as well as depth, no standardized DDF is available for bridges. However, the FEMA Hazus model contains a bridge damage module that can estimate the percent damage on a bridge and the probability of the bridge being functional for a given flood event. This assessment in Hazus is based on failure risk for different magnitude flood events as a function of scour risk. Scour risk for bridges in the USFHWA National Bridge Inventory (FHA 2021) are prepopulated in Hazus and may be leveraged in this analysis. If more recent or refined bridge risk data is available from King County or the hydraulic modeling team, in a format that can be readily applied to the HAZUS methodology, it will be incorporated in this analysis.

2.4.1. Inventory Data

The primary inventory data for this impact category is the National Bridge Inventory, which is prepopulated in the FEMA Hazus database and includes generalized bridge repair cost information for each bridge. The use of the HAZUS methodology to compute bridge risk will also rely on depth outputs from the hydraulic modeling for modeled flood events, which will be coordinated with the hydraulic modeling team.

2.4.2. Damage Function Data

The FEMA HAZUS methodology contains damage functions which estimate the percent damage to a bridge and the probability of the bridge being functional for a given flood event. In combination with a general estimate of total replacement cost, a frequency-damage function may be developed for each modeled bridge. Note that King County has provided historical damage information from four recent flood events that contains some information about damage to bridges for the purpose of FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

2.4.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from bridge damage, the information may inform qualitative description of ESJ impacts to transportation and mobility. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

2.4.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified and no inventory issues are expected in the computation of these impacts.

2.5. DIRECT CRITICAL UTILITIES

This impact category addresses direct impact to critical utility infrastructure not already addressed Sections 2.1 (buildings), 2.3 (roads), and 2.4 (bridges). In each basin, there may be other utility infrastructure at risk of damage, such as water treatment plant or electrical substation infrastructure. There may also be utility infrastructure whose location in the floodplain will be mapped but damages will be not computed, such as buried arterial utility lines. In general, utility networks and connections to individual properties will not be inventoried or mapped.

Note that this impact category addresses direct damage to critical utility infrastructure. Loss of service impacts and equity and social justice impacts related to critical facilities are discussed in Section 5. The definition of critical facilities for the KC LBAMRA is presented in Section 5.

2.5.1. Inventory Data

The FEMA Hazus model contains a default database of critical utility infrastructure that provides facility type and value. This dataset will be cross-referenced with the inventory built from the Assessor's database and refined based on available data to ensure that the inventory of critical facilities is complete.

2.5.2. Damage Function Data

The FEMA Hazus model provides DDFs for critical utility infrastructure by facility type. These functions will be used to estimate impacts. Infrastructure valuation will be based upon local data from King County as available, with the option to use the generalized facility cost information available in Hazus where needed. The use of the Hazus methodology to compute impacts is dependent on the availability of hydraulic outputs to provide depths by flood event. Note that King County has provided historical damage information from four recent flood events as collected for the purpose of FEMA Preliminary Damage Assessment reports (King County 2021a). Preliminary review of the data found that some damages to utility facilities was noted. This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source.

2.5.3. Preliminary Socioeconomic and ESJ Considerations

While this impact category addresses the monetary value loss from physical damage to critical utility infrastructure, the information may inform qualitative description of ESJ considerations and impacts related to access to critical facilities by providing the inventory of critical facilities for consideration in that evaluation. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

2.5.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified and no inventory issues are expected in the computation of these impacts.

2.6. AGRICULTURAL LOSS

Flood risk to agricultural production is typically estimated as a function of crop loss and the associated reduction in income due to flooding of crops and pasture. The USACE provides a standardized methodology (USACE 1987) for such an analysis in the LifeSim model. First, an inventory acreage by crop type is developed. Then, a production budget is entered for each crop. Based on the specified seasonality of flooding, the model computes the impacts to crops, the associated loss in yield and therefore sales, and adjusts for production expenditures that were never realized due to the flooding.

In addition to crop-related losses, there may be other farm-related losses that would need to be separately evaluated, including cost of restoring fields, farm roads, and equipment to regular operation. For example, some farms incur costs to drain fields or address sedimentation and may experience damage to specialized equipment or infrastructure, such as on-farm roads or irrigation equipment, or may experience adverse livestock impacts. Such losses will be estimated as supported by available historical information, stakeholder input about on-farm assets and risk, or application of an estimate per-acre cost for restoration activities.

2.6.1. Inventory Data

The crop loss approach in LifeSim requires identifying acreages of cropland in the floodplain, by crop type. This step is automated by LifeSim, allowing import of a GIS layer from the USDA Cropland Data Layer that covers the study area. The next requirement is the specification of enterprise crop budgets by crop type (planting and harvest dates, yield, price, monthly production expenditures, and optionally a substitute crop that might be planted if the field floods late in the season). This data is not provided in LifeSim, though is commonly available from previous studies or from the local agricultural extension.

For this study, the database maintained by Washington State University (WSU 2021) will be used unless local budgets are available from stakeholders or King County.

2.6.2. Damage Function Data

In the LifeSim model, impacts are affected flood duration and flood timing (time of year).

Specification of an assumed flood date affects how much production expenditure has occurred at the time of flooding for each crop type, the extent to which the planted crop can recover from the flood without impacting yield, and whether the farmer would have time to replant an alternate crop during the same year to recoup some losses. These adjustments are made by the model based on the monthly production budgets that are specified.

Specification of duration-damage functions by crop may utilize one of three generalized curves in LifeSim, for 1-day, 3-day, and 7-day inundation durations. For this study, the hydraulic outputs will be reviewed to determine which of the generalized curves is most appropriate for the study area.

2.6.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary value loss from physical damage to agricultural properties, and as part of the ESJ analysis, the race/ethnicity of farmworkers will be reviewed (to the extent possible) for differential income impacts to farmworkers. The information may inform qualitative description of ESJ impacts related to economic opportunity and the importance of the King County agricultural economy. The analysis will also describe potential impacts to agricultural small-business enterprises, such as U-Pick berry farms or seasonal agrotourism (e.g., pumpkin patches). Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

2.6.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3. RESPONSE AND RESTORATION COSTS

3.1. DEBRIS REMOVAL

Following a major flood event there may be substantial debris requiring cleanup, such as building-related debris and natural debris (vegetation, sediment). The FEMA Hazus model contains a debris tonnage estimation methodology that addresses building debris as a function of building structural components (founding, structure, and finishes), but does not address content, inventory, or natural debris. However, this Hazus methodology represents the best-available debris estimation approach for large inventories. Consideration of building content and interior cleanup is considered separately in Section 3.2. Building Cleanup.

For this debris removal category, impact estimation relies on the depth grids that will be developed by the hydraulics element of the consultant team and the building inventory developed as part of this economics effort. The Hazus methodology will then be used to generate a frequency-to-debris-tonnage relationship. Tonnage may be converted to volume (cubic yards) based on published FEMA Debris Estimating Guides (FEMA 2010) typically employed for disaster recovery field operations. This information may then be converted to a frequency-damage relationship based on average debris removal costs per cubic yard.

3.1.1. Inventory Data

The inventory data required for estimation of these impacts will be finalized building inventory and hydraulic depth grids, both of which are required to implement the Hazus methodology to estimate debris tonnage. The building inventory is described in Section 2.1. Hydraulic depth grids are being developed by the hydraulic element of the project team under separate subtasks.

3.1.2. Damage Function Data

A 2020 study by the USACE Portland District published a range of costs from a minimum of $8 to a maximum of $46 per cubic yard, with an average of $28 for the cleanup, trucking, and disposal of flood debris (USACE 2020). This source will be adjusted for price level and provides the parameters of a triangular distribution for the estimation of debris removal impacts. Note that King County has provided historical damage information from four recent flood events, some of which contain estimates of damage related to debris removal (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source as appropriate.

3.1.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of structural debris cleanup following a flood. Recent research suggests that elsewhere in the country, the cleanup workers for these jobs include low wage, marginalized, and sometimes undocumented immigrant employees. Information on this topic will be reviewed and make up a qualitative discussion of this topic in the context of ESJ.

3.1.4. Inventory Status Summary

All of the inventory data needs are accounted for, and no inventory issues are expected in the computation of these impacts.

3.2. BUILDING CLEANUP

The building cleanup impact category addresses the cleanup costs that would be incurred at residential buildings and some non-residential buildings for the extraction of floodwaters, drying out of the buildings and contents, and any necessary decontamination treatments such as mold and mildew abatement (these impacts are separate from the debris removal impacts discussed previously in Section 3.1). Building cleanup costs will be applied to those buildings whose occupancies indicate there would be a need for such cleanup activities, such as residential buildings, commercial buildings, and public buildings, where engagement with the public is generally expected. Building cleanup impacts will not be estimated for occupancies such as warehouses and industrial buildings, where such incremental cleanup costs may not be applicable due to differences in building materials, contents, and public accessibility.

3.2.1. Inventory Data

The inventory data necessary for cleanup costs is contained in the building inventory. Cleanup costs will be applied to building whose occupancies indicate there would be a need for such cleanup activities, such as residential, commercial retail, and public buildings. Cleanup costs will be calculated by structure based on a cleanup unit cost per square foot for the building's first floor square footage. Estimated cleanup unit costs are available from previous USACE studies, and generally are around $10 per square foot (USACE 2020a) of finished first floor area.

3.2.2. Damage Function Data

Recent studies by the USACE have developed a DDF for cleanup costs, assigning 100% of cleanup cost impacts for flood depths greater than 3 feet, and interpolating impacts at lesser depths. This function will be modified for application to study area occupancies and foundation types.

3.2.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of building cleanup following a flood. Recent research suggests that elsewhere in the country, the cleanup workforce for these jobs include low wage, marginalized, and sometimes undocumented immigrant employees. Information on this topic will be reviewed and make up a qualitative discussion of this topic in the context of ESJ.

3.2.4. Inventory Status Summary

All of the inventory data needs are accounted for, and no inventory issues are expected in the computation of these impacts.

3.3. EMERGENCY RESPONSE

Emergency costs include those expenses resulting from a flood that would not otherwise be incurred. For example, the costs of flood fighting, increased costs of normal operations during the flood, and increased costs of police or fire service.

3.3.1. Inventory Data

The building inventory discussed in Section 2.1 will be used to calibrate estimated emergency costs from previous studies or other published information for use in the study areas.

3.3.2. Damage Function Data

Two USACE sources provide good information about estimating emergency costs associated with flooding.

The first is a report developed by the USACE New Orleans District (USACE 2012) which developed unit cost estimates and DDFs for several types of emergency costs, including emergency response roadway clearing, incremental hospital operating costs, police emergency operations per affected household, and fire emergency operations per affected household. The report also provides an estimate of relocation costs for stations that experienced substantial flooding.

The second is a recent USACE Portland District study on Columbia River (USACE 2020), which included elicitation of emergency operating costs for the Multnomah County Drainage District. This study provides activity-level cost information for flood fighting, inspections, road closures, and other operations in terms of labor, materials, and equipment. These costs will be leveraged to estimate local flood response costs for different size flood events to build a frequency-damage function.

Note that King County has provided historical damage information from four recent flood events that contains estimates of multiple types of damage for the purpose of FEMA Preliminary Damage Assessment reports (King County 2021a). This data will be reviewed in detail and will be used to adjust the standardized values obtained from the reference USACE source as applicable.

3.3.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of emergency flood response. The methodology for this category relies on identification of affected properties, which is addressed by the building inventory in Section 2.1. In addition to property, ESJ considerations related to emergency response include health and safety risk to people experiencing homelessness that may be within the floodplain, which will be considered qualitatively.

3.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

3.4. LANDSCAPE RESTORATION

Landscaping impacts are estimated based on a repair/re-landscaping cost proxy, where flooded facilities, such as parks, golf courses, and schoolyards, would incur landscape restoration costs.

3.4.1. Inventory Data

GIS analysis will be used to identify properties requiring substantial landscape restoration. A point inventory of such areas will be developed and attributed with the ground elevation at the facility centroid and the total size of the area in acres.

3.4.2. Damage Function Data

A recent USACE Portland District study developed an average landscaping restoration cost per acre of $28,000 (USACE 2020) and developed an accompanying DDF. This source facilitates computation of landscape restoration impacts in the economic model in the same manner that building impacts are calculated. Note that King County has provided some historical flood damage information that included damages at parks and recreation facilities (2021a). This information will be reviewed in detail and used to adjust the standardized value from the USACE source as appropriate.

3.4.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of repairing landscaped areas following a flood. Because major landscaped areas include parks, golf courses, and potentially other public or community spaces, the results of this analysis may be leveraged in the ESJ evaluation to qualitatively describe impacts to access to parks and natural areas, consistent with the King County Determinants of Equity.

3.4.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The population of the landscape area inventory is pending, as it will be informed by the final building inventory and related Assessor's data to identify parcels with major landscaping requirements. All necessary data is available, and no inventory issues are expected in the computation of these impacts.

4. OTHER ECONOMIC COSTS

4.1. ROADWAY DETOUR AND DELAY

When roads are flooded and impassable, vehicle occupants experience health and safety risks, as well as adverse economic impacts in the form of lost time due to detours and added vehicle operating costs on those detours. By estimating the volume of traffic affected by flooding in a given event, and estimating the necessary detour, the adverse economic impact can be calculated. Health and safety risk from flooded roadways will be characterized through GIS mapping, showing the nature and extent of roadway flooding for various hydraulic scenarios.

4.1.1. Inventory Data

A roadway inventory will be completed for each basin study area using the USACE LifeSim model, which facilitates generation of a road network based on the OpenStreetMap API (OSM 2021). The resultant GIS dataset will contain road centerlines and attribute information about the roads. Traffic counts are available from King County (2021) as well as from WSDOT (2021) and will be used to attribute flooded roads with estimated traffic volume and affected population. Necessary detours will be estimated based on a map analysis to identify reasonable detours for highways and major arterials for key flood events. Impacts to traffic on small local roads will not be analyzed, as it is typically assumed that trips experiencing significant detour and delay are accounted for by consideration of highways and major arterials.

4.1.2. Damage Function Data

The value of lost time for vehicle occupants can be estimated based on a USACE methodology for value of time saved. This methodology estimates an hourly value of time as a function of median hourly income, adjusted by the vehicle trip purpose (work trip versus recreation trip). This dollar value can be applied to the affected vehicle volume based on the duration of detour.

Increased vehicle operating costs are based on variable operating cost per mile, applied to the incremental mileage required for the detour. Variable operating costs per mile can be readily obtained from industry sources such as AAA (2020).

4.1.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary impact of traffic detours and delays. Part of this analysis requires estimation of affected vehicle trips along relevant roadways. This information may be leveraged in the ESJ analysis to describe the population whose access to transportation and mobility may be affected. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

4.1.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. The road network GIS layers for the entire model hydraulic domains have been generated and will be clipped to flood extents once hydraulic outputs become available. The specifics of the depth/velocity thresholds for identification of damaged roads will be coordinated with the hydraulic element of the consultant team and documented in the Evaluation Approach memo (subsequent Subtask 8.2). No inventory issues are expected in the estimation of these impacts.

4.2. BUSINESS DISRUPTION (REGIONAL ECONOMIC IMPACTS)

Inundation of non-residential properties can result in temporary closure of businesses while owners restore the functionality of the property. During this period of closure, businesses would experience loss in sales and revenue. Estimates of these direct revenue losses will be based upon estimated annual revenue per square foot by occupancy type. In addition to these direct impacts, the IMPLAN input-output model will be used to estimate indirect and induced employment and income impacts on the regional economy[3].

4.2.1. Inventory Data

The non-residential inventory will be identified based on the building inventory dataset that is being developed and is discussed in Section 2.1. For relevant structures, estimated annual sales (revenue) will be estimated based on information provided by King County Assessor (as available), and supplemented as necessary with generalized values for major occupancy types which are contained in the FEMA Hazus model database.

4.2.2. Damage Function Data

The duration of business closure drives the potential magnitude of direct revenue losses. The closure period would include the period of inundation, as well as a restoration period after flood water has receded. The FEMA Hazus model provides estimates of restoration as a function of flood depth for common non-residential occupancy types. The direct loss estimates will be segregated by major industry for use as inputs to the IMPLAN model. This industry segregation will be based on information provided by the King County Assessor in the building inventory discussed in Section 2.1.

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[3] Direct revenue losses for flooded businesses are imported into IMPLAN to estimate the effects of sales and revenues loss on relationships with other industries and spending patterns in the economy (generating indirect and induced output losses). The Subtask 8.2 memorandum will contain more information about display and interpretation of results from the IMPLAN model.

4.2.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses disruption of business activity from flooding. Results from the IMPLAN analysis will include job impacts. These job impact results may be used in the ESJ analysis to support characterization of ESJ impacts from flooding. Low-income workers may be more sensitive to even temporary income loss, and hence this could be more costly to those communities. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

4.2.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

4.3. RECREATION AND NATURAL LANDS ACCESS LOSSES

This impact category estimates the economic impact of flooding on affected recreation, and other natural land resources. For this impact category, the quantitative focus is on public outdoor recreation resources. Impacts associated with private or fee-based recreation facilities (e.g., museums, golf courses) are considered to be addressed by the business interruption analysis discussed in Section 4.2. For public recreation resources, the recreation value being evaluated is user willingness to pay for the resource, regardless of whether use fees are actually charged. For this purpose, the USACE provides the Unit Day Value methodology (USACE 2020b) which uses a scoring rubric to estimate the willingness to pay for recreation resources in the floodplain based on the context of other resources available locally and regionally. The methodology provides annually updated unit costs that can be applied to visitation counts to estimate resource value.

In addition to use value, there may be impacts from physical damage to recreation trails or related facilities.

4.3.1. Inventory Data

Recreation visitation data for public and free recreation areas, such as trails and parks, is not often available. However, if representative data is available from King County, it will be used to develop generalized use rates for different recreation areas or facility types. If local site-specific data is not available, existing published information from past studies or based on other existing published data for outdoor recreation within the study areas will be used to estimate use density, such as based on published visitation volumes for State parks (WSP 2021).

4.3.2. Damage Function Data

Losses will be estimated based on an estimated duration of closure for recreational facilities following flooding. The basis for these estimates will be inundation duration information that will be available from the hydraulic modeling and will be adjusted to account for reasonable inspection and restoration of facilities. Note that King County has provided some historical flood damage information that included damages at parks and recreation facilities (2021a). This information will be reviewed in detail and used to adjust the standardized value from the USACE source as appropriate.

4.3.3. Preliminary Socioeconomic and ESJ Considerations

This impact category addresses the monetary economic impact from reduction in quality and/or quantity of available recreation resources. Information about the type and location of recreation resources in the study area may inform characterization of ESJ conditions with regard to access to parks and natural areas. For example, different cultural groups might be more or less dependent on such resources. Also, subsistence fishing and hunting curtailments may be relevant to low-income as well as racial and ethnic populations. Finally, homeless populations could be more affected by loss of access to parks and other natural public properties. Such impacts will be considered in the context of the King County Determinants of Equity discussed in Section 5.

4.3.4. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

4.4. LOST WORKER PRODUCTIVITY

This impact category is intended to characterize worker productivity impacts that may arise due to adverse human health impacts following a flood, such as from extreme stress and anxiety. The FEMA BCA Methodology for the Hazard Mitigation Assistance grant program establishes a standardized dollar value per affected resident of the floodplain that represents the long-term decrease in productivity (i.e., income) associated with the aforementioned mental health impacts. Because these effects are a function of individual trauma and are an estimate of effects up to 30 months after the flood event, they are not considered duplicative of the business disruption impacts addressed in Section 4.2.

4.4.1. Inventory Data

This impact category is applicable to the affected residential building inventory. The relevant population will be identified for each flood event based upon hydraulic modeling outputs, the residential building inventory discussed in Section 2.1, and the average household size for King County from the best available U.S. Census data.

4.4.2. Damage Function Data

The FEMA BCA Toolkit version 6.0 contains the most recent standard values per affected resident. Based upon the FEMA literature, the standard values already incorporate a distribution of flood impact severity. As such, the standard loss value may be applied to all residences experiencing flood damage. Note, however, that the monetary results of this analysis are secondary to the qualitative characterization of human health impacts as it relates to the ESJ analysis.

4.4.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

5. EQUITY, SOCIAL JUSTICE, AND HEALTH

Equity, social justice, and health impacts are an essential component of understanding flood risk in a community. In addition to monetized expected annual damage, the analysis shall qualitatively consider other demographic and socio-economic considerations to inform and characterize flood risk. This shall include identification of critical facilities, populations at risk, vulnerable populations and ESJ considerations. For the following categories, impacts will be generally qualitative, and will include a spatial analysis of indicators of equity, social, and health within the study area population, overlaid with results of the flood risk modeling outputs.

5.1. EQUITY AND SOCIAL JUSTICE IMPACT INDICATORS

King County's Equity[4] and Social Justice[5] (ESJ) Strategic Plan provides a foundation for pro-equity investment decision making. Where there are disparities in the Determinants of Equity[6] within a region, equity and social justice is not achieved. The Strategic Plan lists 8 key Determinants of Equity, including 1) access to child and youth development, 2) economic development and jobs, 3)

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[4] "Equity is the full and equal access to opportunities, power and resources so that all people achieve their full potential and thrive. Equity is an ardent journey toward well-being as defined by those most negatively affected." (King County 2016)

[5] "All aspects of justice—including legal, political, economic and environmental—and requires the fair distribution of and access to public goods, institutional resources and life opportunities for all people." (King County 2016)

[6] "The social, economic, geographic, political and physical environments and conditions in which people live. Full and equal access to the Determinants of Equity is necessary to have equity for all people regardless of race, class, gender, language spoken and geography." (King County 2016)

environment and climate, 4) health and human services, 5) housing, 6) information and technology, 7) justice system, and 8) transportation and mobility. Within the context of the LBAMRA study, the goal of the ESJ analysis is to understand the extent to which socially and economically vulnerable populations in floodplains are at a higher risk of being disproportionately negatively impacted by levee breaches. Such risk can be related to several of the Determinants of Equity through impacts to educational and park facilities, impacts to businesses providing local jobs, impacts to medical facilities, and impacts to transportation systems which enable access to the aforementioned community resources. The ESJ evaluation will assess the extent to which flooding impacts these determinants through a combination of mapping and quantitative metrics.

This impact category identifies the socially and economically vulnerable populations in the affected areas. Demographic and economic data will facilitate identifying the locations of concentrated racial/ethnic groups and other communities of color (black, indigenous, and other people of color–BIPOC), low-income communities, senior populations, disabled populations, housing-related indicators, and other groups identified as vulnerable. This characterization of population will be based upon existing published information from the U.S. Census Bureau, King County, and other local and state agencies, as described in the next section.

Overlays with other socioeconomic and geographic factors, and the outputs of the hydraulic modeling will serve to inform the analysis. The analysis will use GIS tools and maps to provide a clearer visual interpretation of risks and impacts. Comparison with other nearby locations, such as adjacent census units, will also help demonstrate how populations differ.

5.1.1. Inventory Data

Data from the U.S. Census Bureau, such as the Census 2020 and American Community Survey (ACS) 5-Year estimates will provide the necessary inventory data for this impact category. The U.S. Census Bureau continue to publish additional datasets from the 2020 Census. Best available geographic resolution will be obtained and utilized following the finalization of the Evaluation Approach Memorandum (Subtask 8.2). Other sources of demographic and economic data to supplement the analysis include Washington State Office of Financial Management (OFM), King County Office of Economic and Financial Analysis, and Washington Employment Security Department (ESD). In addition, the analysis will be informed by the Washington Environmental Health Disparities Mapping Tool (WEHD), the EPA Social Vulnerability Index (SVI), and other vulnerability indices. These published indices will provide tract-level information that may be used to generate more detailed estimates at the block group or block level. Specifics of the approach will be detailed in Subtask 8.2, Evaluation Approach Memorandum.

While the U.S. Census Bureau does not provide population projections, it is considered the best source of latest population estimates/data at the census tract level broken down by race, ethnicity, sex, and age groups. If needed, population growth rates for racial and ethnic groups (including BIPOC), gender identity, and different age groups may be estimated based on State-level projections by OFM and applied to ACS population estimates to develop population projections for relevant areas.

Population and demographic information will be compiled and integrated with the final building inventory discussed previously in Section 2.1. This will support estimation of population exposed to flooding as well as support this ESJ evaluation.

5.1.2. Damage Function Data

The identification of vulnerable communities will provide information on geographic pockets where such communities are concentrated. Impacts from the other categories (e.g., structure impacts, roads, utilities, agriculture) will be evaluated for the vulnerable populations and compared with impacts for the less vulnerable populations.

5.1.3. Inventory Status Summary

For this impact category, inventory and data sources have been identified. No inventory issues are expected in the estimation of these impacts.

5.2. RESIDENTIAL EVACUATION, SUBSISTENCE, AND REOCCUPATION

This impact category addresses the potential need for residents to evacuate their homes, subsist following evacuation (food, lodging, etc.), and reoccupation[7]. Relevant population at risk will be identified based upon flood modeling results and the inventory data identified in Section 2.1. This will include identification of total population at risk, as well as the population in buildings with sufficient depth that evacuation is required. This population will be characterized according to the equity and social justice indicators discussed in Section 5.1. To the extent possible, potentially affected homeless populations will also be identified in terms of temporary public outdoor spaces. This category will also qualitatively characterize the flooding of arterial roadways that may affect the viability of evacuation and may result in public safety impacts based on the nature and extent of roadway flooding for various hydraulic scenarios.

5.2.1. Inventory Data

The residential building inventory discussed in Section 2.1 will provide the necessary inventory data for this impact category.

5.2.2. Damage Function Data

Based upon past USACE studies (USACE 2012), evacuation is likely to begin where flood depths exceed 2 feet of water. This criterion will be applied to the flood model results to identify relevant properties and populations.

5.2.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

5.3. PUBLIC SERVICES AND CRITICAL FACILITIES

There are many public services and critical facilities that benefit the community and may be subject to impact from flooding, such as schools, libraries, and community centers. In addition to the direct damage to these buildings (see Sections 2.1 and 2.5) or cost of emergency response (Section 3.3), adverse impacts may additionally include loss of service impacts to local residents (e.g., school closures). This impact category considers the extent to which loss of critical facility services would differentially affect local population local ESJ populations and the King County Determinants of Equity.

For the purpose of this study, critical facilities will be defined consistent with the 2020-2025 King County Regional Hazard Mitigation Plan (King County 2020), which lists the following critical facilities: schools, hospitals, nursing homes, hazardous materials storage facilities, wastewater and stormwater management facilities, animal waste storage facilities. Additional facilities that will be considered critical include assisted living facilities, police and fire stations, facilities with designated emergency management purposes (storage, operations center, shelter, etc.), major sports venues (i.e., stadiums), and jail/correctional facilities. Buildings identified as critical facilities will be flagged in the database. Identification of critical facilities will be based upon existing published data from King County, including GIS datasets and the Regional Hazard Mitigation Plan. Designation as a critical facility will not affect computed structure, content, or inventory damages, but the presence and type of critical facilities in the floodplain may inform the evaluation for other impact categories.

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[7] Following Hurricane Katrina and its associated flooding, the USACE New Orleans District collected and elicited information for this impact category and developed an estimate of up to $5,500 (2010 prices) per affected household (USACE 2012).

5.3.1. Inventory Data

The building inventory discussed in Section 2.1 and the critical utilities facilities analysis discussed in Section 2.5 will provide the necessary inventory data for this impact category. Relevant critical facilities will be mapped in combination with inundation information from the hydraulic modeling outputs.

5.3.2. Damage Function Data

Relevant public buildings experiencing loss of service will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012). It is anticipated that these outage probabilities will be used to adjust the FEMA standard values such that they can be applied to all relevant damaged buildings. Based on these sources, the potential duration of service loss can be characterized and used to describe the magnitude of this impact in a qualitative manner.

5.3.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

5.4. UTILITY LOSS OF SERVICE IMPACTS (ELECTRIC, WATER, WASTEWATER)

Reliable utility service is critical to the daily lives of floodplain residents. This impact category evaluates the potential for interruption of utility service. Risk of utility outage will be used to characterize the potential affected population for each flood event.

5.4.1. Inventory Data

The building inventory discussed in Section 2.1 will serve as the inventory for this impact category. Buildings experiencing outage will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012).

5.4.2. Damage Function Data

Buildings experiencing outage will be estimated based upon the hydraulic modeling outputs and outage probability information available from past USACE expert elicitation reports (USACE 2012). Affected buildings will be used in conjunction with population information to characterize the potential for utility service disruption and the affected population. Duration of disruption will be estimated based upon the FEMA benefit-cost analysis methodology, which estimates the need for approximately 45 days of restoration time per foot of flood depth relative to the first floor.

5.4.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

5.5. MENTAL STRESS, ANXIETY

This impact category is intended to characterize human health impacts following a flood that may result in a decreased quality of life through adverse impacts on mental health. For example, the FEMA BCA Methodology for the Hazard Mitigation Assistance grant program establishes a standardized dollar value per affected resident of the floodplain that represents the costs of mental health treatment following a flood. For this analysis, this risk of human health impact will be considered in the ESJ evaluation to understand whether there would likely be differential human health impacts from flooding that may affect the evaluation of flood risk.

5.5.1. Inventory Data

This impact category is applicable to the affected residential building inventory. The relevant population will be identified for each flood event based upon hydraulic modeling outputs, the residential building inventory discussed in Section 2.1, and the average household size for King County from the best available U.S. Census data.

5.5.2. Damage Function Data

The FEMA BCA Toolkit version 6.0 contains the most recent standard values per affected resident. Based upon the FEMA literature, the standard values already incorporate a distribution of flood impact severity. As such, the standard loss value may be applied to all residences experiencing flood damage. Note, however, that the monetary results of this analysis are secondary to the qualitative characterization of human health impacts as it relates to the ESJ analysis.

5.5.3. Inventory Status Summary

For this impact category, inventory and DDF data sources have been identified. No inventory issues are expected in the estimation of these impacts.

6. QUALITY CONTROL

A quality control review of this memorandum was completed by a senior economist not directly involved with the development of the memorandum. A separate review was performed by a technical editor.

Additional quality control information will be documented as part of the Evaluation Approach Memorandum that will be prepared as part of Subtask 8.2 in a future phase of study.

7. LIST OF DATA SOURCES

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