CLIMATE PREPAREDNESS AND RESILIENCE REGISTER

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Background

The Southwest Coastal Louisiana Project (SWC) is a combined coastal storm damage risk reduction, flood damage risk reduction, and ecosystem restoration project. Because the project area is in the coastal zone, its performance over time is expected to be affected by sea level change among other climate changes. This Climate Preparedness and Resilience Register (CPRR) documents the robustness of the project alternative selection process to climate change, how the selected plan's performance might be expected to change over time, and how the plan might be adapted to continue to deliver performance in a changing climate.

The intent of USACE climate policy is to plan and build projects that are robust and/or adaptable to the full range of feasible future climates. An individual project's climate preparedness and resilience can therefore be summarized in three questions, which will be addressed in this Register:

1) What is the reasonable extent of potential future climate change (particularly sea level change) in this area?
2) Is the selected plan the best alternative under all reasonable future climate scenarios?
3) How does the selected plan balance initial investment with adaptation cost to optimize performance in consideration of future climate change?

Extent of Potential Future Sea Level Change

To put an upper bound on the reasonable potential future extent of sea level change in this area during the project planning horizon, the high rate sea level rise scenario was used to project sea level in the year 2125, which is 100 years after the assumed project start date. In this area, this equates to an increase of 8.8 feet relative to 1992 sea level, or an elevation of 9.57 feet relative to NAVD88 [2004.65]. The resulting inundation map is shown as Figure 1.

Figure 1: Project area inundation map for mean sea level in the year 2125 under the high sea level rise scenario. This provides an upper bound for the reasonable range of potential future sea level, and illustrates the analysis area of interest for this register.

Part 1: NED Plan

Plan Selection

As with other coastal storm damage risk reduction projects, the starting water surface elevation is critical to the probability of flooding and therefore the annualized flood damages reduced by the SWC project. By policy, the project alternative that performs the best regardless of the future sea level should be chosen, even if this alternative does not perform the best under any particular future sea level scenario. The NED Focused Array included nine alternatives (including no action), the eighth of which, after further analysis and optimization, was ultimately identified as the Recommended Plan (RP):

0. No Action	1. Delcambre/Erath
2. Lake Charles Eastbank	3. Abbeville to Delcambre
4. Lake Charles Westbank Sulphur Extended	5. Abbeville
6. Lake Charles Westbank Sulphur South	7. Nonstructural Justified Reaches Plan
8. 100-year Floodplain [1% Annual Chance Exceedance (ACE)] Nonstructural Plan*	

**Plan 8 evolved into 'Modified Plan 8' which focuses on the 0-25-year floodplain and is the RP. See Chapter 2 of the Main Report for more information.*

Table 1: Focused Array of NED Plan Alternatives

Plan Selection Sensitivity to Sea Level Rise

Engineering Regulation 1100-2-8162 "Incorporating Sea Level Change in Civil Works Programs" signed 31 Dec 2013, gives three possible approaches for determining the sensitivity of alternative plans to sea level rise (page 3). Option (1), working within a single sea level rise scenario and determining the preferred alternative under that scenario before evaluating its performance under the other scenarios, was chosen in this case. Per the Regulation, "this approach may be most appropriate when local conditions and plan performance are not highly sensitive to the rate of SLC." The Southwest Coastal project does not fit that description, so the question arises whether any superior alternatives could have been inadvertently screened out due to the reliance on a single seal level rise scenario.

A close examination of the other, eliminated alternatives reveals that this is highly unlikely to be the case. Whereas the selected plan has an estimated benefit-to-cost ratio of approximately 7:1 (based on the screening-level analysis permitted under SMART planning), the other alternatives all have ratios at or below unity (all alternatives were assessed using the intermediate rate of sea level rise over a 50-year economic analysis window). This is due to the fact that the chosen nonstructural plan allocates risk reduction measures only to those structures that are economically justified, whereas the structural alternatives (plans 1 through 6 in Table 1 above) provide risk reduction to both justified and unjustified (i.e. already lower-risk) structures. Furthermore, construction of structural measures such as levees and floodwalls in an area currently without such infrastructure would significantly impede stormwater drainage, necessitating major investment in drainage pumps and canals. Widespread modifications and relocations of roads, railroads, pipelines, and other infrastructure would also be required. It is therefore unlikely that consideration of a different sea level scenario could have changed the economics of plan selection sufficiently to have caused a structural alternative to be chosen.

In addition to the economic considerations described above, the structural alternatives considered have another drawback compared to the selected nonstructural plan: the potential to induce flood risk. Constructing levees in an area where they did not previously exist could encourage people to move into the leveed area. Under certain circumstances this could actually increase overall flood risk as compared to the no action alternative. An increased population inside the leveed area could also constrain future adaptation options, for example by encroaching on the real estate footprint needed to perform a future levee lift. Since a nonstructural plan does not suffer from the possibility of induced risk, this makes it even less likely that a structural plan was truly the best performing under all climate scenarios but was erroneously eliminated from consideration due to the reliance on a single scenario.

The other nonstructural plan that was considered (plan 7 in Table 1) evolved into Plan 8 based on policy review from HQUSACE. Briefly, Plan 7 considered all structures in hydraulic reaches with above a certain probability of flooding to be justified. Plan 8 considers each structure on the basis of its particular risk and further evolved to focus on the most at-risk structures in the study area. This optimization of addressing risk within the 100-year floodplain, which includes additional economic justification for individual structures, resulted in refinements to Plan 8. These led to the alternative being known as 'Modified Plan 8', which focuses on structures in the 0-25-year floodplain. Modified Plan 8 is the RP. Because this plan was modified based on policy review rather than plan performance, the question of appropriate sea level is not relevant to the decision to eliminate it.

In summary, **it is very likely that the RP (Modified Plan 8) is the best alternative** under all reasonable future sea level scenarios. Although the planning process did not consider all three scenarios, it is highly unlikely that such consideration would have resulted in a different plan being chosen.

Plan Sensitivity to Inland Hydrology Non-Stationarity

Much of the flood damage reduced by this project is not strictly coastal flooding, but the combination of elevated coastal water levels and heavy rains that are common in a hurricane. With receiving areas raised by storm surge, drainage is impaired. The resulting backwater flooding can be highly damaging, even during a relatively small storm surge. The probability of this phenomenon occurring is clearly affected by sea level as outlined above, but also by rainfall intensity. If the intensity of rainfall can be expected to change in the future, then the project performance could also be affected, for the better or for worse. Because this possibility was not investigated during plan selection, it is possible that an inferior plan was chosen.

To investigate the possibility of changing rainfall intensities, 38 years of hourly rainfall data from the meteorological station at Jennings, LA were downloaded from the website of the National Centers for Environmental Information (formerly the National Climatic Data Center). The Jennings rain gage is located in a flat farm and pasture area with scattered tree growth. While it is not located in the project area, it is the nearest NCEI rain gage to the project (the next closest being in Galveston, TX).

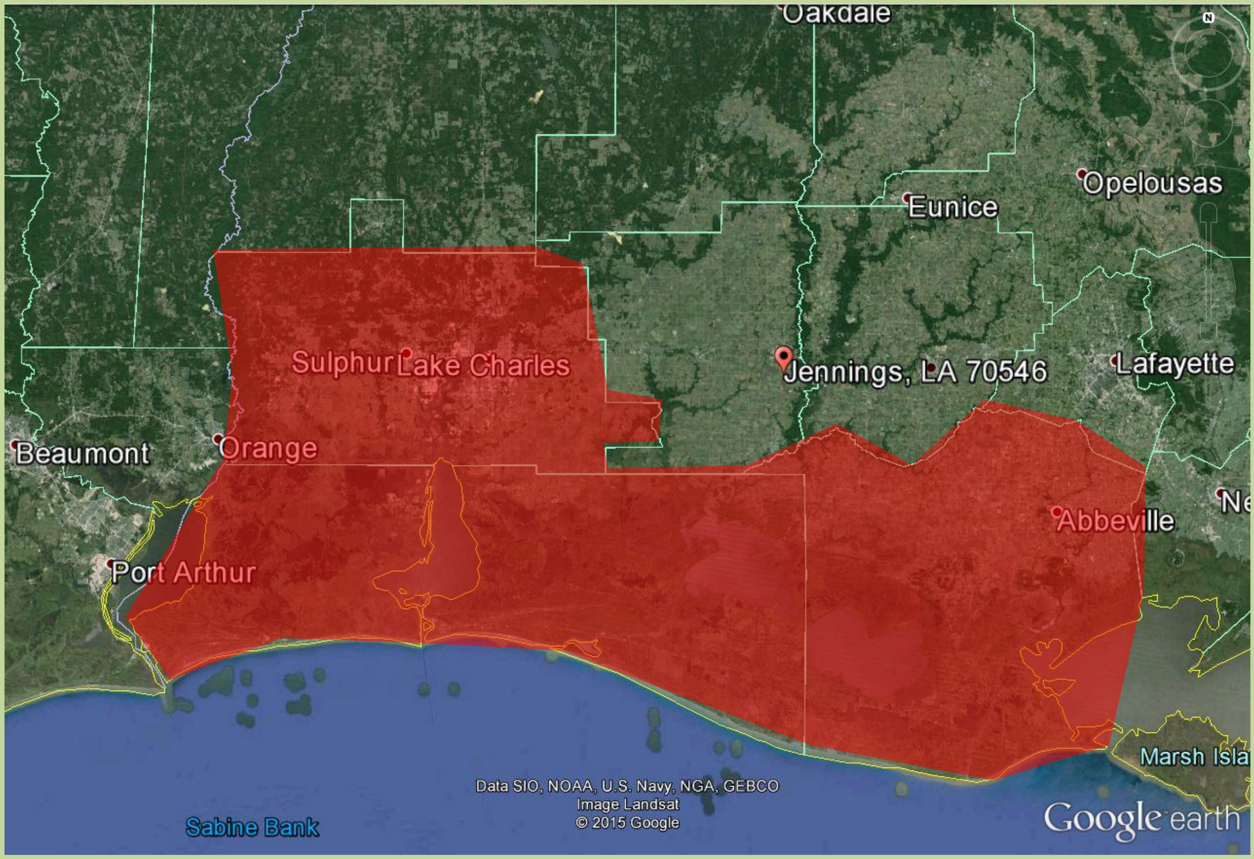

Figure 2. Location of Jennings rain gage in relation to project area. The approximate project area is shown in red.

Because the plan formulation assessed surge in conjunction with the 1% annual chance, 24-hour rainfall, the hourly rain data were summed to daily totals, from which the annual maxima were then extracted. These maxima were then assessed for trends using the trend line tool in Tableau (see Figure 3). The detected trend line had a slight negative slope, but with a p-value of 0.68 the trend is far from significant.

Annual maximum 24-hour rainfall was also assessed for change points using a series of statistical tests in the Tableau and R software packages. The specific tests used were the Pettit test, the Kolmogorov-Smirnoff test (using the CPM package in R), the Barry and Hartigan partitioning model approach to Bayesian change point analysis (using the BCP package in R), and the energy statistic of Székely and Rizzo[1] (using the ECP package in R). As shown in Figure 3, none of these methods detected any change points in the annual maximum 24-hour rainfall data with the exception of the Pettit test. That test detected a difference in means before and after the year 1998, though with a p-value of 0.29 the finding is not statistically significant. The annual maximum 24-hour rainfall in this dataset averages 4.57 inches before 1998 and 2.95 inches after. Therefore, it appears **there is little evidence for a change in rainfall** at this location, though there is some indication that rainfall in this area may have become less intense over time. As a result, the assumption of stationarity of rainfall intensity used in plan formulation appears to be defensible.

[1] Szekely, Gabor J., and Maria L. Rizzo. "Hierarchical clustering via joint between-within distances: Extending Ward's minimum variance method." *Journal of classification* 22.2 (2005): 151-183.

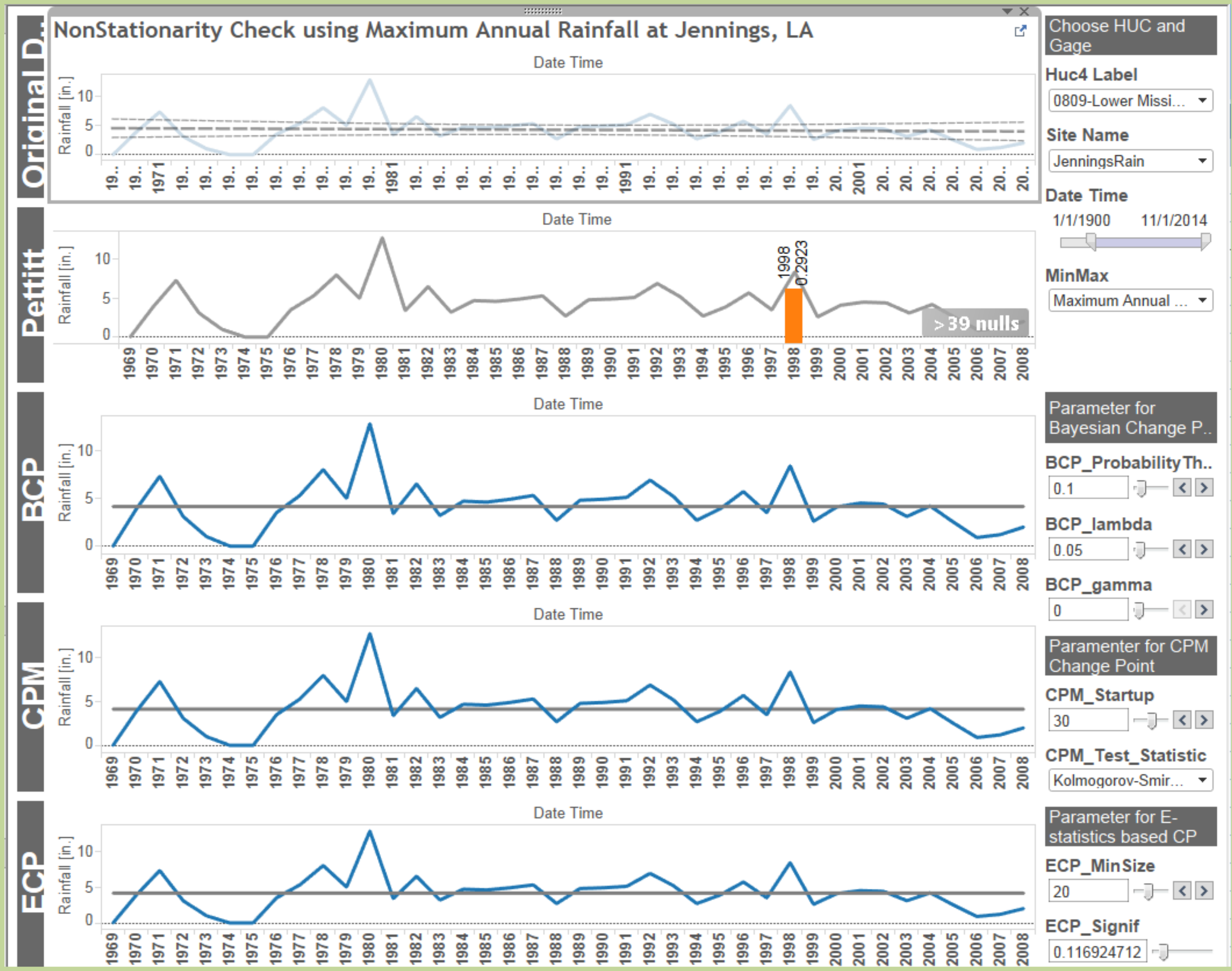

Figure 3. Linear trend and change point analysis for annual maximum daily rainfall at Jennings, LA. Only the Pettit test detected a change point, but that finding is not highly significant.

In addition to past stationarity, it is important to consider potential future changes to rainfall intensity in this area. According to the 2014 National Climate Assessment, precipitation in the southeastern United States may be expected to decrease slightly in a warmer climate, though intense rainfall events may increase in frequency. In other words, mean rainfall may decrease while variance increases. However, projections of future precipitation change are especially uncertain in this region because it is located in a transition zone between projected drier conditions to the south and projected wetter conditions to the north[2]. In light of these uncertainties, **the assumption that future precipitation will be roughly similar to past precipitation appears to be justified**.

Plan Performance

Even if the selected plan is the best of the available options, in order to be compliant with policy it must also perform well into the future either through a robust design or adaptive capacity. If the project is adaptable, it must balance adaptation cost and against initial investment cost. By utilizing the multiple future scenarios approach, the robustness of the plan to potential climate change can be assessed in two main ways: the expected duration of project performance at the desired level, and the level of project performance at a given point in the future. In addition, the potential adaptation pathways (and the triggers, lead times, and expected dates for these adaptations) help inform the adaptability of the plan.

[2] http://nca2014.globalchange.gov/report/regions/southeast

NED Plan Performance: Duration of Desired Performance

Of the two methods of assessing performance over time, the duration of performance at (or above) a desired level is the preferred approach. This "when, not if" approach recognizes that future climate change (particularly sea level change) is inevitable. Though the exact date of occurrence may be unknown, a scenario analysis can bracket when performance can be expected to fall below the desired level. For this project, the main criterion controlling project performance is a design total water level[3] that varies across the project area. This water level is caused by a combination of rainfall and storm surge that varies in space and also transitions from rainfall-controlled to surge controlled over time as the sea level rises. The project planning team optimized this design water level and the project participation criteria to maximize net economic benefits to the nation, resulting in a design that reduces the residual risk of flooding to a 1% chance annually in the year 2075 for all structures within the 4% annual probability floodplain in 2025, both based on the intermediate sea level rise scenario. Basing the inclusion criteria on the future sea level in the year 2025 rather than on present conditions provides an additional level of robustness in anticipation of the federal flood risk management standard established in executive order 13690 ("The Federal Flood Risk Management Standard"), using Engineering and Construction Bulletin 2013-33 ("Application of Flood Risk Reduction Standard for Sandy Rebuilding Projects") as a guide.

At any point in time, a project's performance can be said to equal the probability of a water level that meets or exceeds the design water level. For any higher water level (lower probability), the project would be considered non-performing. For example, if the design water level corresponds to a 0.5% annual chance (i.e. 200-year) water level, the project can be said to be performing at the 0.5% chance level (and the 1%, and any higher frequency) but not at the 0.2% level or any lower frequency. Selecting a given performance level of interest allows us to bracket the duration of performance at that level under the "when, not if" approach. In this example we will use the 1% annual chance level of performance. Following the example used in the Climate Performance and Resilience Register for the Stamford Hurricane Barrier (O'Brien et al., in preparation), the principle of linear superposition is used to simplify the computations for future total water levels. This simplifying assumption presupposes that as mean sea level changes, the magnitudes of all other components remain unchanged, so the total water level changes by the same amount as the mean sea level. This is not true in reality, as surges and waves can be either amplified by deeper water or reduced as the obstructions that push them upward become submerged. However, these nonlinear interactions are frequently too complex to be modeled with confidence, so the linear superposition principle is considered defensible within the range of uncertainty surrounding hydrodynamic modeling in a future climate.

NED plan formulation was based on the Intermediate sea level rise curve (NRC Curve I) using a historical rate of 4.18 mm/yr (note that this has been updated to 5.2 mm/yr in the most recent version of the project reports, but this was still the value used in formulation). This results in a relative sea level rise of 1.2 feet in 2075 as compared to 2025 (the project start date). This 1.2 foot relative sea level rise occurs in the year 2051 under the high scenario, and the year 2111 under the low sea level rise scenario. Under the principle of linear superposition used here, the mean sea level is the only component of total water level that will change over time and affect project performance. Therefore, this project can be expected to perform until sometime between the years 2051-2111, a 60 year range centered on the year 2081. While no sea level scenario can be considered more likely than any other, the project does perform slightly longer on average (2081) when all sea level scenarios are considered than it does under the single scenario used for plan formulation (2075). This amount of robustness to future sea level change will provide a certain amount of buffer to allow for future adaptations when they become necessary.

[3] A total water level is the peak water level in a storm event, including the effects of mean sea level, seasonal sea level variation, astronomical tide, rainfall, storm surge (i.e. pressure deficit effect and large-scale wave setup), and local wave setup and runup.

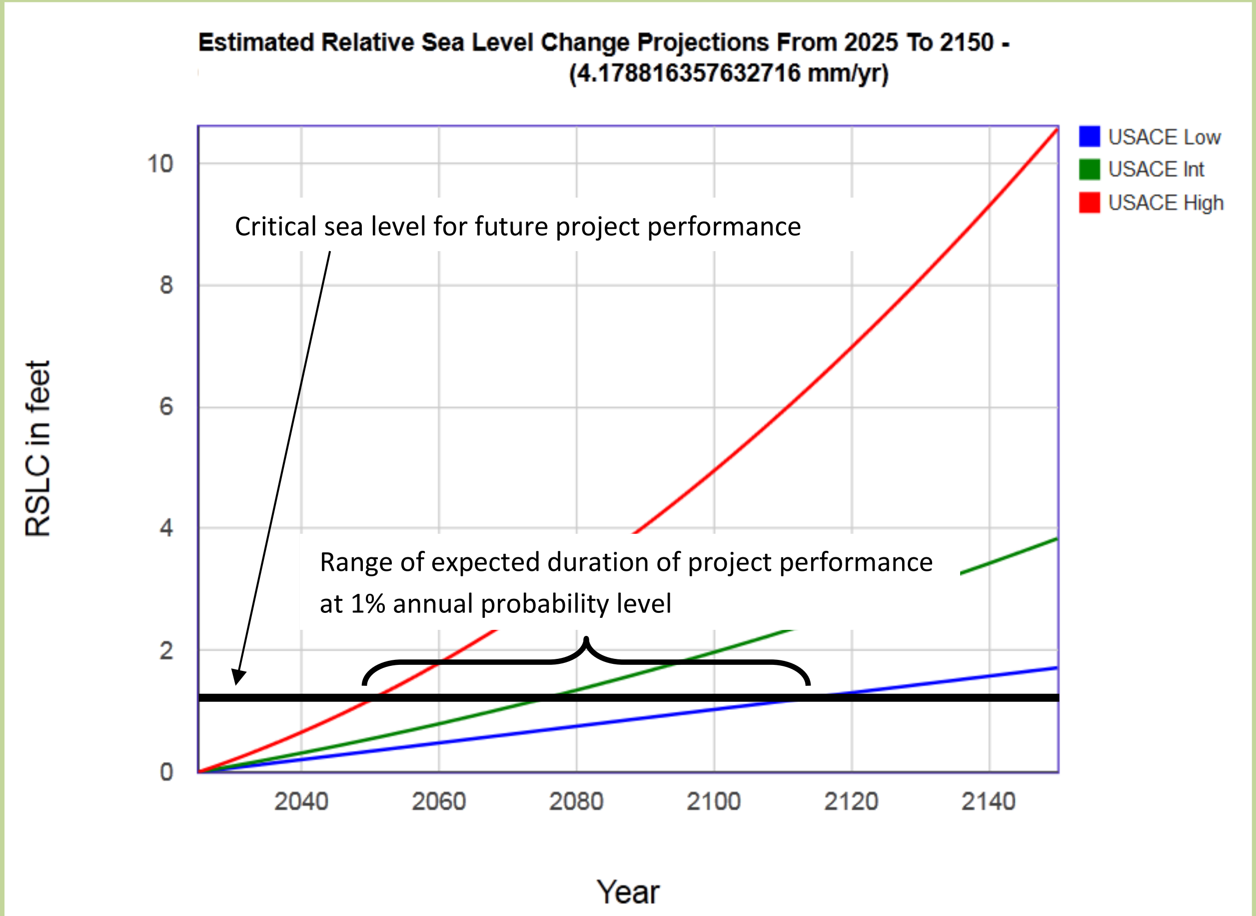

Figure 4. Duration of project performance under a range of potential future sea levels. The NED plan is expected to perform until sometime between 2051 and 2111, depending on the rate of future sea level rise.

While actual design water levels vary across the project area, the duration of performance is the same in every storage area: the project performs at the 1% annual probability level until relative sea level rise reaches 1.2 feet. The following plot illustrates this concept for a single storage area, SA-048.

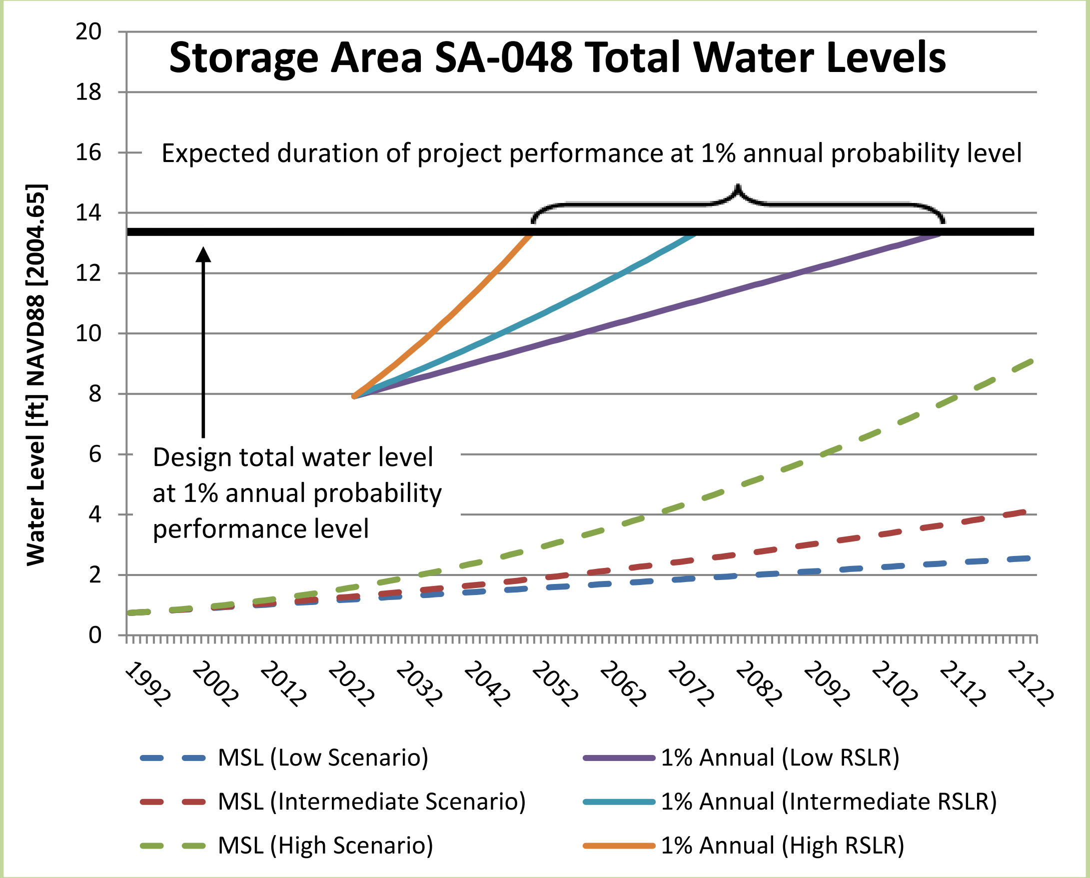

Figure 5: Total water levels over time for Storage Area SA-048

As Figure 5 confirms, the project can be expected to perform at the 1% annual probability level until sometime between the years 2051 and 2111, depending on the rate of future relative sea level rise.

NED Plan Performance: Level of Future Performance

The other way to assess future project performance is in terms of the level of performance delivered at a particular time in the future. In contrast to "when, not if," this approach could be called "if, how much?" It is particularly informative to investigate plan performance 100 years after construction, when future sea level scenarios are highly differentiated.

The Southwest Coastal project has a very large project area, with approximately 4,568 square miles divided into 182 hydraulic reaches. To represent the effects of sea level on total water levels in the year 2125, thirteen sample reaches were chosen for further investigation. While these thirteen reaches contain approximately 4,500 of the approximately 52,000 structures in the project area, they contain a large fraction of the 3,961 structures that will be included in the nonstructural project. For each of the thirteen sample reaches, an annual stage-frequency curve was projected for each of the three sea level rise scenarios. This again required the simplifying assumption of linear superposition of total water level components. While this assumption is not technically justified in this case due to flood stages being a combination of rainfall and storm surge, it is a necessary concession given the limited scope of this report and the resources of SMART Planning. Figures 6-8 show how project performance evolves over time for storage area SA-048, depending on the rate of future sea level rise.

Year	Storage Area SA-048 Total Water Levels [NAVD88 2004.65] (Low RSLR)						
2025	5.43	6.28	7.23	7.50	7.92	8.12	8.60
2030	5.45	6.30	7.31	7.70	8.23	8.48	9.03

2035	5.46	6.33	7.39	7.90	8.55	8.84	9.46
2040	5.48	6.35	7.46	8.10	8.86	9.21	9.89
2045	5.50	6.37	7.54	8.30	9.17	9.57	10.32
2050	5.52	6.40	7.62	8.50	9.48	9.93	10.75
2055	5.53	6.42	7.70	8.70	9.80	10.29	11.18
2060	5.55	6.44	7.78	8.90	10.11	10.66	11.61
2065	5.57	6.47	7.85	9.10	10.42	11.02	12.04
2070	5.59	6.49	7.93	9.30	10.74	11.38	12.47
2075	5.60	6.51	8.01	9.50	11.05	11.74	12.90
2080	5.62	6.54	8.09	9.70	11.36	12.10	13.33
2085	5.64	6.56	8.16	9.90	11.67	12.47	13.76
2090	5.66	6.58	8.24	10.10	11.99	12.83	14.19
2095	5.67	6.61	8.32	10.30	12.30	13.19	14.62
2100	5.69	6.63	8.40	10.50	12.61	13.55	15.05
2105	5.71	6.65	8.48	10.70	12.92	13.92	15.48
2110	5.73	6.68	8.55	10.90	13.24	14.28	15.91
2115	5.78	6.73	8.62	10.99	13.35	14.40	16.05
2120	5.85	6.80	8.69	11.06	13.42	14.47	16.12
2125	5.92	6.87	8.76	11.13	13.49	14.54	16.19
	20%	**10%**	**4%**	**2%**	**1%**	**0.50%**	**0.20%**
	Performance Level [ACE at Design Total Water Level]						

Figure 6: Performance-time table for storage area SA-048 under the low relative sea level rise scenario. Shaded cells indicate non-performance at that combination of time and performance level.

Year	Storage Area SA-048 Total Water Levels [NAVD88 2004.65] (Int. RSLR)						
2025	5.43	6.28	7.23	7.50	7.92	8.12	8.60
2030	5.46	6.31	7.34	7.79	8.37	8.64	9.22
2035	5.48	6.35	7.46	8.09	8.84	9.18	9.86
2040	5.51	6.38	7.58	8.40	9.32	9.75	10.53
2045	5.54	6.42	7.71	8.72	9.83	10.34	11.23
2050	5.57	6.46	7.84	9.06	10.36	10.95	11.96
2055	5.60	6.50	7.97	9.41	10.91	11.58	12.71
2060	5.63	6.54	8.12	9.77	11.48	12.24	13.49
2065	5.66	6.59	8.26	10.15	12.06	12.92	14.30
2070	5.70	6.63	8.41	10.54	12.67	13.62	15.14
2075	5.73	6.68	8.57	10.94	13.30	14.35	16.00
2080	5.87	6.82	8.71	11.08	13.44	14.49	16.14
2085	6.02	6.97	8.86	11.23	13.59	14.64	16.29
2090	6.18	7.13	9.02	11.39	13.75	14.80	16.45
2095	6.33	7.28	9.17	11.54	13.90	14.95	16.60
2100	6.50	7.45	9.34	11.71	14.07	15.12	16.77
2105	6.66	7.61	9.50	11.87	14.23	15.28	16.93
2110	6.84	7.79	9.68	12.05	14.41	15.46	17.11
2115	7.01	7.96	9.85	12.22	14.58	15.63	17.28
2120	7.19	8.14	10.03	12.40	14.76	15.81	17.46
2125	7.38	8.33	10.22	12.59	14.95	16.00	17.65
	20%	**10%**	**4%**	**2%**	**1%**	**0.50%**	**0.20%**
	Performance Level [ACE at Design Total Water Level]						

Figure 7: Performance-time table for storage area SA-048 under the intermediate relative sea level rise scenario. Shaded cells indicate non-performance at that combination of time and performance level.

Year	Storage Area SA-048 Total Water Levels [NAVD88 2004.65] (High RSLR)						
2025	5.43	6.28	7.23	7.50	7.92	8.12	8.60
2030	5.48	6.34	7.45	8.05	8.79	9.12	9.79
2035	5.53	6.41	7.68	8.66	9.73	10.22	11.09
2040	5.59	6.49	7.94	9.32	10.76	11.41	12.51
2045	5.65	6.57	8.21	10.02	11.87	12.69	14.03
2050	5.72	6.66	8.51	10.78	13.05	14.06	15.66
2055	5.97	6.92	8.81	11.18	13.54	14.59	16.24
2060	6.28	7.23	9.12	11.49	13.85	14.90	16.55
2065	6.61	7.56	9.45	11.82	14.18	15.23	16.88
2070	6.96	7.91	9.80	12.17	14.53	15.58	17.23
2075	7.32	8.27	10.16	12.53	14.89	15.94	17.59
2080	7.71	8.66	10.55	12.92	15.28	16.33	17.98
2085	8.11	9.06	10.95	13.32	15.68	16.73	18.38
2090	8.53	9.48	11.37	13.74	16.10	17.15	18.80
2095	8.98	9.93	11.82	14.19	16.55	17.60	19.25
2100	9.44	10.39	12.28	14.65	17.01	18.06	19.71
2105	9.91	10.86	12.75	15.12	17.48	18.53	20.18
2110	10.41	11.36	13.25	15.62	17.98	19.03	20.68
2115	10.93	11.88	13.77	16.14	18.50	19.55	21.20
2120	11.46	12.41	14.30	16.67	19.03	20.08	21.73
2125	12.01	12.96	14.85	17.22	19.58	20.63	22.28
	20%	**10%**	**4%**	**2%**	**1%**	**0.50%**	**0.20%**
	Performance Level [ACE at Design Total Water Level]						

Figure 8: Performance-time table for storage area SA-048 under the high relative sea level rise scenario. Shaded cells indicate non-performance at that combination of time and performance level.

These tables show how flood risk can transition over time in this area. Depending on the rate of sea level rise, a total water level elevation with a 1% annual exceedance probability in 2025 will represent a more frequent event, between a 4% to 10% annual exceedance probability, by 2075 due to relative sea level change. These projections assume that the stage-frequency curve gradually changes shape over the 50 years between 2025 and 2075 in accordance with the acceleration factors corresponding to each sea level rise scenario, then continues to project into the future at the same rate as the rise of mean sea level under that scenario. These evolving performance levels will be important as future decision-makers decide how best to balance further investment against appropriate levels of risk.

Of the thirteen sample reaches investigated, only one (SA-034) would require a structure located on its average elevation to be relocated rather than elevated, under the 1% 2075 flood assuming an intermediate rate of sea level. In practice, the need to relocate structures will depend on their actual elevations and locations within each storage area. Likewise, future project performance will vary across storage areas depending on ground elevation and proximity to the coast.

NED Plan Adaptability

In addition to robustness, plans can be assessed for their adaptability to climate change. By balancing initial investment and adaptation, projects can perform cost-effectively well into the future. As a nonstructural project, adaptation for this plan is somewhat different than for a structural project. A structural project such as a levee or rock structure includes a planned maintenance period with a schedule for future lifts to compensate for subsidence and sea level rise. A non-structural plan does not include such provisions for additional future raises due to the particularities of measures that are applied to individual properties and incrementally justified on a per-structure basis. For example, any additional lifts applied to properties in the future as an adaptation to sea level would first have to be applied to those structures that were not raised initially, since these would now be the most justified. As a result these additional lifts would take on the effect of a new project affecting new structures rather than an adaptation for those properties where the investment was made previously.

Instead of a gradual modification of the project over time as with a structural project, adaptations for non-structural projects like this one occur during implementation. This project will be implemented incrementally over time as funding is appropriated. This allows the project to monitor sea level and adapt implementation accordingly by re-programming funds to focus on areas and structures where elevation is needed and the investment will be lasting. Adaptive implementation can also be used to shift strategies from raises to relocations if indicated by sea level change (though no relocations are recommended in the NED RP. These future investments will be made in consideration of future sea level and compared to structure elevations in the latest geodetic datum issued by NGS. In fact, by the time project implementation begins in 2025, a new geodetic datum (GRAV-D) will be issued to replace NAVD88 (by 2022) and a new sea level will be published corresponding to the end of the present National Tidal Datum Epoch (ending in 2019). Both of these new datums will be critical to guiding project implementation.

Project implementation will also be adapted in consideration of community cohesion and the viability of supporting infrastructure such as roads, water supply lines, wastewater treatment and ecosystem services. Even though a non-structural measure may be technically achievable, it will not be successful if this supporting infrastructure cannot make the area safe and accessible for residents. Furthermore, investments will not be lasting if the surrounding community is not sufficiently intact. Careful consideration of these factors, and how they are changing with the sea level, will be made as the project is implemented over time.

In addition to having an adaptable implementation plan, non-structural projects such as this one offer the additional advantage of not failing catastrophically in the event they are overwhelmed. Unlike a structural solution such as a levee or wall, the nonstructural solution will not suddenly collapse when the loading water level exceeds the project performance level. Even when the project non-performs, it will return to performance when the water recedes again. This is an especially valuable feature when future loading is uncertain due to future sea level rise.

Part 2: NER Plan

Plan Selection

Initial data collection for the NER plan resulted in over 200 features, which were screened and organized into a focused array of 27 plans. These were evaluated using the Wetland Value Assessment (WVA) model and compared against cost in a Pareto optimization. Twelve plans were identified as cost-effective, with eight being best-buy (Pareto optimal) plans. Ultimately, plan CM-4 was chosen as the RP on the basis of being the cost-effective plan with the lowest cost among comprehensive plans (plans where features are distributed across the study area's hydrologic basins). Plan CM-4 includes 49 features, of which nine are marsh restoration through dredged material placement (either beneficial use of navigation dredging or dedicated dredging), five are shoreline protection features (rock dikes), and 35 are chenier reforestation (vegetative plantings and invasive species control). Two hydrologic/salinity control features are also recommended for long-term study (Calcasieu Ship Channel Salinity Control Structure and Cameron-Creole Spillway).

As with the NED plan, the NER plan was formulated using only the intermediate sea level rise scenario. It is therefore necessary to ask whether another plan might have been chosen, had all three scenarios been considered. This is a difficult question to answer due to the inherent uncertainty around the performance of ecosystem restoration projects, which may be larger than uncertainties connected to future sea level. In addition, lack of knowledge around the importance of nonlinear interactions between water level, salinity, and temperature (all influenced by sea level) on marsh health complicates comparisons of plan performance across sea level scenarios. **Nevertheless, it appears unlikely that consideration of all scenarios would have**

resulted in a different plan being chosen. Any of the Pareto-optimal plans could be considered "best;" the choice of plan CM-4 was based on its comprehensiveness and relatively low cost, factors not influenced by sea level change. If a future sea level higher than envisioned in the intermediate scenario had been used in formulation, both project costs and benefits would be correspondingly increased (with the opposite effect occurring in the case of a lower sea level). For another plan to be chosen over plan CM-4, the performance of these plans would have to be differently sensitive to sea level such that costs and benefits would not be changed equally across plans. This appears unlikely as the considered plans were all various formulations of the same features.

One environmental feature that would perform differently under various sea level scenarios is the Calcasieu Ship Channel Salinity Barrier, a movable, navigable barrier that would reduce salinity intrusion into the Calcasieu-Sabine Basin while opening to allow ship traffic to enter and exit the ship channel. The complex engineering considerations, and potential environmental and navigational impacts of this barrier could not be studied adequately within the scope of this SMART planning study Therefore it is recommended for inclusion in the RP as a separate study. An additional feature in the RP, the Cameron-Creole Spillway Structure is also recommended for additional study. Like the Salinity Barrier, it will be highly susceptible to the effects of sea-level change.

Unlike the NED plan, the NER plan is not impacted by altered rainfall patterns, so there is no need to assess the plan's preparedness and resilience to changes in rainfall.

Plan Performance

Under the same assumptions around linear superposition of total water level components that were used in the NED analysis above, the NER plan can be expected to perform for the same duration that the NED plan will provide performance at the 1% annual probability level. Therefore, Figure 4 can be used again to describe future NER plan performance. As long as sea level is the only component of total water level that changes in the future, the NER plan will perform as designed until mean sea level rises 1.2 feet above 2025 sea level, which can be expected to occur sometime between the years 2051 and 2111.

In contrast to the adaptable implementation of the NED plan, **the NER plan provides the opportunity to modify the project over time to adapt to future sea level change**. The marsh restoration (dredged material placement) and shoreline protection (rock/rip-rap structures) features include a schedule for additional future lifts of material to compensate for subsidence and settlement. If future sea level rise is faster or slower than that envisioned in the intermediate scenario, then this schedule can simply be accelerated or decelerated as necessary. The vast majority (35/49) of features in plan CM-4 are chenier restoration features consisting of planting seedlings, protecting these seedlings from herbivores through the use of exclosures, and invasive species control. While these low-cost features are not highly adaptable to changes in sea level, their performance does not exert a strong influence on the overall cost-effectiveness of the RP. In keeping with the "when, not if" approach to sea-level adaptation, the chenier restoration features help these unique coastal environments perform for as long as possible, though their ultimate longevity in the face of rising seas is unknown.