BENEFIT COST ANALYSIS

1. Overview of Economic (Benefit/Cost) Analysis:

This memorandum describes the methods employed in the valuation of flood damage to existing critical resources during extreme tidal events and provides the results of the Economic (Benefit/Cost) Analysis for the proposed projects, completed by Phillip King PhD. A benefit/cost analysis (BCA) is a technique for monetizing select benefits and avoided costs of a project and weighing these benefits against the costs of a project. In this analysis of the Eureka Slough hydrographic area, the primary monetized benefits consist of avoided costs. In particular, the damages caused by flooding and delays or extended travel by motorists that are avoided by implementing adaptation projects. The primary costs are construction costs. Construction costs include the planning, engineering, permitting, materials, and labor cost of implementing projects, such as elevating levees and constructing marsh plains. Operation and maintenance (O&M) costs once the projects are constructed were considered but not directly included in the analyses as these costs are not anticipated to affect the conclusions.

The selected adaptation projects exhibit multiple benefits. Many of these benefits are difficult to monetize due to limited documentation and methods, available information, uncertain futures, regional factors, and inherent differences in defining the value of resources. When feasible, given the scope of this study and available information, other benefits are monetized. Otherwise, these benefits are recognized conceptually and not explicitly included in the benefit/cost monetization.

Damage costs are also limited in scope and do not capture the full breadth of indirect and direct costs and economic impacts incurred by property owners, facility managers, and the local and regional community. Many damages are recognized conceptually and not explicitly included in the benefit/cost monetization.

This economic (benefit/cost) analysis provides an accounting framework for evaluating the benefits and avoided damages of adaptation projects that may be refined as additional information and methods become available.

2. Methodology for Estimating Flood Damage

This section describes the methods used in valuing anticipated damages to critical resources within the Study Area resulting from tidal flooding. The Hazard Scenarios provide a summary of anticipated impacts to critical resources within each cell during a range of extreme tidal and fluvial events. For the purpose of this economic assessment, a range of tidal still water levels were considered to assess flood damage with and without Projects 1, 3 and 4 (Table 1). As presented in the Summary of Hazard Scenarios, the recurrence interval of a specific water level will be reduced (become more frequent), with sea level rise. Project 2 was analyzed based on total water levels, that are comprised of the combined effect and recurrence of tidal still water and, wind and waves, with and without project implementation (Table 2).

Table 1. Tidal still water elevations considered for Projects 1, 3 and 4

Tidal Still Water Elevation (Feet NAVD)	Recurrence 5-yr	100-yr	Flood Characteristics
9.7	Baseline	N/A	Similar to typical winter saturated conditions.
9.9	+0.2 ft SLR	N/A	Limited levee overtopping. Shallow flooding of lowest elevations. Developed areas typically unaffected.
10.3	+0.6 ft SLR	N/A	Extensive overtopping of rail prism. Closure of Highway 101 southbound. Shallow flooding of lowest elevations.
10.6	+0.9 ft SLR	Baseline	Widespread overtopping of levees and flooding. Closure of Highway 101.
11.6	+1.9 ft SLR	+1 ft SLR	Widespread overtopping of levees and flooding. High potential for levee failure. Closure of Highway 101 southbound.
12.6	+2.9 ft SLR	+2 ft SLR	Widespread overtopping of levees and several feet of flooding. High potential for levee failure. Closure of Highway 101 and alternate routes.
13.6	+3.9 ft SLR	+3 ft SLR	

Table 2. Total water levels and wave overtopping characteristics for elevation rail prism for Project 2

Combined Tidal Still Water, Wind, and Waves (Feet NAVD)	Recurrence 5-10 yr	Average Wave Overtopping Rate (cfs/lft)
10.3	Baseline	0.25
11.3	+1 ft SLR	1.0
12.3	+2 ft SLR	1.25*
13.3	+3 ft SLR	1.25*

*At water levels above 11.5 feet, still water overtopping occurs and average wave overtopping rates reach a maximum.

Flood damage to the following critical resources was evaluated either quantitatively or qualitatively based on available information, impacts, and significance.

Land Use by Parcel

- Structures (residential and commercial)

- Open Space and Agricultural Land

Road Use and Damage

Shoreline Infrastructure (Levees or Rail Prism)

Public Trail Usage and Damage

Utility Use and Disruption

Other Economic Impacts

i. Land Use Valuation by Parcel

For this analysis, critical resources or assets were examined in the Study Area for vulnerability to damage from potential flooding that could be ameliorated by improving shoreline protection. The assets at risk comprise both public and privately owned property including land and structures (e.g., buildings). To value public and private property, this analysis used the Humboldt County parcel data, which has each property's location, size, shape and boundaries, as well as the zoning and use designation (e.g., commercial, residential, agricultural, public, etc.). This parcel data also includes "improvements" to property which are typically buildings and other structures. Most private parcels are subject to property tax and hence are assessed by the County. These assessments quantify valuations for the land and improvements; our analysis adjusts these property tax assessments into 2020 market value.[1]

ii. Structure Damage and Replacement Valuation of Commercial and Residential Parcels

To estimate flooding damages to structures, this study used a standard method of applying US Army Corps of Engineers as well as the Federal Emergency Management Agency (FEMA) Flood Depth Damage Curves.[2] The "curves" are expressed as a proportion or percentage of the total value of a structure (obtained from updated parcel data for "improvements") and the depth of flooding. Table 3 below illustrates a typical depth damage curve. Note that damages can exceed 100% (damage > 1). This occurs when the structure has no value after flooding and a cost to remove the debris is required. Commercial property, such as that on Jacobs Avenue generally have higher percentages of damage and removal costs compared to residential structures.

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[1] California's Proposition 13 limits any increase in assessed value to 2% a year, whereas in many years the increase has exceeded 2%; if a property is sold the assessment reverts to whatever the market value is at the time of sale. Fortunately, the parcel data includes this information. Housing Price Index was developed which allows us adjustments to be made based on the last sales date of the property.

[2] See USACE (U.S. Army Corps of Engineers). 2003. Economic Guidance Memorandum (EGM) 04-01, Generic Depth-Damage Relationships. http://www.usace.army.mil/CECW/PlanningCOP/Documents/egms/egm04-01.pdf

Table 3. USACE/FEMA Depth Damage Curve[3]

Depth (Feet)	Single Family Residences	Multi-Family Residences	Commercial Property
0	0.00	0.00	0
0.1	0.22	0.13	0.01
1	0.37	0.27	0.38
2	0.50	0.36	0.74
3	0.62	0.45	0.96
4	0.73	0.56	1.08
5	0.82	0.63	1.13
6	0.90	0.69	1.17
7	0.97	0.74	1.17
8	1.03	0.78	1.21
9	1.08	0.81	1.28
10	1.12	0.84	1.28
11	1.15	0.88	1.28
12	1.17	0.92	1.28
13	1.19	0.98	1.28
14	1.20	1.00	1.28
15	1.20	1.01	1.28
16	1.21	1.01	1.28

iii. Land Valuation of Open Space and Agricultural Parcels

This study valued all undeveloped, open space land, not identified as commercial or residential land use, equivalent to land used for grazing cattle at a current market value of $350/Acre/year.[4] The analysis assumed that flooding would interrupt the grazing for approximately one month, or approximately 10% of a year associated with each flood event and any damaged or failed levees would be rehabilitated to current conditions to prevent long-periods of salt-water intrusion that could permanently impact the productivity. The sensitivity of this valuation was explored and varying this assumption did not meaningfully change results.

Over time more frequent tidal flooding and saltwater intrusion may transform this landscape and make cattle grazing or other agricultural activities less valuable while other activities or ecosystem services (e.g., tidal marsh restoration) may become more valuable. This transformation was not accounted for in this study due to the limited scope of this project and limited, regionally significant information available.

[3] http://www.usace.army.mil/CECW/PlanningCOP/Documents/egms/egm04-01.pdf.

[4] Source: Humboldt County Resource Conservation District.

iv. Road Use and Damage Valuation

Flooding of roadways may result in clean up and reconstruction costs to roadway owners, as well as delay and detour costs to users. Roadways affected by flooding include County, City, and State facilities and affect individual residences, business areas, local commuters, and regional travel.

Standard cost estimating methods for loss of service include additional vehicle mileage traveled and detour time. The FEMA Standard Values for Loss of Service for Roads/Bridges, utilized in FEMA's BCA toolkit use a rate of $38.15 per vehicle per hour for Vehicle Delay Detour Time and the current Federal Mileage Rate for vehicle delay mileage. The Caltrans Cal-B/C V6.0 Sketch[5] uses a rate of $18.95 per vehicle per hour (weighted average for automobiles and trucks), among other parameters and values depending on available information and assumptions. The applicability of these models to the Study Area is limited, as few alternative routes are available at the higher water levels and people's behavior is likely to change in the event that the roadway is flooded on a regular basis (e.g., many trips can be delayed until flooding subsides). Preliminary estimates, using the above models and limited traffic flow information, result in a cost of $10,000 to $20,000 to roadway users during shallow flooding events and limited roadway closures. Additional costs increase significantly, to $2 to $10 million if all vehicles were required to travel an additional 190 miles and 5 hours inland on major roadways or wait until floodwater recede and safe travel conditions are restored. For the purposes of this analysis, roadway use was valued assuming all vehicles utilize a detour route, costing users the federal mileage rate, and the vehicle delay weighted average rate of $18.95. This approach results in a cost of $108 in mileage per vehicle and $95 for the 5-hour detour when all access routes are closed and the 187-mile detour is required. For smaller events, when alternate local routes are available, the cost to users is much less, with less than $3 for additional mileage and time.

Damage to roadways in the Study Area, due to flooding, is not well documented. A review of Caltrans damage assessment forms did not show significant cost requests for roadway damages following the January 31, 2005 storm event that closed the Highway 101 southbound lanes. Damage due to still water flooding is not well-defined in common engineering design manuals reviewed for this project. Damage due to wave overtopping is defined in the Coastal Engineering Manual[6] and EurOtop 2018[7] based on discharge per linear foot. Average discharge and associated damage for wave events and shoreline geometry utilize results from predicted overtopping of the bay shoreline, over the rail prism and future trail, as reported in ESA 2018[8]. However, the intensity and duration of flow across roadways, resulting in damage, requires more detailed methods than what were completed for this planning study and therefore damages to roadways due to flooding,

[5] See https://dot.ca.gov/programs/transportation-planning/economics-data-management/transportation-economics for a more detailed overview.

[6] US Army Corps of Engineers, Coastal Engineering Manual Part VI, Table VI-5-6, April 30 2002

[7] See www.overtopping-manual.com, EurOtop Manual on wave overtopping of sea defenses and related structures, Second Edition 2018.

[8] See ESA, Humboldt Bay Trail South Sea Level Rise Vulnerability and Adaptation Report, June 2018

while expected, were not included. These damage costs could be significant and warrant further analysis in a future study to get a more complete assessment of potential flooding impacts.

v. Shoreline Infrastructure (Levees) Valuation

Levees along the shoreline protect much of the Study Area from daily tidal flooding. Overtopping of these shoreline structures could result in erosion and eventual failure, requiring reconstruction. As used in the Hazard Scenarios, a screening level estimate of levee failure was characterized as overtopping exceeding 1 foot of depth and 2 hours in duration (USBR, 2017). Reconstruction cost was estimated to be $1,500,000 per mile ($284/lft) based on Delta Stewardship Council's estimate for USACE emergency assistance under PL 84-99 during flood event (DSC, 2015). Damage due to wave overtopping along the bay utilized the tolerable overtopping values reported in the Coastal Engineering Manual, EurOtop 2018 and average discharge and associated damage for wave events and shoreline geometry presented in ESA 2018.

vi. Utility Use and Disruption

This analysis also considered potential impacts to disruptions of sewer, water, electrical and gas lines but these were deemed to be insignificant in comparison to other costs. Underground utilities in the project area are subject to saturated soil conditions, especially during typical winter months, when the ground water table is elevated. Flooded conditions do not significantly differ from saturated ground conditions and these utilities are designed to maintain operations year round. Although more significant, deeper flooding could result diminish the effectiveness of facilities such as sewer pump stations, resulting in potential overflows, users at higher elevations would still be able to use their sewer facilities. Environmental damages and fines due to overflows vary significantly and would not likely have significantly affect the benefit cost analysis due to the lower magnitude of anticipated cost compared to property damage.

vii. Public Trail and Rail Prism Damage Valuation

Damage due to wave overtopping was estimated using guidance provided in the Coastal Engineering Manual and EurOtop 2016, based on discharge per linear foot reported in ESA 2018 and finished surface of the trail and rail prism.

viii. Valuation of Other Economic Impacts

In a standard BCA, economic impacts (e.g., losses due to business closures) are not accounted for. However, most cities and counties rely on the tax and other revenues generated by these taxes to fund City and County services. A full analysis of these impacts would require more detailed information of economic activity, primarily along Jacobs Avenue. Such an analysis is beyond the scope of this study. However, it should be noted that flooding along Jacobs Avenue would likely cause substantial disruptions to local businesses including potential loss in jobs and tax revenues. Should these disruptions last for any length of time (e.g., longer than one month) one could anticipate indirect and induced (aka multiplier) effects on other local businesses not directly impacted by the flooding.

The Qualitative Risk Assessment, presented in report provides an overview and discussion of public health, safety, and economic impacts due to flooding. In addition to loss of property, these operations will likely have to suspend their businesses for some time with severe flooding. Some of these businesses (e.g., auto wrecker) may also have toxic chemicals which could leak or leach during a severe flood. This analysis also did not account for flooding to automobiles and trucks, costs of evacuation, or animal livestock loss. Impacts to health and safety and loss of life were also not included in this analysis.

ix. Summary of Flood Damage Valuation

Based on the methods described above, flood damage was estimated for the primary critical resources within the Study Area for extreme tidal events. Table 4 below presents the results for the entire Study Area, and Table 5 presents the same result categories for Cell A only. Notably, a majority of total damages are located within Cell A. There are some high value parcels located outside of Cell A (for example, the Target commercial property) that are particularly vulnerable to the 10.6 water level which are excluded from Table 5.

Table 4. Summary of damage valuation throughout Study Area

Critical Resource Category	Tidal Still Water (Feet NAVD)				
	< 10.3	10.6	11.6	12.6	13.6
Commercial Structures	*No Significant Damage Noted*	$2,220,000	$49,600,000	$53,600,000	$55,600,000
Public, Utility, and Agricultural Lands		$248,000	$759,000	$936,000	$1,150,000
Residential Structures		$5,730,000	$7,080,000	$9,720,000	$11,000,000
Shoreline Infrastructure		$251,000	$1,330,000	$6,430,000	$7,920,000
Roadway Use		$17,000	$8,300,000	$8,300,000	$8,300,000
Roadway Damage		Not Estimated			
Total		**$8,470,000**	**$67,100,000**	**$78,900,000**	**$84,000,000**

Table 5. Summary of damage valuation for Cell A

Critical Resource Category	Tidal Still Water (Feet NAVD)				
Cell A	< 10.3	10.6	11.6	12.6	13.6
Commercial Structures	*No Significant Damage Noted*	$742,000	$44,900,000	$47,300,000	$48,500,000
Public, Utility, and Agricultural Lands		$49,200	$148,000	$177,000	$200,000
Residential Structures		$1,270,000	$3,500,000	$3,770,000	$3,980,000
Shoreline Infrastructure		$886	$854,000	$4,560,000	$6,240,000
Roadway Use		$17,000	$8,300,000	$8,300,000	$8,300,000
Roadway Damage		Not Estimated			
Total		**$2,080,000**	**$57,700,000**	**$64,100,000**	**$67,200,000**

3. Estimating Other Benefits

Projects can provide direct quantifiable benefits as well as indirect benefits that are not quantifiable. For example, Project 1 includes extension of an existing trail along the bay shoreline which connects Eureka and Arcata. Once the project is constructed it will become vulnerable to future extreme events and associated usage disruption and potential damages (ESA 2018). To value the future disruption and/or damage, it was considered that the section of this trail in Arcata has approximately 50,000 trips a year, with roughly half bicyclists and half walkers/runners according to counts taken by the City of Arcata.[9] Based on conversations with County officials and others knowledgeable, a conservative assumption was made that trail usage will double, increasing from 50,000 trips per year to 100,000 trips per year.[10] To estimate the benefits from additional trail use, a "benefits transfer"[11] was applied which involves applying similar studies of similar non-market value.[12] In essence, benefits transfer involves applying economic studies of similar resources, in this case urban trails. In this case, we examined other rail trails in urban corridors (smaller cities). Due to limited data, the estimates are not site-specific but rather based

[9] Source: City of Arcata pedestrian and bike counts taken January 20-Sept 30, 2020.

[10] Count were taken from January 1 to September 30, 2020. Count value adjusted (38,000) to reflect year round attendance of 50,000. Given that these counts were taken for one 9 month period, during the COVID epidemic, these may be too high or too low for a more typical year.

[11] There is a large body of literature in economics on benefits transfer, e.g., see https://www.ecosystemvaluation.org/benefit_transfer.htm.

[12] For more discussion of benefits transfer, see Environmental Policy Analysis: A Guide to Non-Market Valuation, Austrailian Government Productivity Commission, January 2014, https://www.pc.gov.au/research/supporting/non-market-valuation/non-market-valuation.pdf.

on trails and paths with similar settings and usage characteristics. In this project we assigned a non-market value of $10 per trip[13], for both cycling and walking.

Ecological benefits, which could be significant, were not included due to a lack of sufficient site-specific data and transferability to the study area to quantify this benefit. The services of natural ecosystems is often undervalued and future analyses of adaptation in this area should strive to account for all ecosystem services. The co-benefit of implementing a project that protects a developed area and increases habitat functions and values was not monetized.

Benefits to the local region, regarding the use of dredge spoils from Humboldt Bay were not monetized. Dredged sediment is currently disposed of at the expense of the Humboldt Bay Harbor, Recreation, and Conservation District and US Army Corps of Engineers. Use of these dredge spoils could result in the spoils becoming a resource, as opposed to a burden. Additionally, a project, such as Project 2, could provide not only use of a large volume of dredge spoils during construction, but an ongoing location for placement of dredge spoils to increase elevations and resiliency.

It should also be noted that the City of Eureka, and the Redwood Coast Region in general, have significantly higher poverty rates than the State of California. According to the US Census Bureau, 20% of the population in the City of Eureka live below the poverty line[14] compared to 11.8%[15] in California overall. A report prepared by the California Center for Rural Poverty pointed out that: “Compared to California and the United States, the Redwood Coast Region has higher poverty rates for every race/ethnicity.[16]” Two of the City’s main historical economic drivers, fishing and timber, have been in decline for several decades. Many of these vulnerable households are located in areas vulnerable to coastal flooding. Within the Study Area, mobile home park communities are located in low-elevation, levee-protected areas, surrounded by industrial and commercial areas. The projects proposed in this study would protect some of these vulnerable residences, for example the mobile home community on Jacobs Avenue.

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[13] The estimates for the non-market value of hiking are based on prior studies of the non-market value or consumer surplus to users from walking trails. Due to limited data, our estimates are not site-specific but rather based on trails and paths with similar settings and usage characteristics. The value of a path, adjusted for inflation, ranges from $8/day to $33/day. See: Siderelis, C., & Moore, R. (1995). Outdoor Recreation Net Benefits of Rail-Trails. Journal of Leisure Research, 27(4). pg 355. Betz, C. J., Bergstrom, J. C., & Bowker, J. M. (2003). A Contingent Trip Model for Estimating Rail-trail Demand. Journal of Environmental Planning and Management, 46(1), 79-96. doi:10.1080/713676704. Moore, R., Gitelson, R, and Graefe, A. (1994). The Economic Impacts of Rail-Trails. Journal of Parks and Recreation Administration, 12(2). Such a wide range exists because the estimate depends heavily on the context of the trail and the demographics of the users surveyed. To be conservative, we used a value on the lower end of the scale.

[14] See https://www.census.gov/quickfacts/eurekacitycalifornia

[15] See https://www.census.gov/quickfacts/fact/table/CA/PST045219.

[16] See Rural Poverty and its Health Impacts: A Look at Poverty in the Redwood Coast Region By The California Center for Rural Policy at Humboldt State University https://ccrp.humboldt.edu/sites/default/files/ccrp-rural-poverty-report_0.pdf, 2008, p. 11.

4. Benefit Cost Analysis

This section describes the benefit-cost analysis (BCA) conducted for the proposed projects. The proposed projects are located within Cell A only, so all of the direct benefits of these projects are associated with Cell A.

i. Project Construction Costs

Estimates of probable construction costs were developed for each project as described in the report. For the purpose of this benefit cost analysis, the conservative upper range of the construction costs were applied. For Project 1, the project cost was obtained from the Project Study Report and included engineering, environmental compliance.

ii. Time Value of Money (Discount Rate)

As with all BCAs, the analysis includes time. For consistency, the base year for the economic analyses is 2021. All benefits and costs in future years are discounted at a discount rate of 3% per year, which is generally consistent with the County's cost of capital as well as the discount rate currently recommended by the US Army Corps of Engineers. Consequently, future costs and benefits are all expressed in Present Value (PV) based on a 3% discount rate.

Time is also an important component of the analysis given sea-levels are projected to rise over time, and the analysis incorporates two rates of sea-level rise based on guidance curves from the California Ocean Protection Council, for the likely (66% probability) and 1-in-200 chance (0.5% probability) projections.

The analysis also allows the optimal timing to implement a project to be assessed. With rising sea levels, the benefits of levee construction in terms of property protection are likely to increase over time, and a project which is not cost effective in 2021 may be cost effective in 2040, or the benefits from waiting an additional 20 years may outweigh the costs.

iii. Probability of Flooding

The BCA incorporates the impacts of episodic storms and water levels (events), that will become more frequent with rising sea levels and are consistent with the Hazard Scenarios previously described. Water levels were assigned recurrences or annual probabilities, based on existing and future rates of sea level rise.

iv. Long Term Projections (through 2100)

The Ocean Protection Council (OPC) recommends that local governments select their planning horizons to evaluate a broad range of planning concerns (OPC, 2018). A typical planning horizon for General Plans is 20 years. However, the OPC recommends using a planning horizon of 75 to 100 years for development of residential and commercial areas and a longer timeframe of more than 100 years for critical infrastructure such as bridges and industrial facilities.

The probability that a 100-year event will occur in any given year is 1/100 or 1%. Consequently, to estimate the expected damages from a 100-year event, one multiplies the estimated damages of a 100-year water level by 1/100. Since these events are assumed to be independent, the damages can be multiplied—in 20 years one has a probability of 20%.[17]

Similarly, a five-year event has a probability of 20% or 0.2 in any given year and in a 20-year period one can expect, on average, four such events (0.2*20=4). The analysis assumes that all events are independent, which allows us to sum the event damages throughout the Study Area for multiple probabilities using the probability of a flooding event in any given year and the damages from that event (Eqn-1).

$$E = \sum_{i=1}^{n} D * P$$

Where:

E=$Expected\ Event\ Damages\ within\ the\ Study\ Area$
D=$Damage\ Cost\ (sum\ of\ all\ quanitified\ damages)$
P=$Annual\ Probability\ of\ Event$ (0.2 and 0.01)
i=$Year$
n=$Total\ Number\ of\ Years$

Given the projected increased water levels associated with sea-level rise, the likelihood of a given water level will increase each year. For example, a water level of 9.9 feet currently has a 10% chance of occurring in any given year (10-year event). With 0.2 feet of sea-level rise, the same water level of 9.9 feet will have a 20% chance of occurring in any given year. Therefore the estimated event damages for each year incorporate the increased probability of the event occurring. Our analysis examines the (discounted) expected damages *for each year* from 2021-2100 and sums these expected damages for every parcel and critical resource selected in the Study Area over the relevant timeframe.

Two recurrence events were selected for this analysis, the 100-year and 5-year events. These two events were selected in order to incorporate a relatively frequent event (5-year) and a relatively infrequent event (100-year). The equation presented above may be used for additional events, such as the 2-year, 10-year, 25-year and 50-year. For this analysis, it is assumed that one low probability event (100-year) and 20 higher probability events (5-year) will occur in the next 100-years.

Table 6 provides an example of damages for a given water level accounting for sea-level rise and changes in probability of the event. Additionally, an example of the multiple events that may occur in a given year is presented in Table 7. These two methods are utilized, summed in a given year and a net present value calculated.

[17] The expected number of 100-year storms in 20 years is actually less than 20. However, it is also possible that one will experience more than one event in 20 years; since this is a binomial distribution, the expected value of a storm occurring is 20% http://www.stat.yale.edu/Courses/1997-98/101/binom.htm.

Table 6. Example changes in probability due to sea-level rise for a given water level.

Water Level 10.6 feet	2020	2050
Water Level Damage Estimate*	$2,000,000	$2,000,000
Projected SLR* (66% likelihood)	0 ft	1.1 ft
Recurrence*	100-yr	5-yr
Probability*	0.01	0.2
Damage Cost	$20,000	$400,000
Present Value (PV)*	$20,000	$120,000
Event Damage (PV)	**$140,000**	

*Values are approximate, intended for demonstration purposes

Table 7. Example calculation of summing multiple damage costs considering multiple independent events for a given year

Year 2050 (1.1 ft SLR)	5-yr	100-yr
Water Level	10.8 ft	11.7 ft
Water Level Damage Estimate*	$2,000,000	$58,000,000
Probability*	0.2	0.01
Damage Cost	$400,000	$580,000
Present Value (PV)*	$120,000	$180,000
Event Damage (PV)	**$300,000**	

*Values are approximate, intended for demonstration purposes

v. Scenario-Based Projections

A long-term planning horizon exceeding 75 to 100 years, poses significant challenges for resource managers and local governments. Over the course of 100 years, spanning three generations, the landscape of the Study Area has dramatically changed, as detailed in Rhode (2020). Landscape change can be attributed to changes in socioeconomic, political, technological, natural, and cultural forces[18]. These forces can dramatically change the course of the future landscape. For example, in the early 1950s "traffic counts . . . [indicated] that the portion of the Redwood Highway, Route 101, between Eureka and Arcata was one of the most congested two-lane highways in the State of California" (Rohde, 2020). At the time, the post-World War II housing boom was occurring along with a thriving local timber industry and population and development was likely on the rise. However, as the local economic factors, market economy, environmental laws, and other driving forces changed, the local timber industry is a small fraction of what it once was and population growth in Humboldt County has been negative or below 1% over the past 10 years.

[18] Bürgi M.HerspergerA. M.Schneeberger N. Driving forces of landscape change-current and new directions. Landscape Ecology2004857868

A scenario-based approach can be used to evaluate specific events happening in specific years to provide insight into shorter term planning horizons, when the landscape changes may be more similar to existing conditions. For the purposes of this study, two scenarios have been selected and are displayed below in Table 8 and Table 9 to better understand the economic magnitude of similar events occurring over different planning horizons. Events 1 and 2 in Scenario A result in a negligible market loss within the scope of this study, while Event 3 results in $38.3 million in damages in 2040 if Projects 1-4 are not implemented. The events in Scenario B result in a total $56.3 million prior to Projects 1-4.

Table 8. Scenario A: Example 20-year Planning Horizon where three extreme events occur.

Scenario A	Event 1	Event 2	Event 3	TOTAL (PV)
Year	2025	2030	2040	*N/A*
Water Level (ft NAVD)	9.9	9.9	11.6	
SLR Projection* (ft) (OPC 66% Probability)	0.25	0.5	0.8	
Approx. Recurrence w/ SLR	5 to 10-yr	2-yr	~100-yr	
Total Market Loss in Corresponding Year prior to project implementation	$-	$-	$58M	
Total Market Loss (PV) prior to project implementation	**$-**	**$-**	**$ 33M**	**$ 33M**

*2012 base case

Table 9. Scenario B: Example 50-year Planning Horizon where five extreme events occur.

Scenario B	Event 1	Event 2	Event 3	Event 4	Event 5	TOTAL (PV)
Year	2025	2030	2040	2050	2070	*N/A*
Water Level (ft NAVD)	9.9	9.9	11.6	10.6	11.6	
SLR Projection* (ft) (66% Probability)	0.25	0.5	0.8	1.1	1.7	
Approx. Recurrence w/ SLR	5 to 10-yr	2-yr	100-yr	2-yr	10-yr	
Total Market Loss (Corresponding year prior to project implementation)	$-	$-	$58M	$2M	$58M	
Total Market Loss (PV) prior to project implementation	**$ -**	**$-**	**$ 33M**	**$1M**	**$ 14M**	**$ 48M**

*2012 base case

The use of the scenario-based approach does not apply the annual multiplier described previously. Damages resulting from the given water levels are applied to the year in which they occur and are reported in Present Value by applying the discount rate described above.

vi. Net Benefits

All results are expressed in terms of net benefits—subtracting the project costs from the benefits:

$$\text{Net Benefits} = \text{Total Benefits} – \text{Total Costs}$$

In a proper BCA, all of these benefits and costs are expressed in the same terms. For this study, the unit of analysis is constant 2021 dollars with future values discounted at 3% a year (present value). The main benefits are from flood mitigation, though the project benefits.

5. Results

i. Project 1 – Humboldt Bay Trail South and Elevation of Rail Prism

The implementation of the Humboldt Bay Trail South Project was compared to existing conditions flooding for still water levels between 10.3 and 13.6 feet. The project significantly reduces the volume of tidal water overtopping from the bay, between Brainard and Bracut, for water levels up to 11.6 feet. The most significant avoided costs are associated with the prevention of six feet of flooding to parcels and the closure of Highway 101 north and southbound, when water levels exceed 11.6 feet. Table 10 shows the reduction in damage costs, assuming the project was implemented in 2021 and the water levels shown occur immediately following implementation.

Table 10. Avoided Damage Costs with Implementation of Project 1

Critical Resource Category	Tidal Still Water Level				
Cell A	< 10.3	10.6	11.6	12.6	13.6
Commercial Structures	*No Significant Damage Noted*	$742,000	$44,900,000	$0	$0
Public, Utility, and Agricultural Lands		$39,500	$148,000	$0	$0
Residential Structures		$1,270,000	$854,000	$0	$0
Shoreline Infrastructure		$0	$815,000	$3,320,000	$0
Roadway Use		$17,000	$8,280,000	$0	$0
Total		**$2,070,000**	**$55,000,000**	**$3,320,000**	**$0**

Applying the long-term method described previously, Table 11 below presents the results of the analysis for Project 1. Under both the OPC 66% (Likely) and 0.5% sea level rise probability scenarios, the greatest benefits are to commercial property, mostly on Jacobs Avenue. Note that under the 0.5% probability scenario, net benefits are lower than under the Likely Range (66% probability) scenario. This may seem counterintuitive, but in this instance, there is a “tipping point” at a water level of 12.6 feet when the project ceases to add additional flood protection and the trail and levee are overtopped by more than 1 foot. Under the 0.5% probability scenario, this tipping point is reached sooner, hence the lower net benefits. Avoided damages to residential structures, roadway use and public/utility and agricultural lands represent a small fraction of the total avoided damage costs. The benefits from the trail over this time period, $3.28 million, are substantial, but small in comparison to other costs and benefits. Other significant avoided damages not monetized include potential loss of life, exposure to hazardous materials, roadway damage, and vehicle accidents/damage. Benefits likely realized but not monetized include non-motorized trips, safety, public health, and tourism. Under the two OPC sea level rise probability scenarios evaluated, and project cost of $22.6 million, a net benefit of $73.2 to $91.4 million.

Table 11. Project 1 Net Benefits with Sea Level Rise 2021-2100

Costs and Benefits	OPC 66% Probability	OPC 0.5% Probability
Avoided Damages		
Commercial Structures	$97,400,000	$80,300,000
Public, Utility, and Agricultural Lands	$221,000	$168,000
Residential Structures	$8,280,000	$6,910,000
Roadway Use	$682,000	$847,000
Levee Reconstruction Damage	$3,760,000	$4,330,000
Key Avoided Damages Not Monetized	Loss of Life, Exposure to Hazardous Materials, Roadway Damage, vehicle accidents/damage	
Added Benefit Value		
Public Trail Use	$3,280,000	$3,280,000
Key Benefits Not Monetized	Non-motorized trips, safety, public health, tourism	
Total	**$114,000,000**	**$95,800,000**
Project 1 Costs	**$22,600,000**	**$22,600,000**
Net Benefits:	**$91,400,000**	**$73,200,000**

In the 20-year planning scenario (**Table 12**), there are $38.2 million in avoided damages with the implementation of Project 1, entirely from the 100-yr flood event in 2040. Events 1 and 2 are scenarios with a 9.9 water level, which yields no significant damages within the scope of this study (and therefore, no benefits). In the 50-year planning scenario, again we see no damages from events at the 9.9 water level, and therefore no benefits. However, Events 3, 4, and 5 yield a total of $56.2 million in damages avoided once the trail is completed.

Table 12. Planning Scenarios for 20-year and 50-year avoided damages for Project 1

Planning Scenario	Event 1	Event 2	Event 3	Event 4	Event 5
Year	2025	2030	2040	2050	2070
Water Level (ft NAVD)	9.9	9.9	11.6	10.6	11.6
SLR Projection* (ft) (66% Probability)	0.25	0.5	0.8	1.1	1.7
Approx. Recurrence w/ SLR	5 to 10-yr	2-yr	100-yr	2-yr	10-yr
Avoided Damages in Corresponding Year	$ -	$ -	$55M	$2.07M	$55M
Damages Avoided with Project 1 (PV)	**$ -**	**$ -**	**$33.2M**	**$0.984M**	**$15.7M**
20-yr Planning (PV)			**$33.2M**		
50-yr Planning (PV)					**$56.2M**

ii. Project 2 – Natural Shoreline Infrastructure

The Natural Shoreline Infrastructure Project (Project 2) reduces wave erosion of the rail prism and trail, as well as overtopping and the associated flooding resulting from wave runup and overtopping along the bay shoreline. The reduced wave overtopping of Project 2 was compared to wave overtopping that would occur with only Project 1 being implemented. Average wave overtopping discharge rates were used to estimate flood depth and roadway flooding. Project 2 effectively eliminates all waves generated at water levels up to 11.5 feet. While the implementation of Project 1 provides a majority of flood benefit to Cell A, Project 2 adds resiliency to the rail prism and trail which serve as the primary protection for Highway 101. The primary benefit of Project 2 monetized in this study is associated with reduced flooding of parcels and preventing the closure of Highway 101 southbound. However, significant ecological services would be provided as well, along with co-benefits in the use of dredge spoils from Humboldt Bay.

Water levels exceeding 11.5 feet result in still water overtopping of the rail prism and trail and therefore the project does not provide additional benefit for higher water levels. Water levels and average wave overtopping rates were developed by ESA as a part of the Humboldt Bay Trail South project. The 10.3 ft water level used in this analysis corresponds to a tidal still water level, wind setup, and wind waves. Sea level rise is then added in 1 foot increments. Based on average wave overtopping flow rates presented previously, and guidance provided in the Coastal Engineering Manual and EurOtop, no significant damage to paved surfaces is expected, only to lightly armored surfaces, such as the elevated rail prism. The water levels presented in Table 13 represent the combined event with estimated 5-year recurrence, the largest event analyzed by ESA, and shows the reduction in damage costs, assuming the project was implemented in 2021 and the water levels shown occur immediately following implementation.

Table 13. Damages avoided with implementation of Project 2

Critical Resource Category	Water Level: Tidal Still Water and Wind Waves (Feet NAVD)				
Cell A	< 10.3	10.3	11.3	12.3	13.3
Commercial Structures	*No Significant Damage Noted*	$0	$4,130,000	$0	$0
Public, Utility, and Agricultural Lands		$14,800	$46,100	$0	$0
Residential Structures		$0	$1,280,000	$0	$0
Shoreline Infrastructure		$0	$269,000	$0	$0
Roadway Use		$17,000	$4,150,000	$0	$0
Total		**$31,800**	**$9,870,000**	**$0**	**$0**

The results of the long term analysis for Project 2 is presented in Table 14 below. As with Project 1, by far the largest benefits are to commercial property, mostly on Jacobs Avenue, ranging from $21.2 to $37.3 million. Avoided damages to residential property is a small fraction of the total avoided damages and roadway use and public lands are significantly smaller still, totaling $3.9 to $5.9 million combined. The net benefit of Project 2 ranges from $17.2 million to -$800,000. Under the 1-in-200 chance (0.5% probability) scenario, Project 2 is the only instance where net benefits are negative. Given the substantial benefit of Project 1 and the limited ability of the horizontal levee to diminish wave heights ceases at still water levels that overtop the rail prism, and overtopping occurs much sooner in this scenario. This does not mean that the project is not viable, but it does mean that net benefits regarding property damage and roadway closures will decrease more quickly over time and this project is more cost-effective when implemented sooner. The most effective time to implement each project is described later in this report in section 6.

Table 14. Project 2 Net Benefits-Sea level Rise 2021-2100

Costs and Benefits	OPC 66% Probability	OPC 0.5% Probability
Avoided Damages		
Commercial Structures	$37,300,000	$21,200,000
Public, Utility, and Agricultural Lands	$104,000	$68,600
Residential Structures	$4,780,000	$2,930,000
Roadway Use	$673,000	$559,000
Levee Reconstruction Damage	$350,000	$403,000
Key Avoided Damages Not Monetized	Loss of Life, Exposure to Hazardous Materials, Roadway Damage, vehicle accidents/damage, temporary loss of trail use	
Added Benefit Value		
Key Benefits Not Monetized	Safety/Injury Prevention of Trail Users, Ecological Benefits of Marsh Habitats, Use of Dredge Spoils and continued sediment accretion potential of marsh.	

Total	**$ 43,200,000**	**$25,200,000**
Project 2 Costs	**$ 26,000,000**	**$26,000,000**
Net Benefits:	**$17,200,000**	**$ (800,000)***
*Should Project 2 cost be reduced by more than $800,000 the project would provide a positive net benefit.		

The analyses of other projects include the summation of the 5-year and 100-year events after discount rates and multipliers are applied. Due to the limited available information on overtopping rates for combined tidal still water and wind effects, and extent of analysis needed to develop rates for other events, the analysis of Project 2 is limited to the 5-year only, resulting in a reduced net benefit if a larger. Additional analyses are being prepared for Project 2 as a part of a separate project. The analysis also assumes that the rail prism remains in place with minor reconstruction of the top material when overtopping occurs. However, without the reduction of wave energy and overtopping provided by Project 2, larger events, not evaluated in this study, could result in more significant erosion and potential failure of the rail prism. Avoided damage costs of Project 2 would then more closely resemble the avoided damage costs of Project 1, due to several feet of flooding within Cell A along with additional damage and delays on Highway 101. Additionally, avoided damages including loss of life, exposure to hazardous materials, roadway damage, vehicle accidents/damage, temporary loss of trail use were not monetized; nor were the benefits that include safety/injury prevention of trail users, ecological benefits of marsh habitats, use of dredge spoils.

Under the 20-year planning scenario, Project 2 provides $5.63 million in avoided damages with an 11.3 ft water level with wind waves occurring in 2040, the projected 10-yr event after 0.8 feet of SLR has occurred (Table 15). The 2-yr and 1-yr events in 2025 and 2030 respectively do not result in damages, so Project 2 does not provide a benefit for these events. In the 50-year planning scenario approximately $7.96 million in damages are avoided. Nearly all of these benefits come from avoiding damages associated with the 11.3-foot water level with wind waves that occurs in 2040 and again in 2070. The 9.9-foot water level with wind waves does not result in significant damages, and the limited avoided damages associated with the 10.3-foot water level with wind waves provides a minor benefit.

Table 15. Planning Scenarios for 20-year and 50-year avoided damages for Project 2

Planning Scenario	Event 1	Event 2	Event 3	Event 4	Event 5
Year	2025	2030	2040	2050	2070
Water Level (ft NAVD)	9.9	9.9	11.3	10.3	11.3
SLR Projection* (ft) (66% Probability)	0.25	0.5	0.8	1.1	1.7
Approx. Recurrence w/ SLR	2-yr	1-yr	10-yr	1-yr	5-yr

Avoided Damages in Corresponding Year	$ -	$ -	$9.87M	$0.03M	$9.87M
Avoided Damages Present Value	**$ -**	**$ -**	**$5.63M**	**$0.01M**	**$2.32M**
20-yr Planning (PV)			**$5.63M**		
50-yr Planning (PV)					**$7.96M**

iii. Project 3 – Jacobs Avenue Flood Resiliency

This project proposes to isolate the densely populated Jacobs Avenue area from the flood risk associated with levee overtopping/failure potential along Fay Slough. Under current conditions, the crest elevations of the Fay Slough levee are generally lower relative to Eureka Slough levee backing Jacobs Avenue and the first indicators of potential levee failure occur along Fay Slough. Additionally, the project is intended to improve the current stormwater drainage deficiencies and associated nuisance flooding along Jacobs Avenue in addition to stabilizing known eroded sections of the levee adjacent to Murray Field. Damages avoided from a breach of the Fay Slough levee after implementation of this project are presented in Table 16. At 12.6 feet and above, the project does not provide further benefits because the levee is overtopped.

Table 16. Damages avoided with implementation of Project 3

Critical Resource Category	Tidal Still Water (Feet NAVD)				
Cell A	< 10.3	10.6	11.6	12.6	13.6
Commercial Structures	*No Significant Damage Noted*	$16,300,000	$16,400,000	$0	$0
Public, Utility, and Agricultural Lands		$651	$103	$0	$0
Residential Structures		$2,940,000	$3,210,000	$0	$0
Shoreline Infrastructure		$0	$0	$0	$0
Roadway Use		$0	$0	$0	$0
TOTAL		$19,200,000	$19,600,000	$0	$0

The long term analysis results of Project 3 are presented in Table 17. Similar to previous results, most of the benefits are realized from protecting commercial property ($50.9 to $70.3 million). There is also a $9.6 to $12 million in avoided damages to residential property by protecting the mobile home community on Jacobs Avenue, and a minimal benefit to public lands. Because Project 3 targets defense of Jacobs Avenue, there is no avoided damage to Highway 101 or levee reconstruction. Project 3 results in a net benefit of $48.6 to $70.3 million. Similar to other analyses, these avoided damages do not include potential loss of life, stranding, exposure to hazardous materials, roadway damage, or vehicle accidents/damage. Nor did this analysis monetization of the creation of restoration and adaptation opportunities in Cell A or ecosystem services provided by salt marsh enhancement.

Table 17. Project 3 Net Benefits-Sea level Rise 2021-2100

Costs and Benefits	OPC 66% PROBABILITY	OPC 0.5% PROBABILITY
Avoided Damages		
Commercial Structures	$70,300,000	$50,900,000
Public, Utility, and Agricultural Lands	$1,510	$1,070
Residential Structures	$12,000,000	$9,660,000
Roadway Use	$0	$0
Levee Reconstruction Damage	$0	$0
Key Avoided Damages Not Monetized	Loss of life, stranding, exposure to hazardous materials, roadway damage, vehicle accidents/damage, loss of business and sales tax revenue	
Added Benefit Value		
Key Benefits Not Monetized	Creation of restoration and adaptation opportunities in Cell A, ecosystem services provided by salt marsh enhancement	
Total	**$82,300,000**	**$60,600,000**
Project 3 Costs	**$12,000,000**	**$12,000,000**
Net Benefits:	**$70,300,000**	**$48,600,000**

The 20-year and 50-year planning scenario results are presented in Table 18, Project 3 results in $11.2 million in avoided damages from a water level of 11.6 feet occurring in 2040. It is important to note that the benefits of Project 3 are calculated assuming that Fay Slough is breached, as levee overtopping conditions suggest a likelihood of failure at a water level of 11.6 feet. The damages from a breach of Fay Slough are excluded from the existing conditions provided earlier in this report, but are similar in regards to depth and extent of flooding prior to the implementation of any projects. Project 3 prevents $23.2 in total damages in the 50-year planning scenario. Nearly half of those damages avoided occur in 2040 in Event 3 with a 100-yr event when compared to a breach of Fay Slough.

Table 18. Scenario B: Avoided damages from Project 3

Scenario B	Event 1	Event 2	Event 3	Event 4	Event 5
Year	2025	2030	2040	2050	2070
Water Level (ft NAVD)	9.9	9.9	11.6	10.6	11.6
SLR Projection* (ft) (66% Probability)	0.25	0.5	0.8	1.1	1.7

Approx. Recurrence w/ SLR	5 to 10-yr	2-yr	100-yr	2-yr	10-yr
Avoided Damages in Corresponding Year	$ -	$-	$19.6M	$19.6M	$19.6M
Avoided Damages Present Value	**$-**	**$-**	**$11.2M**	**$8.15M**	**$4.6M**
20-yr Planning (PV)			**$11.2M**		
50-yr Planning (PV)					**$23.9M**

iv. Project 4 – Jacobs Avenue Levee Resiliency

This project proposes to increase the elevation of the existing Jacobs Avenue levee system and implement improvements to maintain or improve factors of safety related to seepage and slope stability. Improvements are intended to provide flood protection for Jacobs Avenue up to water levels of 13.6 feet. Table 19 displays the damages avoided with the implementation of Project 4. This project does not provide additional benefits at the 10.6 or 11.6 water levels because those benefits have already been realized by Projects 1-3.

Table 19. Damages avoided with implementation of Project 4

Critical Resource Category	Tidal Still Water (Feet NAVD)				
Cell A	< 10.3	10.6	11.6	12.6	13.6
Commercial Structures	*No Significant Damage Noted*	$0	$0	$46,300,000	$18,100,000
Public, Utility, and Agricultural Lands		$0	$0	$171,000	$985
Residential Structures		$0	$0	$3,750,000	$3,610,000
Shoreline Infrastructure		$0	$0	$43,500	$932,000
Roadway Use		$0	$0	$0	$0
TOTAL		**$0**	**$0**	**$50,200,000**	**$22,600,000**

The long term analysis results of Project 4 are presented in Table 20. The trend in the majority of the benefits to commercial property is carried through this analysis with $32 to $52 million in benefits with avoided damages to commercial structures. Avoided damages to residential structures in a higher percentage than with other projects. Project 4 does not provide any benefit to roadway use, as it does not protect Highway 101, but does provide a small savings in levee reconstruction. Unlike Projects 1-3, Project 4 provides a higher benefit at the 0.5% probability scenario than the 66% probability scenario. This is because the project provides more benefits at higher water levels, which occur sooner under the 0.5% probability scenario.

Table 20. Project 4 Net Benefits with Sea Level Rise 2021-2100

Costs and Benefits	OPC 66% Probability	OPC 0.5% Probability
Avoided Damages		
Commercial Structures	$32,000,000	$54,000,000

Public, Utility, and Agricultural Lands	$1,620	$2,760
Residential Structures	$6,230,000	$10,500,000
Roadway Use	$0	$0
Levee Reconstruction Damage	$286,000	$1,250,000
Key Avoided Damages Not Monetized	Loss of life, stranding, exposure to hazardous materials, roadway damage, vehicle accidents/damage	
Added Benefit Value		
Key Benefits Not Monetized	Creation of restoration and adaptation opportunities in Cell A	
Total	**$38,500,000**	**$65,800,000**
Project 4 Costs	**$9,000,000**	**$9,000,000**
Net Benefits:	**$29,500,000**	**$56,800,000**

The selected water level events for Scenarios A and B are 11.6 ft and below. The improvements recommended in Project 3 provide drainage improvements that would convey overtopping flow up to water levels of 11.6 feet and have those benefits have been allocated to Project 3. Project 4 focuses on providing flood protection for water levels above 11.6 feet and therefore does not result in benefits for the scenarios used in the evaluation of other projects.

6. Timing of Project Implementation

This analysis also examined the net benefits from delaying project implementation. The main benefit of delaying a project is that one does not have to lay out the initial cost for these projects, which may be challenging for smaller entities to implement. In the analysis, the main benefits to these projects are flood reduction. Delaying these projects delays these flood reduction benefits but saves the County (or other funder) the initial expense while one delays the project.

Figure 1 below presents a graph of the net benefits of starting each project over time under the likely (66% probability) scenario. As one can see, Projects 1 and 3 yield positive net benefits throughout the time period. These benefits diminish towards 2100 as water levels increase and the projects provide less benefit. Maximum net benefits for Projects 1, 2, 3, and 4 are realized at 2040, 2022, 2021, and 2042 respectively. Because each project builds on the one before it, this suggests that Projects 1, 2, and 3 are most cost-effective to implement as soon as possible, while Project 4 could be delayed and implemented at a later date under the 66% probability scenario.

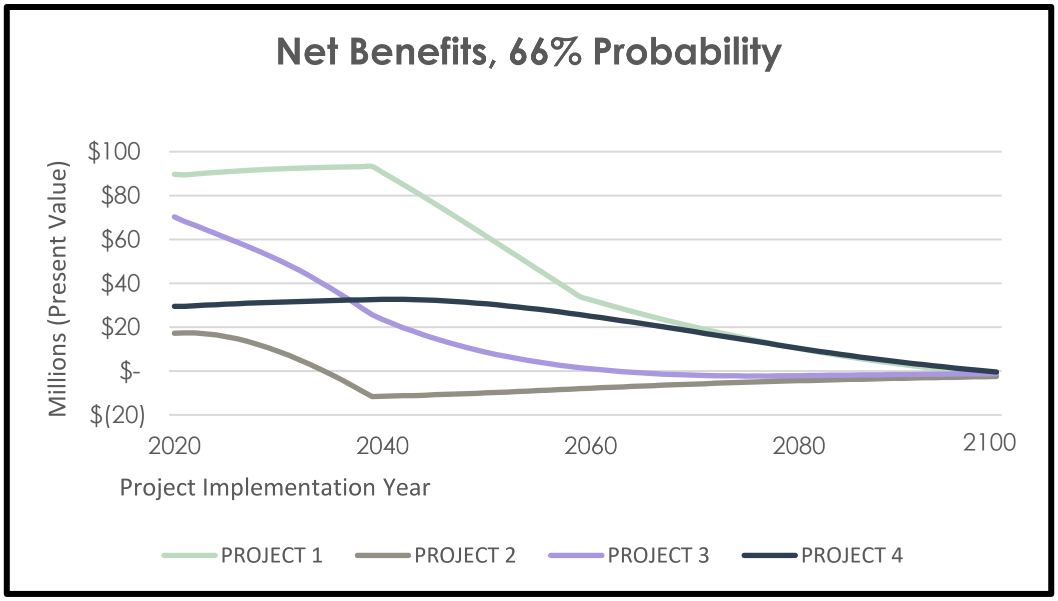

Figure 1: Net Benefits of projects over time, 66% probability

Under the 0.5% probability scenario, net benefits for all four projects experience the highest net benefits much earlier in time; we see maximum net benefits in 2030, 2022, 2021, and 2032 for Projects 1 through 4 respectively. This suggests that to plan for a more extreme sea-level rise scenario, all four projects should be implemented as soon as possible to provide the highest flood reduction benefits at the lowest cost, though there is some room for delay for Project 4. Project 2 sees negative net benefits throughout the entire time period because it only provides benefits up to 11.6 feet, and this water level is reached much sooner for the water levels and resulting overtopping damage information available.

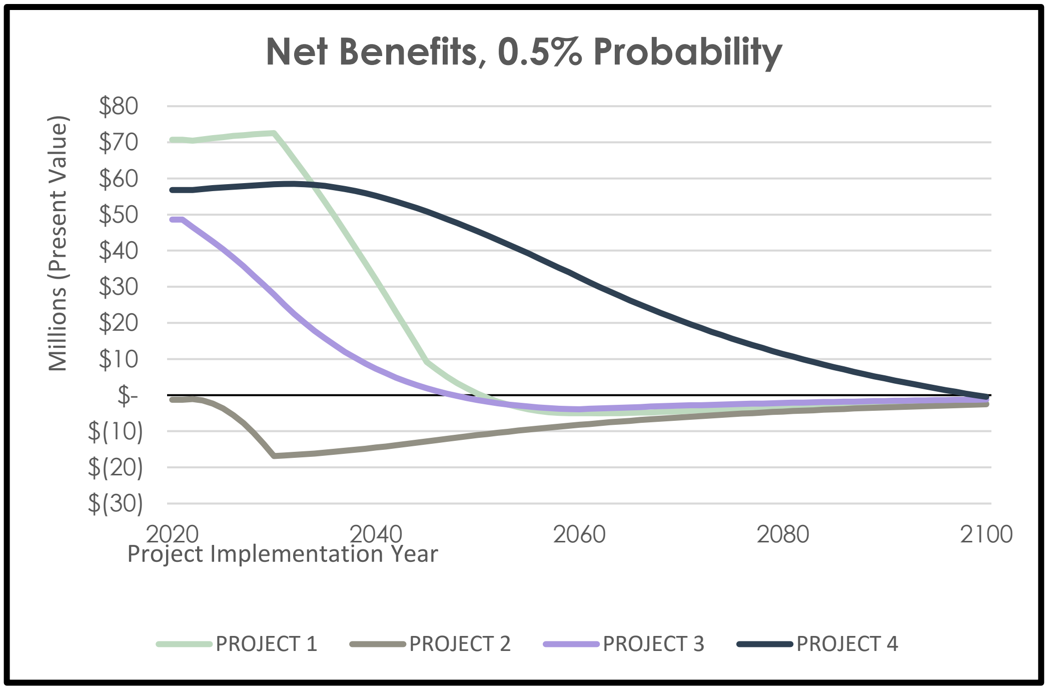

Figure 2: Net Benefits of projects over time, 0.5% probability

7. Comparison to Previous Cost Analyses

The 2014 Caltrans District 1 Climate Change Vulnerability Assessment presented order of magnitude construction cost estimates for five adaptation options for the Highway 101 corridor between Eureka Slough and Arcata. The adaptation projects included 1) strengthen and protect 10 miles of existing protective shoreline structures that currently protect Highway 101, 2) elevate Highway 101 for 6 miles on a fill prism, 3) elevate Highway 101 for 6 miles on a causeway, 4) re-route Highway 101 east for 8 miles and 5) no project with as-needed repairs and maintenance. For each project, costs were developed to prevent roadway flooding associated with the 2050 and 2100 king tides, as 10.95 feet and 14.61 feet, respectively (**Table 21**). Option 1 received the highest ranking based on the criteria established by the stakeholders and Technical Advisory Group (TAG) in 2014. The four adaptation projects proposed in this plan remain aligned with the intent of Option 1, strengthening and adding protection to existing protective structures. In considering the benefit-cost analysis methodology described above, a direct use of the 2014 construction cost versus the damage cost developed in this study (**Table 4** and **Table 5** above), can not be made given damage costs in this study were not developed between Bracut and Arcata. However it should be noted that Cell A contains a much greater density of critical resources relative to the areas protected by Highway 101 between Bracut and Arcata and therefore the options from the 2014 study may not yield a benefit cost ratio greater than one.

Table 21. Order of Magnitude Construction Costs for Ranked Adaptation Options developed for Highway 101 Corridor between Eureka Slough and Arcata (2014 Caltrans District 1 Climate Change Vulnerability Assessment). King Tide Elevations reported for 2050 and 2100 as 10.95 feet and 14.61 feet (NAVD 88), respectively.

Rank	Adaptation Option	Project Description	2050		2100	
			Score	Order of Magnitude Cost Estimate	Score	Order of Magnitude Cost Estimate
1	Provide protection at existing elevations/ locations	Strengthen/ add protection to existing protective structures (RR berm, dikes, and fill areas) for 10 miles, including increasing height to 1 ft above 2050/2100 water level at a King tide	189	$121.3M	189	$121.5M
2	Elevate the infrastructure above the impact zone	Increase the height of the roadway by building up the fill prism 1 ft above 2050/2100 water level at a King tide for 6 miles	152	$60.6M	148	$117.6M
3	Elevate the infrastructure above the impact zone	Construct a causeway, 6 miles, at a height of 5 ft above 2050 water level at a King tide	137	$173.7M	137	$368M
4	Relocate infrastructure (horizontally)	Assumed 8 mile re-route to the east of the existing Hwy 101	126	$350M	126	$350M
5	Increase the infrastructure's maintenance and inspection interval and continue to monitor/ evaluate	Equivalent to the No project alternative. Only temporary measures enacted and repairs made on an as needed basis.	30	$0.95M	30	$0.95M

8. Limitations

This BCA utilized commonly accepted methods for the valuation and damage of shoreline infrastructure, land, road use, public trail use due to flooding. Flooding levels and recurrence were limited to still water flooding developed as a part of this study and wind wave overtopping flow developed as a part of a separate study. The avoided damage costs and net benefits evaluated using long term projections (through 2100) and the scenario-based approach (20 and 50 years) is intended to provide a range of potential damages and benefits to better understand project performance under a variety of potential events and sea level rise projections. This BCA selected limited still water levels and combined still water and wind events to begin the development and evaluation of projects to improve resiliency in Cell A of the Study Area. The development of additional, combined still water and wind events and associated flooding and erosional damage is recommended to further assess the benefits of Project 2, as the combined events may result in higher water levels and wave overtopping occurring more frequently, further impacting Highway 101.

The evaluation of roadway use was limited to simple assumptions regarding average daily traffic, distance of detour and travel time. The BCA did not account for the capacity of alternate routes, changes in traffic speeds, vehicle restrictions of alternate routes, changes in motorist behavior, disruption of public transportation, or the local and regional impacts to the flow of goods and services. For these reasons, the value of roadway use is likely undervalued and requires additional studies and models to be developed to better understand the full economic impact of roadway closures.

Modeling of overland flow hydraulics within the interior of Study Area cells was not conducted as a part of this planning study. This BCA utilized flood depths, based on the volume of overtopping, to assess damages to structures and property. Overtopping depth and duration were used to estimate damage to levees and the rail prism. These parameters did not provide the necessary information to assess roadway damages, such as erosion of the road embankment as flooding flows on and off the roadway. Additional modeling of still water and wind wave overtopping, combined with modeling of flooding within the interior of cells and on roadways is recommended, to assess additional damages, delays, and hazardous conditions.