Lowell Creek Flood Diversion Feasibility Study

Appendix D: Economics

Lowell Creek, Alaska

September 2020

U.S. Army Corps
of Engineers
Alaska District

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1.0 BACKGROUND INFORMATION

1.1 INTRODUCTION

General. This appendix presents an economic evaluation of the riverine flood risk reduction measures for the Lowell Creek Feasibility Study. The evaluation area includes the downstream community of Seward, Alaska. The report was prepared in accordance with Engineering Regulation (ER) 1105-2-100, Planning Guidance Notebook, and ER 1105-2-101, Planning Guidance, Risk Analysis for Flood Damage Reduction Studies. The National Economic Development Procedures Manual for Flood Risk Management and Coastal Storm Risk Management, prepared by the Water Resources Support Center, Institute for Water Resources, was also used as a reference, along with the User's Manual for the Hydrologic Engineering Center Flood Damage Analysis Model (HEC-FDA).

The economic appendix consists of a description of the methodology used to determine National Economic Development (NED) damages and benefits under existing conditions and the project's costs. The damages and costs were calculated using FY 2020 price levels. Costs were annualized using the FY 2020 Federal discount rate of 2.75 percent and a period of analysis of 50 years with the year 2025 as the base year. The expected annual damage and benefit estimates were compared to the annual construction costs and the associated OMRR&R costs for each of the project measures.

NED Benefit Categories Considered. The NED procedure manuals for coastal and urban areas recognize four primary categories of benefits for flood risk management measures: inundation reduction, intensification, location, and employment benefits. The majority of the benefits attributable to a project measure generally result from the reduction of actual or potential damages caused by inundation. Inundation reduction includes the reduction of physical damages to structures, contents, and vehicles and indirect losses to the national economy.

Physical Flood Damage Reduction. Physical flood damage reduction benefits include the decrease in potential damages to residential and commercial structures, their contents, and the privately owned vehicles associated with these structures.

Emergency Cost Reduction Benefits. Emergency costs are those costs incurred by a community during and immediately following a major storm. The cost of debris removal from inundated residential and non-residential structures was the only emergency cost reduction benefit considered for this analysis.

Flood Fighting Cost Reduction Benefits. Flood fighting costs are those costs incurred by the City of Seward in combating the heavy sediment load exiting the tunnel outfall before entering Resurrection Bay. The flood-fighting efforts are to save the only bridge that connects portions of the study area to Seward.

NED Benefit Categories NOT Considered. The following NED benefit categories were not addressed in this economic appendix before selection of a Tentatively Selected Plan (TSP) include the following:

- Costs associated with evacuation and reoccupation activities before, during and following a flood event incurred by property owners and governments;
- Indirect losses to the national economist as a result of disruptions in the production of goods and services by industries affected by the storm or riverine flooding
- The increased cost of operations for industrial facilities following a flood event relative to normal business operations
- Costs associated with local tourism being impacted by a flood event

Regional Economic Development. When the economic activity lost in a flooded region can be transferred to another area or region in the national economy, these losses cannot be included in the NED account. However, the impacts on the employment, income, and output of the regional economy are considered part of the RED account. The input-output macroeconomic model RECONS can be used to address the impacts of the construction spending associated with the project alternatives. The RED account has not been addressed in the Economic Appendix before the selection of the TSP.

Other Social Effects. The other social effects (OSE) account includes impacts on life safety, vulnerable populations, local economic vitality, and community optimism. Impacts on these topics are a natural outcome of civil works projects and are most commonly qualitatively discussed in the OSE account. Life loss modeling software such as HEC-FIA and HEC-LifeSim can quantify the loss of life for a given alternative to determine if life safety risk decreases or is induced as a result of federal investment. HEC-LifeSim 1.0 was utilized to measure life safety for this study, and the consequences chapter can be found in Appendix X.

1.2 DESCRIPTION OF THE STUDY AREA

Geographic Location. The Lowell Creek study area includes the town of Seward and extends from the Lowell Creek Diversion Dam down into Resurrection Bay. The Lowell Creek measures for the study area will be analyzed in this part of the Economics Appendix. An inventory of residential and non-residential structures was developed using Kenai Peninsula Borough tax assessed data. The structure inventory within the Kenai Peninsula is shown in Figure 1.

Figure 1. Lowell Creek Structure Inventory (Seward, AK)

The study area was further divided into 6 study area reaches. Dividing the study area into reaches was done to help reduce the variability within the hydraulic data that represented an alluvial fan floodplain. Structures located within each reach were assigned that area in HEC-FDA. The study area reach boundaries are shown in Figure 2. Of particular note is Reach 6, which is located from the diversion dam to the canyon exit. This area receives the highest depth and velocity flows during an overtopping event and includes an elderly apartment building and hospital.

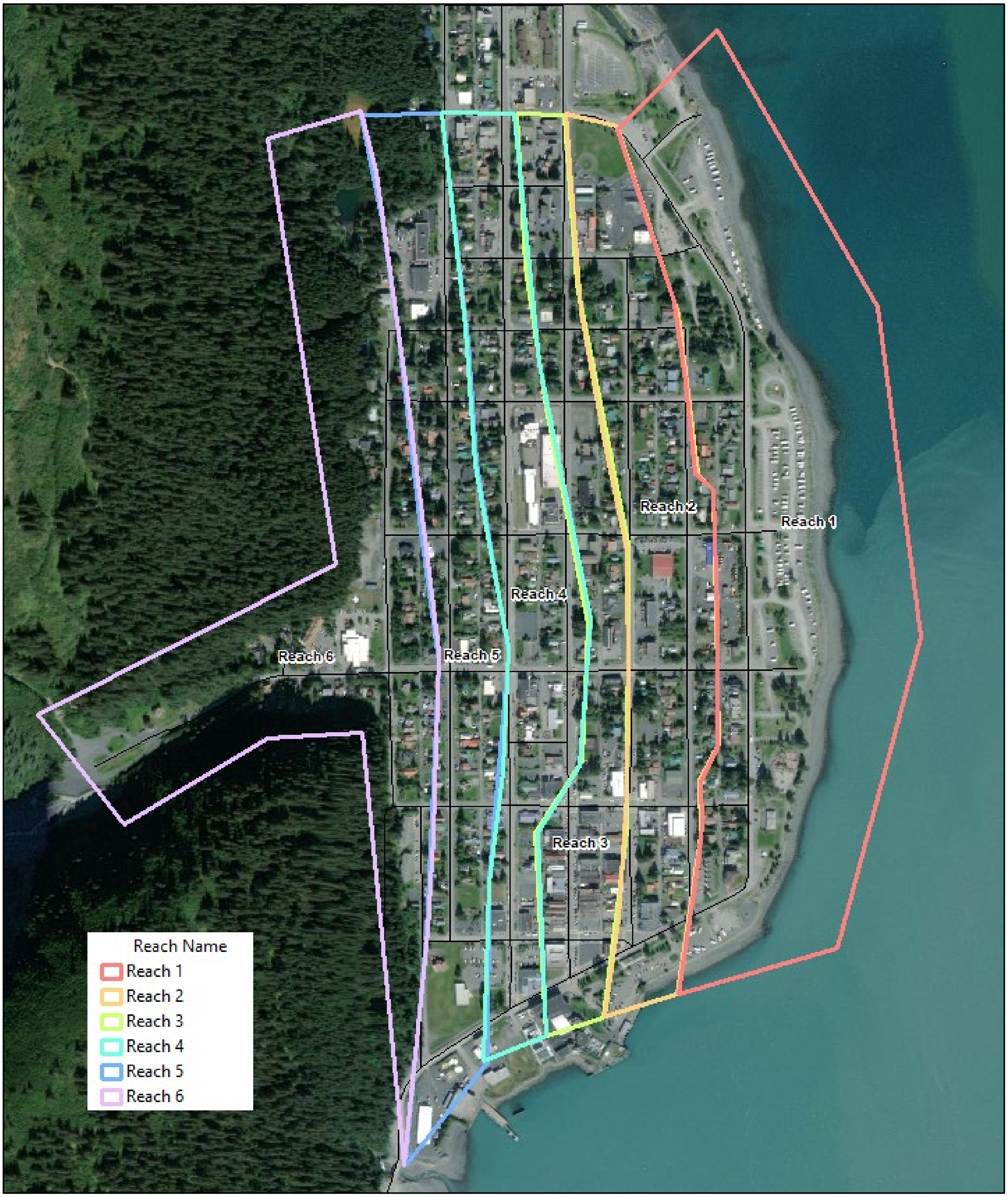

Figure 2. Study Subunits (Reaches)

A structure count by reach, split by the structure being either residential or non-residential, which includes commercial, industrial, and public structures are shown in Table 1. The study area has a total of 564 structures located across the 6 study area subunits. Reach 1 of the study area includes 65 mobile home structures that are parked for 66% or more of the year. Research performed for the Semi-Quantitative Risk Assessment (SQRA) determined that the perception of the flood hazard by the local population is minimal, and therefore evacuation of the mobile homes before an event would be unlikely.

Table 1. Structure Count by Reach

Reach	Residential Count	Non-Residential Count
1	99	1
2	86	14
3	51	49
4	61	39
5	89	11
6	61	3

Existing Flood Damage Reduction Infrastructure. The Lowell Creek study area includes the Lowell Creek Diversion Dam and Tunnel that runs through Bear Mountain and empties into Resurrection Bay. The economic analysis assumed that the tunnel could handle floods up to the 1% AEP event. The economic analysis also assumed the tunnel will be properly maintained and operated and therefore does not have any fragility curves associated with it that would lead to failure prior to its maximum level of performance.

1.3 SCOPE OF THE STUDY

Problem Description. The study area is characterized as an alluvial fan of Lowell Creek. Alluvial fans are depositional landforms, located at the base of mountain ranges where a steep mountain stream emerges onto lesser valley slopes. Sediments deposited on alluvial fans are generally coarse-grained, composed of sand, gravels, and boulders. Lowell Creek is a unique alluvial fan in that the river no longer actively flows over the fan but instead is diverted through Bear Mountain, and the entire alluvial fan is developed with the only available conveyance being overland flooding through the city.

The City of Seward was rapidly developed after the tunnel and diversion dam construction was completed in the fall of 1940. The economic problem of the study area is two-fold, the first being the risk of inundation from events that exceed the tunnel capacity, approximately a 1% AEP level of risk reduction. The second economic problem is sedimentation and the City of Seward's ability to manage sediment coming through the tunnel through flood-fighting efforts. These two problems are interrelated at times as the high sediment loads can increase the stage of flood flows.

Project Measures. The suite of measures carried through to the final array included:

- Improve Existing Flood Diversion System

- Enlarge Existing Flood Diversion System
- Construct New Flood Diversion System
- Constructing an Upstream Debris Retention Basin
- Nonstructural Acquisition of Critical Infrastructure

The Economic Appendix only includes basic descriptions of measures carried through to the final array (4th planning iteration). A full description of measures included in the focused array (3rd planning iteration) and the final array can be found in Chapter X.

Improve Existing Flood Diversion System. This alternative would refurbish the existing tunnel without enlarging the tunnel. This alternative would extend the outfall of the tunnel to Resurrection Bay, leading to a reduction in flood fighting activities associated with sediment deposition.

Enlarge Existing Flood Diversion System. This alternative would increase the size of the existing tunnel to either an 18-foot diameter or 24-foot diameters to pass flood events exceeding the 0.2% AEP frequency event. This alternative would also extend the outfall of the tunnel to Resurrection Bay, leading to a reduction in flood fighting activities associated with sediment deposition. Enlarging the existing flood diversion system would require significant delays in flood risk reduction due to limited construction windows since construction activities could only take place during low-flow conditions.

Construct New Flood Diversion System. This alternative would construct a new flood diversion tunnel (18-feet or 24-feet in diameter) and include a landslide mitigation feature. The new tunnel would have an extended outfall into Resurrection Bay, leading to a reduction in flood fighting activities associated with sediment deposition. During this alternative, both tunnels could be utilized, which would improve operation and maintenance and rehabilitation efforts by having a dedicated tunnel to divert flow. The construction timeline could be expedited under this condition since existing flows would not have to be rerouted to complete construction.

Construct an Upstream Debris Retention Basin. This alternative would construct an upstream retention basin that would gather sediment flowing through Lowell Creek and retain the sediment during the duration of the flood event. The retention basin would have to be cleaned regularly to maintain effectiveness. This alternative would not have a measurable impact on flood damage reduction benefits but would lead to a reduction in flood fighting activities associated with sediment deposition.

Nonstructural. Nonstructural measures include the implementation of an early warning system, evacuation plan, relocation of critical infrastructure, and the removal of trees from the upstream watershed. Currently, there is no system or plan to monitor the tunnel or diversion dam, and the flashy system can be overwhelmed quickly with little to no warning to the downstream residents within Seward. Additionally, trees could be removed from the upstream watershed to reduce the likelihood of a surge release event that results from debris blocking the stream and temporarily impounding water.

The final nonstructural measure is relocating critical infrastructure. Located less than a tenth of a mile from the diversion dam sits an elderly apartment complex and a hospital. These structures sit at the edge of the Lowell Creek canyon and experience the full force of depth and velocity flows resulting from an event that overtops the diversion dam. A nonstructural measure includes acquiring the two buildings and relocating them outside of the floodplain. While this measure does not significantly reduce flood damages, it does reduce the potential for life loss since both structures have at least 40 people occupying them at any given time. This measure was screened due to a lack of qualifying locations to relocate structures within the study area. The location of the critical infrastructure relative to the diversion dam is shown in Figure 3.

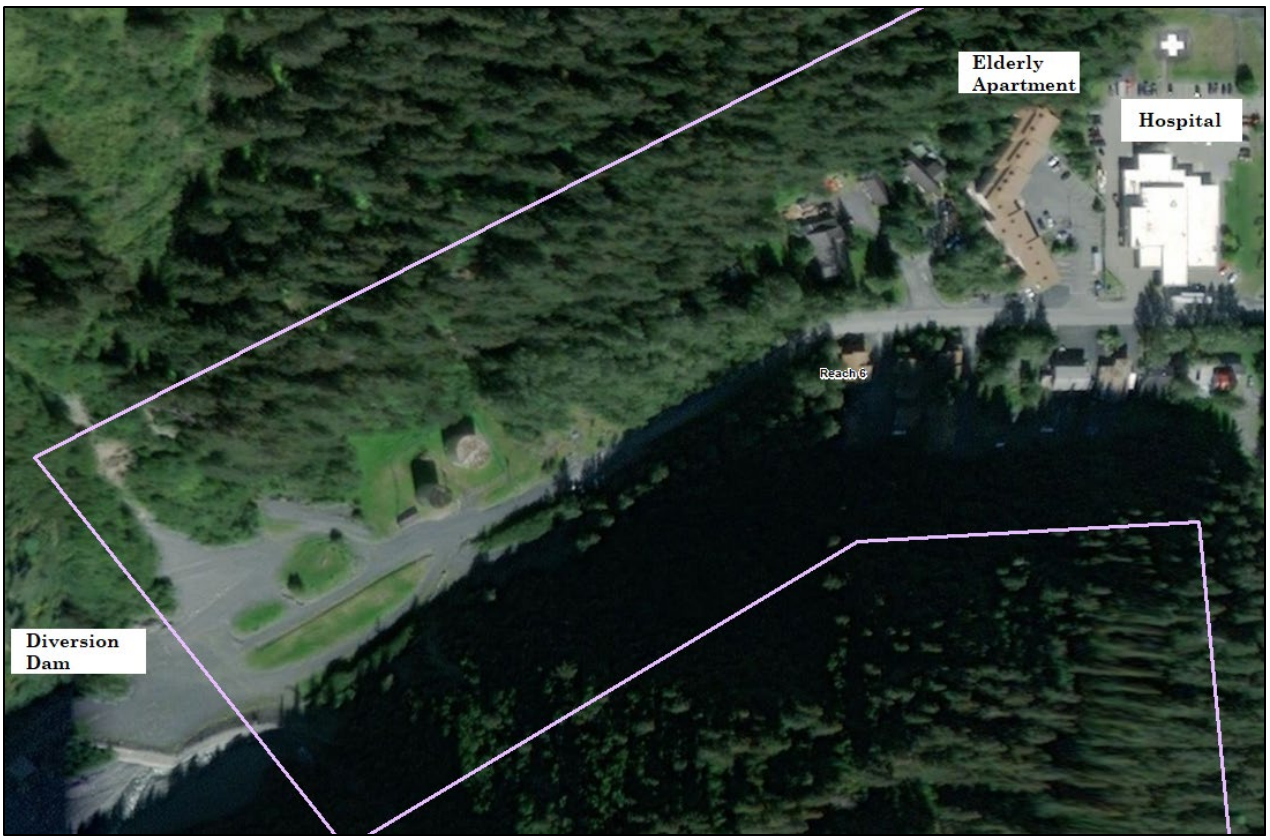

Figure 3. Seward Critical Infrastructure

2.0 ECONOMIC AND ENGINEERING INPUTS TO THE HEC-FDA MODEL

2.1 HEC-FDA MODEL

Model Overview. The Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) Version 1.4.2 Corps-certified model was used to calculate the damages and benefits for the South Central Coastal Louisiana evaluation. The economic and engineering inputs necessary for the model to calculate damages for the project base year (2020) include the existing condition structure inventory, contents-to-structure value ratios, vehicles, first floor and ground elevations, and depth-damage relationships, and without-project and with-project stage-probability relationships.

The uncertainty surrounding each of the economic and engineering variables was also entered into the model. Either a normal probability distribution, with a mean value and a standard deviation, or a triangular probability distribution, with a most likely, a maximum and a minimum value, was entered into the model to quantify the uncertainty associated with the key economic variables. A normal probability distribution was entered into the model to quantify the uncertainty surrounding the ground elevations.

The number of years that stages were recorded at a given gage was entered for each study area reach to quantify the hydrologic uncertainty or error surrounding the stage-probability relationships. For this study, there was not a gage on Lowell Creek, and therefore the hydraulic engineer interpolated values from nearby Spruce Creek. To represent the uncertainty of interpolating from a nearby gage, a gage record of 25 years was recommended by the hydraulic engineer.

2.2 ECONOMIC INPUTS TO THE HEC-FDA MODEL

Structure Inventory. A structured inventory of residential and non-residential structures for the Lowell Creek study area was obtained using Kenai Peninsula Borough tax assessed data. The structure inventory was imported into GIS using the tax assessor's shapefile. Each structure point was geospatially relocated to the structure building footprint to ensure an accurate ground surface elevation and flood depth extraction. Assessed values were multiplied by a factor provided by the Borough's tax assessor to obtain a proxy to depreciated replacement value. Post-TSP, RS Means will be utilized to re-valuate the structure inventory and obtain a more refined depreciated replacement valuation.

Windshield Survey. A vehicle-based windshield survey was conducted in March 2017 to record structural attributes such as foundation height, effective age, condition, story count, exterior wall types, foundation types, and exterior wall types. The windshield survey sampled 100% of the structures that could not be properly surveyed using Google Street View. Once back at the office, the remaining structures were surveyed using Google Street View. The windshield survey sampled a total of 489 structures. The remaining 75 mobile homes were assumed to have similar attributes to those of national averages. The structure count by occupancy type and the associated average and standard deviation of the foundation heights from the survey is shown in Table 2.

Table 2. Windshield Survey Results

Occupancy Type	Number of Structures	Average. Foundation (ft.)	Standard Deviation (ft.)
Oreswbsmt	27	1.86	1.17
Oreswoutbsmt	178	1.05	0.86
Treswbsmt	24	1.63	1.30
Treswoutbsmt	98	1.43	1.18
MobHome	75	2.00	0.00
Apt1	41	1.11	0.92
Pub2	11	0.30	0.35
Retail	87	0.63	0.91
School*	23	0.69	1.16

*Note: The Alaska Vocational Technical Center is made up of multiple buildings, each independently analyzed, which explains the high structure count for schools.

Structure Value Uncertainty. The uncertainty surrounding the residential structure values includes the depreciation percentage applied based on the effective age and condition of the structures as well as the four exterior wall types utilized in RS-Means. A triangular probability distribution was developed for residential structures using the following RS Means information:

- Minimum Depreciation – Effective Age: 10 Years & Good Condition
- Most Likely Depreciation – Effective Age: 20 Years & Average Condition
- Maximum Depreciation – Effective Age: 30 Years & Poor Condition

Effective age for this uncertainty analysis was defined as the average observed age of a structure as recorded during the windshield survey. These values were then converted to a percentage of the most-likely value with the most-likely value equal to 100 percent of the average value for each exterior wall type and occupancy category. The triangular probability distributions were entered into the HEC-FDA model to represent the uncertainty surrounding the structure values in each residential occupancy category.

The uncertainty surrounding the non-residential structure values was based on the depreciation percentage applied to the average replacement cost per square calculated from the six exterior wall types. A triangular probability distribution was developed for non-residential structures using the following RS Means information:

- Minimum Depreciation – Effective Age: 10 Years & Masonry on Masonry/Steel
- Most Likely Depreciation – Effective Age: 20 Years & Masonry on Wood
- Maximum Depreciation – Effective Age: 30 Years & Frame

These values were then converted to a percentage of the most-likely value with the most-likely value being equal to 100 percent and the minimum and maximum values equal to percentages of the most-likely value. The triangular probability distributions were entered into the HEC-FDA model to represent the uncertainty surrounding the structure values for each non-residential occupancy category. The minimum and maximum percentages of the most-likely structure values assigned to the various structure categories are shown in Table 3.

Table 3. RS Means Structure Value Uncertainty Factors

	RS Means Cost per Sq Ft Factor		
RS Means Occupancy Type	Minimum	Most Likely	Maximum
Non-Residential	0.80	1.00	1.23
1 Story Res	0.69	1.00	1.16
2 Story Res	0.69	1.00	1.16
Mobile Home	0.48	1.00	1.47

Residential and Non-Residential Content-to-Structure Value Ratios. Based on Economic Guidance Memorandum (EGM), 04-01, dated 10 October 2003, a content-to-structure value ratio (CSVR) of 100 percent was applied to all of the residential structures in the structure inventory and the error associated with CSVR was set to zero. The EGM states that the 100 percent CSVR is to be used with the generic depth-damage relationships developed for residential structures, which were also used for this study.

The content-to-structure value ratios (CSVRs) applied to the non-residential structure occupancies were taken from an extensive survey of business owners in coastal Louisiana for three large coastal storm risk management evaluations. These interviews included a sampling from the eight non-residential content categories from each of the three evaluation areas. A total of 210 non-residential structures were used to develop CSVRs for each of the non-residential categories.

Content-to-Structure Value Ratio Uncertainty. For each of the occupancy types, a mean CSVR and a standard deviation was calculated and entered into the HEC-FDA model using the information gathered from the survey performed for the three large coastal storm risk management evaluations. A normal probability density function was used to describe the uncertainty surrounding the CSVR for each content category. The expected CSVR percentage values and standard deviations for each of the occupancy types are shown in Table 4.

Table 4. Content-to-Structure Value Ratios and Uncertainty

	Average	Standard Deviation
1-Story Res	100%	0%
2-Story Res	100%	0%
Mobile Home	114%	79%
Pub2	57%	90%
School	57%	90%
Retail	124%	111%

Vehicle Inventory and Values. Based on the 2017 Census information for the Kenai Peninsula area, there is an average of 2 vehicles associated with each household (owner-occupied housing or rental unit). Given that a large portion of Seward's population is seasonal during the warmer months, it was probabilistically determined 1 of the 2 vehicles had the potential to not be within the study area during a flood event. According to Edmund, the average value of a used car was $19,700 as of June 2018. An average vehicle value of $19,700 was assigned to each residential automobile structure record in the HEC-FDA model.

If an individual structure contained more than one housing unit, then the adjusted vehicle value was assigned to each housing unit in a residential or multi-family structure category. Only vehicles associated with residential structures were included in the analysis. Vehicles associated with non-residential properties were not included in the evaluation.

Vehicle Value Uncertainty. The uncertainty surrounding the values assigned to the vehicles in the inventory was determined using a triangular probability distribution function. The average value of a used car, $19,700, was used as the most-likely value. The average value of a new vehicle, $33,560, before taxes, license, and shipping charges was used as the maximum value. In contrast, the average 10-year depreciation value of a vehicle, $3,000, was used as the minimum value. The percentages were developed for most-likely, minimum, and the maximum values with the most-likely equal to 100 percent, and the minimum and the maximum values as percentages of the most-likely value (minimum=16%, most-likely=100%, maximum=180%). These percentages were entered into the HEC-FDA model as a triangular probability distribution to represent the uncertainty surrounding the vehicle value for both residential and non-residential vehicles.

Elevation Data. Elevation data associated with the ground surface, foundation heights, and first floors of structures are critical to the economic analysis and feasibility of studies.

Ground Surface Elevations. Topographical data based on Light Detection and Ranging (LiDAR) data using NAVD 88 vertical datum was obtained by the Alaska District GIS department in a 5-meter resolution raster format. The 5-meter LiDAR data was used to assign ground elevations to structures and vehicles in the study area.

First Floor Elevations. The ground elevation was added to the height of the foundation of the structure above the ground in order to obtain the first-floor elevation of each structure in the study area. Vehicles were assigned to the ground elevation of the adjacent residential structures and did not include adjustments for foundation heights.

Elevation Uncertainty. There are two sources of uncertainty surrounding the first floor elevations: the use of the LiDAR data for the ground elevations, and the methodology used to determine the structure foundation heights above ground elevation. The error surrounding the LiDAR data was determined to be plus or minus 0.5895 feet at the 95 percent level of confidence. This uncertainty was normally distributed with a mean of zero and a standard deviation of 0.3 feet.

The uncertainty surrounding the foundation heights for the residential and commercial structures was estimated by calculating the standard deviations surrounding the sampled mean values. An overall weighted average standard deviation for the four structure groups was computed for each structure category. The distribution of the foundation height uncertainty for each occupancy type is displayed in Table 4.

The standard deviations for the ground elevations and foundation heights were combined, which resulted in a 1.21 feet standard deviation for one story residential structures with basements (Oreswbsmt) structures and 1.22 feet for two-story residential structures without basements (Treswoutbsmt), as examples. The calculations used to combine the uncertainty surrounding the ground elevations with uncertainty surrounding the foundation height to derive the uncertainty surrounding the first floor elevations of residential, commercial, and public structures are displayed in Table 5.

Table 5. First Floor Stage Uncertainty Standard Deviation (SD) Calculation

Ground - LiDAR (conversion cm to inches to feet)		
+/- 18 cm @ 95% confidence		18cm
	x	0.393
z = (x - u)/ std. dev.		7.074in
	÷	12
1.96 = (0.5895 - 0)/ std.dev.		0.5895ft
0.3007 = std.dev.		

First Floor Combined Std. Dev (shown in feet)								
Residential					Commercial	Public		
Oreswbsmt	Oreswoutbsmt	Treswbsmt	Treswoutbsmt	Apt1	Retail	Pub2	School	
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	ground std. dev.
0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	ground std. dev. Squared
1.17	0.86	1.3	1.18	0.92	0.35	0.91	1.16	1st floor std. dev.
1.37	0.74	1.69	1.39	0.85	0.12	0.83	1.35	1st-floor std. dev. Squared
1.46	0.83	1.78	1.48	0.94	0.21	0.92	1.44	Sum of Squared
1.21	**0.91**	**1.33**	**1.22**	**0.97**	**0.46**	**0.96**	**1.20**	**Square Root of Sum of Squared**

Debris Removal Costs. Debris removal costs are typically discussed in the Other Benefit Categories section of the Economic Appendix. However, since debris removal costs were included as part of the HEC-FDA structure records for the individual residential and non-residential structures in the Lowell Creek study area, these costs are being treated as an economic input. The HEC-FDA model does not report debris removal costs separately from the total expected annual without-project and with-project damages.

Following Hurricanes Katrina and Rita, interviews were conducted by the New Orleans District with experts in the fields of debris collection, processing, and disposal to estimate the cost of debris removal following a storm event. Information obtained from these interviews was used to assign debris removal costs for each residential and non-residential structure in the Lowell Creek structure inventory. The experts provided a minimum, most likely, and maximum estimate for the cleanup costs associated with the 2 feet, 5 feet, and 12 feet depths of flooding. A prototypical structure size in square feet was used for the residential occupancy categories and the non-residential occupancy categories. The experts were asked to estimate the percentage of the total cleanup caused by floodwater and to exclude any cleanup that was required by high winds.

In order to account for the cost/damage surrounding debris cleanup, values for debris removal were incorporated into the structure inventory for each record according to its occupancy type. These values were then assigned a corresponding depth-damage function with uncertainty in the HEC-FDA model. For all structural occupancy types, 100% damage was reached at 12 feet of flooding. The debris clean-up values provided in the report were expressed in 2010 price levels for the New Orleans area. These values were converted to 2020 price levels for the Lowell Creek area using the indexes provided by Gordian's 2020 edition of "Square Foot Costs with RS Means Data." The debris removal costs were included as the "other" category on the HEC-FDA structure records for the individual residential and non-residential structures and used to calculate the expected annual without-project and with-project debris removal and cleanup costs.

Debris Removal Costs Uncertainty. The uncertainty surrounding debris percentage values at 2-foot, 5-foot, and 12-foot depths of flooding were based on the range of values provided by the four experts in the fields of debris collection, processing, and disposal. The questionnaires used in the interview process were designed to elicit information from the experts regarding the cost of each stage of the debris cleanup process by structure occupancy type. The range of responses from the experts were used to calculate a mean value and standard deviation value for the cleanup costs percentages provided at 2 feet, 5 feet, and 12 feet depths of flooding. The mean values and the standard deviation values were entered into the HEC-FDA model as a normal probability distribution to represent the uncertainty surrounding the costs of debris removal for residential and non-residential structures. The depth-damage relationships containing the damage percentages at the various depths of flooding and the corresponding standard deviations representing the uncertainty are shown with in-depth–damage tables.

Depth-Damage Relationships. The United States Army Corps of Engineers (USACE) generic depth-damage relationships for one-story and two-story residential structures with no basement from EGM, 01-03, dated 4 December 2000, were used in the analysis. The mobile home depth-damage relationships were based on the relationships developed by a panel of insurance experts as part of the New Orleans District Morganza to the Gulf feasibility study. The vehicle depth-damage functions were based on the generic depth-damage curves from EGM, 09-04, generic depth-damage relationships for vehicles, dated 22 June 2009. The generic vehicle curves for sedans were used for vehicles associated with residential structures.

Since site-specific non-residential depth-damage relationships were not available for the Lowell Creek study area, depth-damage relationships developed for the 2011 Fargo-Moorhead Feasibility Study were utilized. These curves were developed for study areas with freshwater riverine flooding characteristics similar to the Lowell Creek basin. The ideal depth-damage relationship curves would have incorporated the increase in damages due to sedimentation. Still, such a relationship could not be established for this study, and as a result, the economic damages reported from HEC-FDA are likely understated.

Depth-damage relationships indicate the percentage of the total structure value that would be damaged at various depths of flooding. For residential and non-residential structures, damage percentages were provided at each one-foot increment from two feet below the first-floor elevation to 16 feet above the first-floor elevation for the structural components and the content components.

Uncertainty Surrounding Depth-Damage Relationships. A normal distribution with a standard deviation for each damage percentage provided at the various increments of flooding was used to determine the uncertainty surrounding the generic depth-damage relationships used for residential structures and vehicles. For non-residential structures and mobile homes, a triangular probability density function was used to determine the uncertainty surrounding the damage percentage associated with each depth of flooding. A minimum, maximum, and most-likely damage estimate was provided by a panel of experts for each depth of flooding.

The damage relationships for structures, contents, vehicles, and debris removal, contain the damage percentages at each depth of flooding along with the uncertainty surrounding the damage percentages, are shown in Section 7 of this appendix (supplemental tables).

2.3 ENGINEERING INPUTS TO THE HEC-FDA MODEL

Stage-Probability Relationships. Stage-probability relationships were provided for the existing without-project condition (2020). The ADCIRC model was originally developed for the 2010 LACPR coastal study, and the SCCL study used unmodified versions of the ADCIRC outputs for the existing and future conditions.

The hydraulic model provided water surface profiles for eight annual exceedance probability (AEP) events including the 0.50 (2-year), 0.20 (5-year), 0.10 (10-year), 0.04 (25-year), 0.02 (50-year), 0.01 (100-year), 0.004 (250-year), and 0.002 (500-year). The without-project water surface profiles assume the Lowell Creek tunnel and diversion dam are in operation and contain 2,600 CFS, or approximately the 1% AEP event. In events larger than the 1% AEP, the diversion dam is overtopped and flows follow Jefferson Street into Seward, eventually dumping into Resurrection Bay.

To account for the sedimentation of the hydraulics within Lowell Creek, the hydraulic engineer applied a bulking factor of 1.11 to increase the amount of CFS and stage modeled within HEC-FDA. The bulking factor is the only assumption utilized in the economic analysis to account for increased depth and velocities as a result of rocks, boulders, and other sedimentation forms. See the Hydraulic Appendix for additional information on bulking factors.

Uncertainty Surrounding the Stage-Probability Relationships. A 25-year equivalent record length was used to quantify the uncertainty surrounding the stage-probability relationships for each study area reach. Based on this equivalent record length, the HEC-FDA model calculated the confidence limits surrounding the stage-probability functions. The 25-year record length was selected by the hydraulic engineer to represent the uncertainty in the stage-probability relationships given the conversion process of using nearby Spruce Creek hydraulic records for the Lowell Creek watershed. More information about the flow frequency conversion between Spruce and Lowell Creek can be found in Section 3.5 of the Hydraulic Appendix.

Use of HEC-GeoFDA. The Geospatial Preprocessor for Flood Damage Reduction Analysis (HEC-GeoFDA) program was utilized for the Lowell Creek study. GeoFDA preprocesses hydraulic and economic data in a GIS format so that HEC-FDA can read non-native hydraulic data formats. For the Lowell Creek study, the alluvial fan could not be properly modeled using traditional cross-section data that HEC-FDA requires. Instead, hydraulic data was provided in a two-dimensional depth grid format in GIS. The GeoFDA model extracted depth of flooding data from the grid to each structure point and then treated it as a station within FDA. GeoFDA has been officially released by the Hydrologic Engineering Center and does not have to comply with traditional model certifications, given that it is a preprocessor.

3.0 NATIONAL ECONOMIC DEVELOPMENT (NED) FLOOD DAMAGE AND BENEFIT CALCULATIONS

3.1 HEC-FDA Model Calculations

The HEC-FDA model was utilized to evaluate flood damages using risk-based analysis. Damages were reported at the index location for each of the 6 study area reaches for which a structure inventory had been created. A range of possible values, with a maximum and a minimum value for each economic variable (first-floor elevation, structure and content values, and depth-damage relationships), was entered into the HEC-FDA model to calculate the uncertainty or error surrounding the elevation-damage, or stage-damage, relationships.

The number of years that stages were recorded at a given gage was entered for each study area reach to quantify the hydrologic uncertainty or error surrounding the stage-probability relationships. For this study, there was not a gage on Lowell Creek, and therefore the hydraulic engineer interpolated values from nearby Spruce Creek. To represent the uncertainty of interpolating from a nearby gage, a gage record of 25 years was recommended by the hydraulic engineer.

The possible occurrences of each variable were derived through the use of Monte Carlo simulation, which used randomly selected numbers to simulate the values of the selected variables from within the established ranges and distributions. For each variable, a sampling technique was used to select from within the range of possible values. With each sample or iteration, a different value was selected. The number of iterations performed affects the simulation execution time and the quality and accuracy of the results. This process was conducted simultaneously for each economic and hydrologic variable. The resulting mean value and probability distributions formed a comprehensive picture of all possible outcomes.

3.2 Stage-Damage Relationships with Uncertainty

The HEC-FDA model used the economic and engineering inputs to generate a stage-damage relationship for each structure category in each study area reach. The possible occurrences of each economic variable were derived through the use of Monte Carlo simulation. A total of 1,000 iterations were executed in the model for stage-damage relationships. The sum of all sampled values was divided by the number of samples to yield the expected value for a specific simulation. A mean and standard deviation was automatically calculated for the damages at each stage.

3.3 Without-Project Expected Annual Damages**.**

The model used a Monte Carlo simulation to sample from the stage-probability curve with uncertainty. For each of the iterations within the simulation, stages were simultaneously selected for the entire range of probability events. The sum of all damage values divided by the number of iterations run by the model yielded the expected value, or mean damage value, with confidence bands for each probability event. The probability-damage relationships are integrated by weighting the damages corresponding to each magnitude of flooding (stage) by the percentage chance of exceedance (probability). From these weighted damages, the model determined the expected annual damages (EAD) with confidence bands (uncertainty). For the without-project alternative, the expected annual damages (EAD) were totaled for each study area reach to obtain the total without-project EAD under base year (2020) conditions. The number and type of structures that are damaged the annual exceedance probability events for the year 2020 under without-project conditions are shown in Table 6. It is assumed that the tunnel is functional up to the 1% AEP event, and therefore damages are shown at the 1% AEP frequency, but not at more frequent events.

Table 6. Total Economic Damage by Probability Events in 2020 ($1,000s)

Annual Exceedance Probability (AEP)	**Residential**	**Non-Residential**	**Total**
0.50 (2 yr)	-	-	-
0.20 (5 yr)	-	-	-
0.10 (10 yr)	-	-	-
0.04 (25 yr)	-	-	-
0.02 (50 yr)	-	-	-
0.01 (100 yr)	10,598	10,365	20,963
0.005 (200 yr)	11,811	11,882	23,693
0.002 (500 yr)	13,492	14,673	28,165

The total expected annual damages by damage category for the existing condition and with project condition measures are shown in Table 7. Both enlarging and construction new flood diversion tunnels reduce expected annual damages to below $10,000. A debris retention basin does not reduce expected annual damages relative to the existing condition, which improves the existing flood diversion system and construction.

Table 7. Expected Annual Damages by Damage Category ($1,000's)

Plan	**Vehicle**	**Commercial**	**Public**	**Residential**	**Total**
Without Project	88.28	132.02	432.25	247.29	899.84
Improve Existing Flood Diversion System	88.28	132.02	432.25	247.29	899.84
Enlarge Existing Flood Diversion System	0	3	5	2	10.00
Construct New Flood Diversion System	0	3	5	2	10.00
Debris Retention Basin	88.28	132.02	432.25	247.29	899.84

Relocate Infrastructure	88.28	132.02	412.25	232.62	865.17

Expected annual damages can also be presented as damages reduced, which is the opposite as Table 7. The expected annual damages reduced for each of the measures in Table 8. The probability of damages being reduced, exceeding 75%, 50%, and 25% thresholds, but this was not reported since the structure detail out table was utilized for some of the project measures.

Table 8. Expected Annual Damages Reduced by Measure ($1,000's)

Plan	**Total Without Project**	**Total With Project**	**Damages Reduced**
Without Project	899.84	899.84	0.00
Improve Existing Flood Diversion System	899.84	899.84	0.00
Enlarge Existing Flood Diversion System	899.84	10.00	889.84
Construct New Flood Diversion System	899.84	10.00	889.84
Debris Retention Basin	899.84	899.84	0.00
Relocate Infrastructure	899.84	865.17	34.67

3.4 Expected Annual Flood Fight Cost Reductions

The current design of the Lowell Creek Tunnel leads to discharge from the tunnel to flow past Lowell Point Road into Resurrection Bay. Since the tunnel has been completed, the City of Seward has built Lowell Point Road to connect the City of Seward with Lowell Point, which is a popular destination for recreational vehicles and campers. The only road leading to Lowell Point is the one that is impacted by outflows from Lowell Creek Tunnel. As a result, the City of Seward flood fights the outfall to maintain accessibility to Lowell Point and maintain a place for the outfall to dump. Without proper maintenance of the outfall, sediment would quickly deposit and lead to performance issues.

To estimate the costs of flood-fighting activities, three economists interviewed the City of Seward's Public Works Director and his team in the fall of 2019. The interview resulted in the ability to fill out a table that shows the amount of heavy machinery, human labor, fuel, and bridge repair costs that are associated with various frequency rain events. Flood fighting begins with as little as 3 inches of rain over 24 hours, which is expected to occur at least four times per year and results in approximately $40,000 of flood-fighting related costs for the City. The City also explained the maximum extent of flood-fighting efforts, which is limited by the amount of space the city can fit heavy machinery. The maximum flood fight effort is a 0.8 AEP event, which is expected to lead to close to $628,000 in flood fighting related costs for the City. The costs dramatically increase as the city must also pay for all of the sediment to be trucked away, which can take up to 7 days of constant loads after a flood event concludes.

Expected annual reductions in flood fight costs were calculated by computing the average annual value of flood fighting in the existing condition and under a condition where flood-fighting would only be required for events that exceed the tunnel capacity and overtop the diversion dam. The difference in average annual values between these conditions yielded average annual damage reduced to $556,000. Alternative 2 (improving the existing tunnel with a modified outfall) and Alternative 5 (debris retention basin) reduce sedimentation at the outfall of the tunnel enough to qualify for this benefit category. Calculations showing how this figure was quantified can be found in the Supplemental Tables section of the Economic Appendix.

4.0 OTHER SOCIAL EFFECTS (OSE) LIFE SAFETY CALCULATIONS

4.1 HEC-Lifesim Model Calculations

The HEC-LifeSim model was utilized to evaluate the potential for loss of life in the study area. Life Loss was aggregated at the study area level and was not broken down into reaches, as was conducted for the HEC-FDA modeling results. The HEC-LifeSim model contains both economic variables (first-floor elevation, structure and content values, and depth-damage relationships), and evacuation effectiveness variables (warning issuance delay, first alert warning, protective action initiation, hazard communication delay, submergence criteria, stability criteria, etc.). Each of the HEC-LifeSim assumptions previously listed is subject to uncertainty and can play a significant role in the HEC-LifeSim output. Each scenario was computed within the model, sampling values for each parameter from these distributions, until the model reached the specified amount of iterations, in this case, 1,000 resulting in an output distribution that represents the range of possible consequences for each scenario. More information and details about individual assumptions, model uncertainties, and computation processes can be found in Appendix D.

The HEC-LifeSim model computes loss of life for selected hydraulic scenarios. In the case of Lowell Creek, multiple hydraulic scenarios were run for Alternative 2, Alternative 3, and Alternative 4. These scenarios included the 10%, 1%, 0.01%, 0.001%, and 0.0000063% (Probable Maximum Flood (PMF)) AEP events. Further hydraulic scenarios were run for events where the diversion tunnel was blocked or for conditions where surge flow events were present. The HEC-LifeSim model results are organized using standardized incremental risk methodology, meaning the loss of life associated with hydraulic scenarios with an operational tunnel are subtracted from hydraulic scenarios with the tunnel is blocked.

4.2 The Life Safety Story

The Lowell Creek Dam's location relative to the town of Seward, Alaska, provides unique hydraulic and consequence modeling conditions. During the probable maximum flood (PMF), the diversion dam will be overtopped, and floodwaters will rapidly flow through a narrow canyon less than a quarter of a mile in length before reaching a group of structures that includes a hospital and elderly apartment building. If the PMF flood is combined with a surge release, floodwaters will reach the Lowell Canyon structures within minutes, supporting flood depths between 7-12 feet and velocities exceeding 16 feet per second. Of the 16 structures in the canyon, 14 are collapsed by the combined depths and velocity forces. As the flood wave exits the canyon, its depths and velocities remain destructive throughout its path along Jefferson Street, leading to several more collapsed structures before dissipating into Resurrection Bay.

If a structure collapses from floodwaters, it does not guarantee that there are fatalities within the model. The evacuation process that the HEC-LifeSim uses attempts to quantify human behavior by estimating when Seward will receive an evacuation warning and how households will react to such a warning. Historical flooding data from Seward has shown that water will pond behind the Lowell Creek Dam at an expedient rate, providing limited opportunities for emergency staff to identify the hazard and warn the town of Seward. As a result of these assumptions, the town of Seward has a chance to receive the warning, but is inundated before any successful town-wide evacuations can finish occurring. In HEC-LifeSim, Seward residents in structures that have not mobilized are considered to have sheltered in place. However, they are still subject to the limitations of the structure's story height or stability criteria (potential for collapse). Residents that have evacuated may find themselves in even worse conditions, given the rapid onset of life-threatening flows combined with the flood-prone position of being stuck in a car rather than sheltered within a building.

The alternatives presented within the Economic Appendix can limit the potential for life loss resulting from hydraulic scenarios that block the tunnel and/or overtop the dam. HEC-LifeSim has been run for the alternatives, and the reduction in incremental risk is presented along with traditional NED metrics such as net benefits.

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[redacted]

4.6 Average Annual Life Loss Results

The final life safety metric to be used to evaluate alternatives is average annual life loss (AALL). This metric takes into account the hazard, which includes the frequency of the hydraulic scenario, and performance, which includes how well the diversion dam will perform during the hydraulic scenario. [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

5.0 PROJECT COSTS

Construction Schedule. To compute interest during construction (IDC), the construction of the project alternatives is expected to begin in the year 2020. It will continue for one year for every measure except for enlarging the existing flood diversion system (Alternative 3A and 3B). For this measure, seasonal peak flows cannot be diverted. Therefore construction activities are limited to the winter months, and therefore construction must be prolonged over a period of 7 years.

Structural Costs. Structural cost estimates for the final array were developed by the Alaska District Cost Engineering Branch and were commensurate with a class 4 cost estimate. An abbreviated cost risk analysis was completed to determine the contingencies used for all structural measures.

Interest during construction was calculated for each of the structural alternatives and assumed the construction period as identified in the Construction Schedule section. Interest during construction was calculated using an end of year payment schedule and 2.75% discount rate.

Annual Project Costs. Life cycle cost estimates were provided for the nonstructural measures in FY20 price levels. The initial construction costs (first costs) and the schedule of expenditures were used to determine the interest during construction and gross investment cost at the end of the installation period (2020). The FY 2020 Federal interest rate of 2.75 percent was used to discount the costs to the base year and then amortize the costs over the 50-year period of analysis.

Operations, maintenance, relocations, rehabilitation, and repair (OMRR&R) costs associated with the final array of measures was computed for each alternative. Alternative 2, 3, and 4 are assumed to be maintained and rehabilitated based on historic costs dating back to the tunnel’s construction. Additional maintenance costs were added to dredge Resurrection Bay, where the proposed extended tunnel outfall will outlet sediment. The maintenance included for Alternative 5 includes removing sediment build up from the retention basin. There are no costs for any alternative associated with wetland mitigation, real estate, or cultural resources.

A breakdown of costs associated with each of the project measures is shown in Table 16.

Table 16. Summary of Costs for Structural Measures ($)

	Alternative 2	**Alternative 3A**	**Alternative 3B**	**Alterative 4A**	**Alterative 4B**	**Alterative 5**
	Improve Existing Flood Diversion System	Enlarge Existing Flood Diversion System – 18' Tunnel	Enlarge Existing Flood Diversion System – 24' Tunnel	Construct New Flood Diversion System – 18' Tunnel	Construct New Flood Diversion System – 24' Tunnel	Debris Retention Basin
Construction First Cost	53,061,221	157,282,815	314,846,026	122,928,162	172,606,683	15,800,000
Interest During Construction	730,000	13,587,000	27,199,000	1,690,000	2,373,000	436,000
Total Cost	53,791,221	170,869,815	342,045,026	124,618,162	174,979,683	16,236,000
Average Annual Construction	1,992,476	6,329,175	12,669,662	4,615,971	6,481,408	601,396
Average Annual OMRR&R	916,000	1,087,000	1,216,000	1,152,000	1,290,000	692,000
Total Average Annual Cost	2,908,476	7,416,175	13,885,662	5,767,971	7,771,408	1,293,396

6.0 RESULTS OF THE ECONOMIC ANALYSIS

6.1 NET BENEFIT ANALYSIS

Calculation of Net Benefits. The expected annual benefits attributable to the final array of alternatives were compared to the annual costs to develop a benefit-to-cost ratio for the measures. The net benefits for the measures were calculated by subtracting the annual costs from the expected annual benefits. The net benefits were used to determine the economic justification of the project measures. In addition to net benefits, average annual life loss reduced, and total life loss reduced were displayed to show a comprehensive representation of project benefits.

Net benefit calculations for the with-project condition were computed differently by alternative. Alternatives 3 and 4 assumed that the with project condition would be able to pass highly infrequent events, and therefore limited residual damages remained. Alternatives 2 and 5 do not reduce structural damages downstream of the diversion dam and therefore were not run through HEC-FDA as a with project condition. The comparison of the net benefits for each of the alternatives is shown in Table 17.

Table 17. Structural Economic Benefits (Damages Reduced)

	Alternative 2	**Alternative 3A**	**Alternative 3B**	**Alterative 4A**	**Alterative 4B**	**Alterative 5**
Damage Category	Improve Existing Flood Diversion System	Enlarge Existing Flood Diversion System – 18' Tunnel	Enlarge Existing Flood Diversion System – 24' Tunnel	Construct New Flood Diversion System – 18' Tunnel	Construct New Flood Diversion System – 24' Tunnel	Debris Retention Basin
Structural	-	399,066	399,066	399,066	399,066	-
Contents	-	436,424	436,424	436,424	436,424	-
Vehicle	-	36,843	36,843	36,843	36,843	-
Debris Removal	-	27,508	27,508	27,508	27,508	-
Flood Fight Costs Avoided	556,000	556,000	556,000	556,000	556,000	556,000
Total Average Annual Benefits	556,000	1,455,840	1,455,840	1,455,840	1,455,840	556,000
Total Average Annual Cost	2,908,476	7,416,175	13,885,662	5,767,971	7,771,408	1,293,396
Net Benefits	(2,352,476)	(5,960,335)	(12,429,822)	(4,312,131)	(6,315,568)	(737,396)
BCR	0.19	0.20	0.10	0.25	0.19	0.43

Table 18 displays the tentatively selected plan (TSP) for the alternative ~~that reasonably maximizes net benefits~~. The TSP would reduce flood damage and the potential for loss of life for a total of 250 structures.

Table 18. Economic Benefits of the Tentatively Selected Plan (TSP)

Alternative 4A (TSP)	Expected Annual Benefits and Costs
Structure, Contents, Vehicles, and Debris Removal	$899,840
Flood Fight Costs Avoided	$556,000
Total Annual Benefits	$1,455,840
First Costs	$122,928,162
Interest During Construction	$1,690,000
Annual Operation & Maintenance Costs	$1,152,000
Total Annual Costs	$7,771,408
B/C Ratio	0.25
Expected Annual Net Benefits	($4,312,131)

[redacted]

[redacted]

6.2 RISK ANALYSIS

The risk analysis is a section of the report that discusses the risk and uncertainty associated with the HEC-FDA model and the economic benefits. The HEC-FDA model was utilized for the existing condition and with project alternatives to an extent previously described in Section 5.1.

6.3 Benefit Exceedance Probability Relationship

Based on the information and inputs available at this point in the study, there is a high likelihood that the net benefits associated with the structural alternatives presented will remain negative. The cost estimates have been conservative, combined with the fact that the alternatives with the highest reduction in damages assume that nearly all damage in rare frequency events will be fully mitigated.

The exception to this statement is that the sedimentation issue that the study area experiences is currently underrepresented in the economic analysis. The risks that remain from this is that proper quantification of the sedimentation issue could lead to additional NED benefits. A sensitivity analysis could be performed using existing depth-damage relationships to determine what escalation of damages would have to occur to justify one of the alternatives that reduce structural damages.

An additional risk not quantified is the effects of climate change and sea-level rise, which are currently not addressed by the hydraulic engineering team. Using future year hydraulics may show a significant increase in stages within the watershed, and thereby increasing structural damages.

6.4 Residual Risk

The flood risk that remains in the floodplain after the proposed alternatives are implemented is known as the residual flood risk. For Lowell Creek, the residual risk depends on the alternative selected. For the TSP, Alternative 4A, a risk to life safety is limited to extremely remote events that exceed the Probable Maximum Flood (PMF) event. The risk to infrastructure and structural damage is also greatly reduced and would only occur in events that the tunnel or diversion dam did not perform as designed. Incorporation of a fragility curve in HEC-FDA would be one way to quantify the residual risk associated with infrastructure that may not perform as designed.

6.5 Compliance with Section 308 of WRDA 1990

Section 308 of the Water Resource Development Act (WRDA) 1990 limits structures built or substantially improved after July 1, 1991, in designated floodplains not elevated to the 1% AEP flood elevation from being included in the benefit base of the economic analysis. The economic analysis complies with Section 308 of WRDA 1990 since it includes no structures that have been built or substantially improved in the designated floodplain. Reach 2, 3, 4, 5, and 6 are all outside of the designated floodplain. Portions of reach 1 are inside the designated floodplain, but the only structures impacted are temporary recreational vehicles and mobile homes that are not designated as a built structure. [redacted]

[redacted]

6.6 Surge flow sensitivity analysis

The current condition of the economic analysis for Lowell Creek assumes that there is no potential for surge flows within the HEC-FDA output that computes average annual damages (AAD). To model surge flows, the economics team examined the joint probability for surge flow defined by two variables with the potential to change:

1. Stage increase as a result of surge flow
2. The associated decrease in the frequency of the surge flows occurring

The first condition was incorporated in HEC-FDA by overlaying the structure inventory in GIS with the max depth grid for the 10% (10YR) AEP frequency for the with and without surge conditions. The flood depths were extracted to each structure to determine what the change in flood stage would be with and without the surge flows. This same procedure was followed for the 1% (100YR) AEP frequency. Increases in flood stage for the 1% (100YR) AEP frequency averaged between 0.5 and 1.5 feet depending on the location of flooding.

To independently model the first condition, the water surface profiles for each structure were modified as if the increased stage associated with surge flow were the existing condition with no change to the frequency of the surge flow occurring. Isolating increased stages to represent surge flow resulted in a condition where the Lowell Creek diversion tunnel could no longer retain flows from events exceeding the 10% (10YR) AEP frequency. This change in modeling conditions leads to a spike in average annual damages from $899,840 (existing condition) to $8,193,360 (surge condition with no frequency Δ). The order of magnitude jump in average annual damages occurred due to highly frequent flood events (10%, 4%, 2%, etc.) now being able to inundate the town of Seward. Where in events without surge, these frequencies would ordinarily be contained by the Lowell Creek diversion tunnel.

Damages associated with the first condition (surge condition with no frequency Δ) were high enough to justify structural alternatives. Therefore, a decrease in frequency associated with surge flows needed to be added to the HEC-FDA model to account for the likelihood of the flows occurring. Exact surge flow-frequencies could not be incorporated into HEC-FDA. Therefore, the second modeling condition assumed the joint probability of a surge flow during a 10% (10YR) AEP frequency event could not occur at a rate more frequent than a 1% (100YR) AEP frequency.

To model the second condition (surge condition with frequency Δ), the HEC-FDA model was modified to change the Lowell Creek diversion tunnel capacity to be able to pass surge flows up to the 1% (100YR) AEP frequency event. By adjusting the stage-frequency curve, the HEC-FDA model resulted in a condition where damages associated with surge flow events can only occur at frequencies larger than the 1% (100YR AEP) frequency event. This change in modeling conditions resulted in a smaller increase in average annual damages from $899,840 (existing condition) to $1,021,150 (surge condition with frequency Δ).

Both conditions are visually explained in Figure 5. The flood stage on the Y-axis and flows frequency on the X-axis (defined as the return interval, 10-YR for 10% AEP, etc.) is shown in Figure 5. The blue line represents the existing condition, where there are no increases in stage and, therefore, no additional average annual damages (AAD). The red line represents the first surge condition with an increase in stage from surge flow, but no change in frequency. As shown in the figure, nearly all of the increased average annual damages comes from flows occurring before the 1% (100YR AEP) frequency (red box). The dashed black line represents the second surge condition where an increase in stage from surge flow, and a decrease in frequency only leads to an increase in average annual damages for events less frequent than the 1% (100YR AEP) frequency (block box).

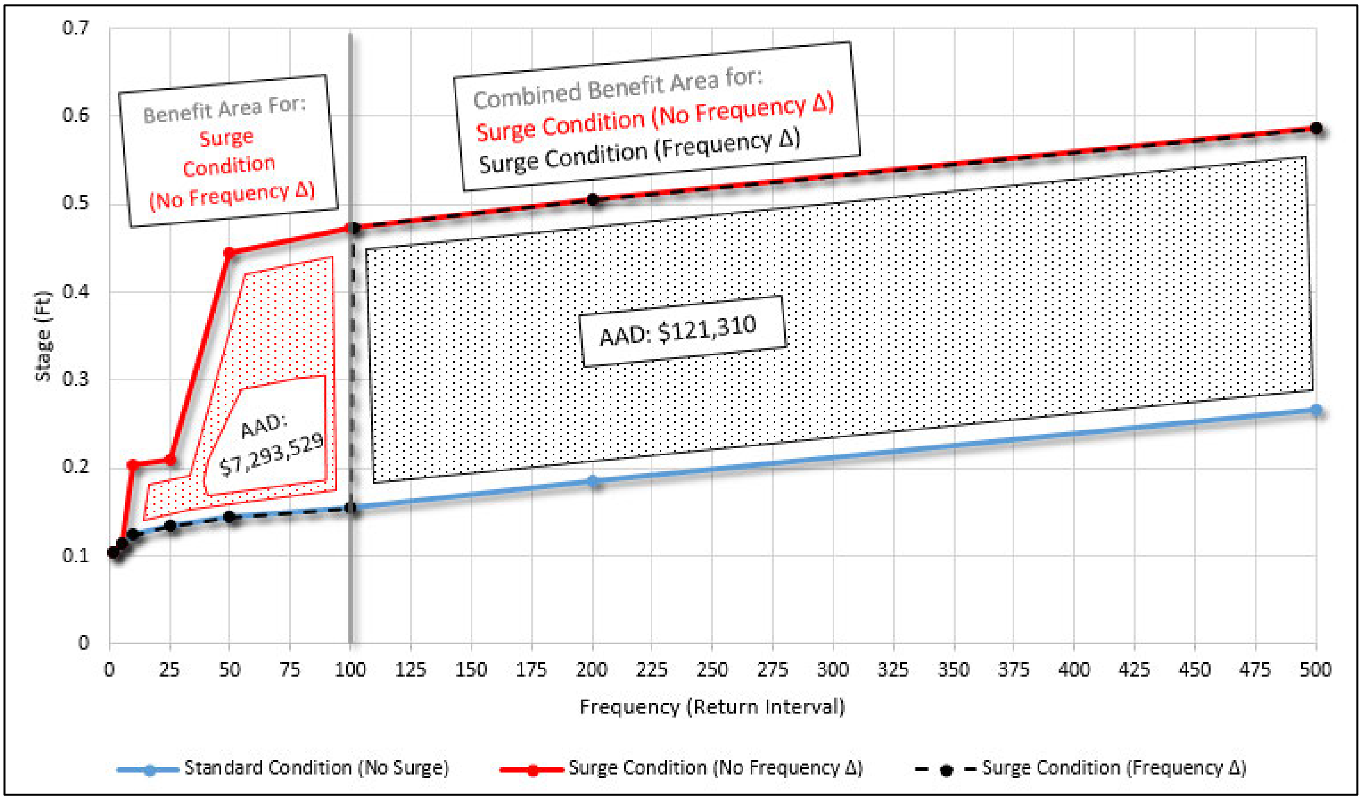

Figure 5. Surge Flow Stage-Frequency Curve

7.0 SUPPLEMENTAL TABLES

Supplemental Table 1. Lowell Creek Feasibility Study. Depth – Damage Relationships for Structures, Contents, and Vehicles, including Debris Removal.

Residential - Oreswbsmt
One Story, With Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-8.0	0.0	0.0
-7.0	0.7	1.3
-6.0	0.8	1.1
-5.0	2.4	0.9
-4.0	5.2	0.9
-3.0	9.0	0.9
-2.0	13.8	0.9
-1.0	19.4	0.8
0.0	25.5	0.9
1.0	32.0	1.0
2.0	38.7	1.1
3.0	45.5	1.4
4.0	52.2	1.6
5.0	58.6	1.9
6.0	64.5	2.1
7.0	69.8	2.4
8.0	74.2	2.5
9.0	77.7	2.7
10.0	80.1	2.8
11.0	81.1	2.9

Residential - Treswbsmt
Two Story, With Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-9.0	0.0	0.0
-8.0	1.7	2.7
-7.0	1.7	2.7
-6.0	1.9	2.1
-5.0	2.9	1.8
-4.0	4.7	1.7
-3.0	7.2	1.6
-2.0	10.2	1.5
-1.0	13.9	1.4
0.0	17.9	1.3
1.0	22.3	1.4
2.0	27.0	1.5
3.0	31.9	1.8
4.0	36.9	2.0
5.0	41.9	2.3
6.0	46.9	2.6
7.0	51.8	2.9
8.0	56.4	3.1
9.0	60.8	3.4
10.0	64.8	3.7
11.0	68.4	4.2
12.0	71.4	5.0
13.0	73.7	6.2
14.0	75.4	7.8

Residential - Oreswoutbsmt
One Story, No Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-2.0	0.0	0.0
-1.0	2.5	2.7
0.0	13.4	2.0
1.0	23.3	1.6
2.0	32.1	1.6
3.0	40.1	1.8
4.0	47.1	1.9
5.0	53.2	2.0
6.0	58.6	2.1
7.0	63.2	2.2
8.0	67.2	2.3
9.0	70.5	2.4
10.0	73.2	2.7
11.0	75.4	3.0
12.0	77.2	3.3
13.0	78.5	3.7
14.0	79.5	4.1
15.0	80.2	4.5
16.0	80.7	4.9

Residential - Treswoutbsmt
Two Story, No Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-2.0	0.0	0.0
-1.0	3.0	4.1
0.0	9.3	3.4
1.0	15.2	3.0
2.0	20.9	2.8
3.0	26.3	2.9
4.0	31.4	3.2
5.0	36.2	3.4
6.0	40.7	3.7
7.0	44.9	3.9
8.0	48.8	4.0
9.0	52.4	4.1
10.0	55.7	4.2
11.0	58.7	4.2
12.0	61.4	4.2
13.0	63.8	4.2
14.0	65.9	4.3
15.0	67.7	4.6
16.0	69.2	5.0

Depth in Structure	Contents Percent Damage	Contents Standard Deviation
-9.0	0.0	0.0
-8.0	0.1	1.6
-7.0	0.8	1.2
-6.0	2.1	0.9
-5.0	3.7	0.8
-4.0	5.7	0.8
-3.0	8.0	0.8
-2.0	10.5	0.7
-1.0	13.2	0.7
0.0	16.0	0.7
1.0	18.9	0.8
2.0	21.8	1.0
3.0	24.7	1.2
4.0	27.4	1.4
5.0	30.0	1.6
6.0	32.4	1.8
7.0	34.5	2.0
8.0	36.3	2.1
9.0	37.7	2.3
10.0	38.6	2.4
11.0	39.1	2.5

Depth in Structure	Contents Percent Damage	Contents Standard Deviation
-8.0	0.0	0.0
-7.0	1.0	2.3
-6.0	2.3	1.8
-5.0	3.7	1.5
-4.0	5.2	1.4
-3.0	6.8	1.3
-2.0	8.4	1.2
-1.0	10.1	1.1
0.0	11.9	1.1
1.0	13.8	1.1
2.0	15.7	1.2
3.0	17.7	1.4
4.0	19.8	1.7
5.0	22.0	1.9
6.0	24.3	2.2
7.0	26.7	2.4
8.0	29.1	2.6
9.0	31.7	2.8
10.0	34.4	3.0
11.0	37.2	3.5
12.0	40.0	4.1
13.0	43.0	5.1
14.0	46.1	6.4
15.0	49.3	8.1

Depth in Structure	Contents Percent Damage	Contents Standard Deviation
-2.0	0.0	0.0
-1.0	2.4	2.1
0.0	8.1	1.5
1.0	13.3	1.2
2.0	17.9	1.2
3.0	22.0	1.4
4.0	25.7	1.5
5.0	28.8	1.6
6.0	31.5	1.6
7.0	33.8	1.7
8.0	35.7	1.8
9.0	37.2	1.9
10.0	38.4	2.1
11.0	39.2	2.3
12.0	39.7	2.6
13.0	40.0	2.9
14.0	40.0	3.2
15.0	40.0	3.5

Depth in Structure	Contents Percent Damage	Contents Standard Deviation
-2.0	0.0	0.0
-1.0	1.0	3.5
0.0	5.0	2.9
1.0	8.7	2.6
2.0	12.2	2.5
3.0	15.5	2.5
4.0	18.5	2.7
5.0	21.3	3.0
6.0	23.9	3.2
7.0	26.3	3.3
8.0	28.4	3.4
9.0	30.3	3.5
10.0	32.0	3.5
11.0	33.4	3.5
12.0	34.7	3.5
13.0	35.6	3.5
14.0	36.4	3.6
15.0	36.9	3.8
16.0	37.2	4.2

Debris Depth	Debris Percent Damage	Debris Variance Lower	Debris Variance Upper
0.5	5.8	5.2	6.4
1.0	7.5	6.8	8.3
2.0	9.1	8.2	10.0
3.0	10.7	9.6	11.8
4.0	12.4	11.2	13.6
5.0	14.0	12.6	15.4
6.0	15.7	14.1	17.3
7.0	17.3	15.6	19.0

Note: the same Debris Depth-Damage Relationships were used for all residential structures

Supplemental Table 2. Lowell Creek Feasibility Study. Depth – Damage Relationships for Structures, Contents, and Vehicles.

Residential - Apartment
One Story, No Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-1.0	0 0	0.0
0.0	1 0	0.5
1.0	12 5	1.6
2.0	20.4	1.6
3.0	25 9	1.8
4.0	31.7	1.9
5.0	33 5	2.0
6.0	37 5	2.1
7.0	39.4	2.2
8.0	42 2	2.4
9.0	45 0	2.4

Public - Pub2
One Story, No Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-8.0	0.0	0 0
-1.0	0.0	0 0
0.0	0.0	0 0
1.0	10.0	2 0
2.0	14.0	2 8
3.0	26.0	5 2
5.0	29.0	5 8
10.0	46.0	9 2
15.0	50.0	10 0

Public - School
One Story, No Basement

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-8 0	0.0	0 0
-1 0	0.4	0.0
0 0	0.6	0.0
1 0	15.3	0 5
2 0	26.1	0.7
3 0	33.0	1 3
5 0	44.0	1.4
10 0	60.0	2 3
15 0	75.0	2 5

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-1.0	0 0	0.0
0.0	0 0	0.5
1.0	21.7	2.1
2.0	30.4	3.8
3.0	39 0	4.4
4.0	45 0	5.1
5.0	47 9	5.7
6.0	51 9	6.3
7.0	55.7	6.7
8.0	59 3	7.1
9.0	60.6	7.6

Depth in Structure	Structure Percent Damage	Structure Standard Deviation
-8.0	0 0	0 0
-1.0	0.0	0 0
0.0	0.0	0 0
1.0	33 0	6.6
2.0	40 0	8 0
3.0	50 0	10 0
5.0	50 0	10 0
10.0	50 0	10 0
15.0	50 0	10 0

Depth in Structure	Contents Lower Percent	Contents Percent Damage
-8 0	0.0	0 0
-1 0	0.0	0 0
0 0	0.0	0 0
1 0	25.5	0.1
2.0	39.0	0.1
3.0	50.0	0 2
5.0	62.0	0 2
10.0	80.0	0.4
15.0	100.0	0.4

Supplemental Table 3. Lowell Creek Feasibility Study. Depth-Damage Relationships for Structures, Contents, and Vehicles.

Residential - Mobile Home
One Story, No Basement

Depth in Structure	Structure Lower Percent	Structure Percent Damage	Structure Higher Percent
-2.0	0 0	0.0	0.0
-1.0	1.1	0.0	9.9
0.0	17 2	10.2	38.9
1.0	45.4	40.5	49.4
2.0	49 2	44.6	53.8
3.0	49 2	44.6	53.8
4.0	51.7	47.2	86.8
5.0	57.1	52.7	56.2
6.0	57 9	53.5	61.5
7.0	57 9	53.5	62.3
8.0	66 3	62.2	62.3
9.0	66 3	62.2	70.4
10.0	66 3	62.2	70.4
11.0	66 3	62.2	70.4
12.0	66 3	62.2	70.4
13.0	66 3	62.2	70.4
14.0	66 3	62.2	70.4
15.0	66 3	62 2	70.4

Commercial - Retail
One Story, No Basement

Depth in Structure	Structure Lower Percent	Structure Percent Damage	Structure Higher Percent
-2.0	0.0	0 0	0.0
-1.0	0.0	0 0	0.0
0.0	0.2	0.1	0.3
1.0	7.6	5.7	9.5
2.0	8.3	6 2	10.4
3.0	11.4	8.6	14.2
4.0	15.0	12 8	17.2
5.0	15.8	13.4	18.2
6.0	15.8	13.4	18.2
7.0	15.8	13.4	18.2
8.0	22.2	18 9	25.5
9.0	26.6	22.6	30.1
10.0	28.7	24.4	30.1
11.0	28.7	27 3	30.1
12.0	28.7	27 3	30.1
13.0	32.4	30.1	34.0
14.0	39.7	37.7	41.7
15.0	41.2	39.1	43.3

Auto
Vehicles

Depth in Structure	Structure Percent Damage	Structure Percent Damage	Structure Higher Percent
0 0	0.0	0 0	0.0
0 5	0.0	0 0	0.0
1 0	100.0	100 0	100 0
1 5	100.0	100 0	100 0
2 0	100.0	100 0	100 0
3 0	100.0	100 0	100 0
4 0	100.0	100 0	100 0
5 0	100.0	100.0	100 0
6 0	100.0	100.0	100 0
7 0	100.0	100.0	100 0
8 0	100.0	100.0	100 0
9 0	100.0	100.0	100 0
10 0	100.0	100.0	100 0
11 0	100.0	100.0	100 0
12 0	100.0	100.0	100 0
13 0	100.0	100.0	100 0
14 0	100.0	100.0	100 0
15 0	100.0	100.0	100 0
16 0	100.0	100.0	100 0

Depth in Structure	Contents Lower Percent	Contents Percent Damage	Contents Higher Percent
-2.0	0 0	0 0	0.0
-1.0	0 0	0 0	0.0
0.0	0.0	0 0	0.0
1.0	38.8	26.7	49.7
2.0	53.7	34 2	61.4
3.0	75.2	43.4	86.8
4.0	77.2	57.1	86.8
5.0	84.5	66 3	90.9
6.0	84.5	67.4	90.9
7.0	84.5	67.4	90.9
8.0	84.5	67.4	90.9
9.0	84.5	67.4	90.9
10.0	84.5	76 3	90.9
11.0	84.5	76 3	90.9
12.0	84.5	76 3	90.9
13.0	84.5	76 3	90.9
14.0	84.5	76 3	90.9
15.0	84.5	76 3	90.9

Depth in Structure	Contents Lower Percent	Contents Percent Damage	Contents Higher Percent
-2.0	0.0	0 0	0.0
-1.0	0.0	0 0	0.0
0 0	0.0	0 0	0.0
1 0	35.3	15 3	55.3
2 0	48.2	28 2	68.2
3 0	54.1	34.1	74.1
4 0	54.3	34 3	74.3
5 0	54.8	34 8	74.8
6 0	54.8	34 8	74.8
7 0	54.8	34 8	74.8
8 0	54.8	34 8	74.8
9 0	54.8	34 8	74.8
10 0	98.9	78 9	100.0
11 0	99.9	79 9	100.0
12 0	100.0	80 0	100.0
13 0	100.0	80 0	100.0
14 0	100.0	80 0	100.0
15 0	100.0	80 0	100.0

Supplemental Table 4. Lowell Creek Feasibility Study. Flood Flight Average Annual Damages Reduced.

Flood Fight Without Project Condition		
YEAR	FREQUENCY	VALUE
	-	627,800
500	0.002	627,800
250	0.004	627,800
100	0.010	627,800
50	0.020	627,800
10	0.100	627,800
5	0.200	627,800
1.25	0.800	627,800
1.11	0.900	285,480
1.02	0.980	105,800
1.01	0.990	61,860
0.25	4.000	40,140
AVERAGE ANNUAL VALUE =		**718,000**

Flood Fight With Project Condition		
YEAR	FREQUENCY	VALUE
	-	627,800
500	0.002	627,800
250	0.004	627,800
100	0.010	627,800
50	0.020	40,140
10	0.100	40,140
5	0.200	40,140
1.25	0.800	40,140
1.11	0.900	40,140
1.02	0.980	40,140
1.01	0.990	40,140
0.25	4.000	40,140
AVERAGE ANNUAL VALUE =		**169,000**
AA DAMAGES REDUCED =		**549,000**