TECHNICAL MEMO

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RE: STORM SELECTION FOR THE ICM - UPDATES & IMPROVEMENTS

To support the 2023 Coastal Master Plan, the Coastal Protection and Restoration Authority (CPRA) is building upon existing technical tools and approaches developed for previous master plan efforts with targeted updates and improvements. This document reports on activities to develop a new, probabilistic approach for selecting storm sequences and to apply that approach to identify the storms to be included in Integrated Compartment Model (ICM) runs for the 2023 Coastal Master Plan.

For ICM runs supporting the 2017 Coastal Master Plan, individual storms were selected from a set of synthetic storms to most closely approximate and represent historic storms. Because the 2023 Coastal Master Plan draws upon a suite of synthetic storms developed for the US Army Corps of Engineers' (USACE) Coastal Hazards System (CHS) (Melby et al., 2015; Nadal-Caraballo et al., 2020), we needed to update the synthetic sequence representing historic storms. We also have developed a sequence of synthetic storms that is more "balanced" across the coast, in that it maintains the same frequency and distribution of intensities as the historic record, while reducing the variability in the number and severity of events each ICM compartment experiences. This statistical approach was developed to address concerns about possible bias from the localized storm effects and their influence on project selection across master plan modeling tools.

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1.0 HISTORIC STORM SEQUENCE

Between 1970 and 2019, 61 Atlantic tropical cyclones impacted Louisiana and/or Mississippi (i.e., made landfall within 3 degrees longitude of the states' boundaries). The maximum number of events in a single year was five (in 1971 and 2005); 15 years had no storms. This analysis matched each historical tropical cyclone from 1970 onward to the most similar synthetic storm in the CHS suite, generating a sequence of synthetic storms resembling the historic record. For each event, we first select synthetic storms with a heading within 20 degrees of the historical cyclone's heading at landfall; if no synthetic storm tracks have a heading within 20 degrees, we consider storms from the track with the minimum difference in heading. We also only consider synthetic storms which make landfall within 0.4 degrees longitude of the historical event (approximately 38-39 km in the Louisiana coastal zone). If there are no such synthetic storms, the radius is iteratively increased by 0.2 degrees longitude until at least one storm is selected. From the resulting set of synthetic storms, the synthetic storm is matched which minimizes the sum of the squared difference between the historic and synthetic storms' central pressure deficit, forward velocity, and radius of maximum winds, each normalized by the range of values present in the synthetic storm suite. Parameters missing from the Hurricane Database (HURDAT) record of a given historical storm are ignored when matching that storm. If only forward velocity or central pressure deficit are observed, a non-unique synthetic storm match (i.e., a tie) may occur, which is broken arbitrarily. The sequence of historic cyclones and matching synthetic storms is provided in Table A1.

2.0 DEVELOPING BALANCED STORM SEQUENCES

2.1 CALCULATING WATER SURFACE ELEVATION EXCEEDANCES

Our second objective was to identify sequences that are "balanced," in the sense of all regions of the coastal zone experiencing events of similar likelihood. To do this, we sampled the centroids of each of 33 ICM compartments, shown in Figure 1. The 33 compartments were selected so that water levels would be extracted from both interior water bodies and more exposed coastal waters. Large water bodies on the interior where water level data were extracted included: Sabine, Calcasieu, Grand and White Lakes in the Chenier Plain; Vermilion Bay; Lac des Allemands; and Verret, Salvador, Little, Maurepas, and Pontchartrain Lakes. More exposed, coastal water levels were extracted from: offshore of Rockefeller Wildlife Refuge; Atchafalaya Delta; Terrebonne, Caminada, and Barataria Bays; Lake Borgne; and Chandeleur Sound. Additional points were placed offshore of each barrier island group stretching from Raccoon Island in Caillou Bay eastward to Chandelier Island.

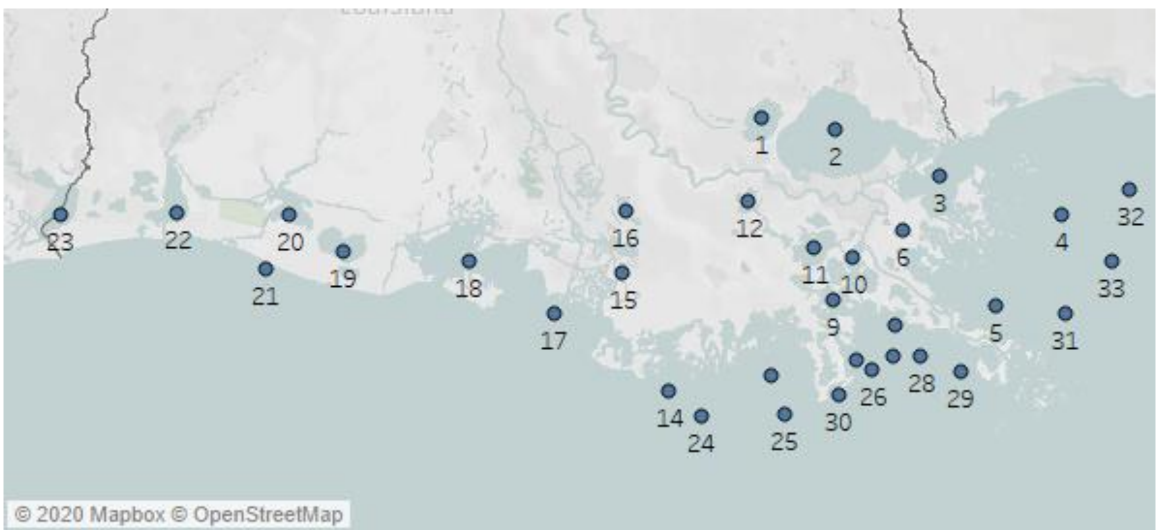

Figure 1. Sample points located within 33 ICM compartments.

At each point, peak water surface elevations (WSE, i.e., surge) were recorded from ADCIRC simulations of the 645 synthetic storms under the 2017 Coastal Master Plan's Current Conditions landscape (representing 2015). Because of delays in receiving materials related to the new JPM-OS methods under development at USACE, we have adapted the 645 storm suite to CLARA's previous implementation of JPM-OS methodology. This was a non-trivial task due to differences in the design structure of the 645 synthetic storms compared to the previous suite of 446. In the 446 storm suite, tracks were defined by landfall location, identified as the point where a storm crosses 29.5 N latitude.

Headings could take three distinct values at landfall, with 0 denoting the mean heading of historical storms making landfall within 3 degrees longitude. Additional storms on the same track made landfall at approximately the same location but with headings differing by ±45 degrees. The probability mass associated with a storm's angle in the 2017 JPM-OS methodology is conditional upon the landfall location (i.e., track). This conditional relationship relies on having a synthetic storm suite structured such that track angles represent variations on an initial subset which are spread across multiple landfall locations.

The new synthetic storm suite is not structured in this way. It treats landfall location as a parameter varying conditionally upon a given landfall angle rather than vice-versa, and tracks are no longer grouped by landfall location alone. Instead, storms originating on the same path through the Gulf of Mexico diverge such that their heading at landfall varies at 20-degree intervals from due west, north to due east. Each "heading track" was then shifted east and west in 60 km intervals in order to span the study region.

To impose a structure on the 645 storm suite that is compatible with the 2017 CLARA methodology, we treat the regularly spaced "heading tracks" traveling due north as primary tracks, each of which was assigned a track identifier. We then assign to every other storm the track ID of the primary track with the nearest landfall location (based on an idealized coastline at 29.5° N latitude). To be further consistent with the prior methodology, the absolute heading of each storm was converted to be expressed relative to the mean heading of historical events making landfall within 3 degrees longitude of each track. The imposed track structure results in some tracks being composed of storms with irregular angle spacing. We do not presently believe that this unbalanced structure presents a problem, but for the sake of future sensitivity analysis we have retained data on a subset of storms which excludes certain track-angle combinations, so that all tracks have storms with a balanced angle structure. We also discarded 98 synthetic storms on tracks that do not make landfall sufficiently near the CLARA domain to produce an impact on water surfaces within the study region.

Water surface elevation exceedance curves for each ICM sample point followed methods from the 2017 Coastal Master Plan (Fischbach et al., 2017), adapted to incorporate some elements of the updated JPM-OS methodology developed by USACE. The probability mass of each of the 547 storms was calculated using CLARA's existing JPM-OS methodology, as was the underlying storm recurrence rate. The cumulative probabilities for each water surface elevation, conditional on a storm occurring, were converted to annual exceedance probabilities by treating storm arrivals as a Poisson process with mean interarrival rate equal to the average storm frequency from the HURDAT record (1950-2019).

2.2 STORM SELECTION ALGORITHM

Synthetic storms were selected for the ICM with the goal of producing a sequence that maintains a similar frequency and distribution of intensity of storms to the historical record over the last 50 years. However, we also wish to produce a more “balanced” sequence, in the sense that each sample point experiences a similar number of events with a given return period. The ICM synthetic storm sequence is based on balancing the number of 5-, 10-, 50-, and 100-year water surface elevation events over the 33 sample points. A synthetic storm is considered to “match” a given return period if its peak WSE is within 0.5 ft of the estimated WSE exceedance corresponding to that return period.

To achieve this, the selection algorithm starts with the synthetic historic sequence and counts how many events occur at each point corresponding to each of the four targeted return periods. For each synthetic storm in the historic sequence, we consider swapping it with any other synthetic storm of identical central pressure. The proposed swap that would result in the largest reduction in the variance of the counts of target events, across all sample points and return periods, is accepted. The algorithm repeats until no more swaps would reduce the variance in the number of qualifying events for each point-return period combination. Consequently, the resulting sequence preserves the number and timing of synthetic storms compared to the historic record. It also maintains the distribution and order of cyclone intensities.

Only 23 synthetic storms are required to match the 5-, 10-, 50-, and 100-year WSEs at all 33 ICM locations to within a ±0.25 ft tolerance. The historic sequence of 61 synthetic storms matches many point-exceedance combinations multiple times. However, achieving a more balanced sequence of storms requires expanding the tolerance to ±0.5 ft. The number of synthetic storms that match target exceedances with this tolerance are summarized in Figure 2. These facts combine to provide many options for swapping storms that hit various target return periods at many points. As a result, the final sequence of synthetic storms reduces the variance of the number of storms matching each storm-return period combination from 24.6 to 1.6, a reduction of 93.5 percent. However, this algorithm does not guarantee that every storm-return period combination is matched by at least one storm. The balanced sequence does not yield a 50-year event at four points, nor a 100-year event at one location. This still represents an improvement over the historic synthetic sequence, which is missing a 10-year event at one point, 50-year events at five points, and 100-year events at ten points. The number of storms matched by the historic synthetic sequence and the balanced sequence, with a WSE within 0.5 ft of each ICM point’s exceedance value, is summarized in Table 1 for the 5-, 10-, 50-, 100-, and 500-year return periods. The WSE exceedance is also provided in NAVD88 feet. To easily see the synthetic storms that are changed between the historic synthetic and balanced sequences, Table A1 provides both sequences along with the original historical storm ID and year of occurrence.

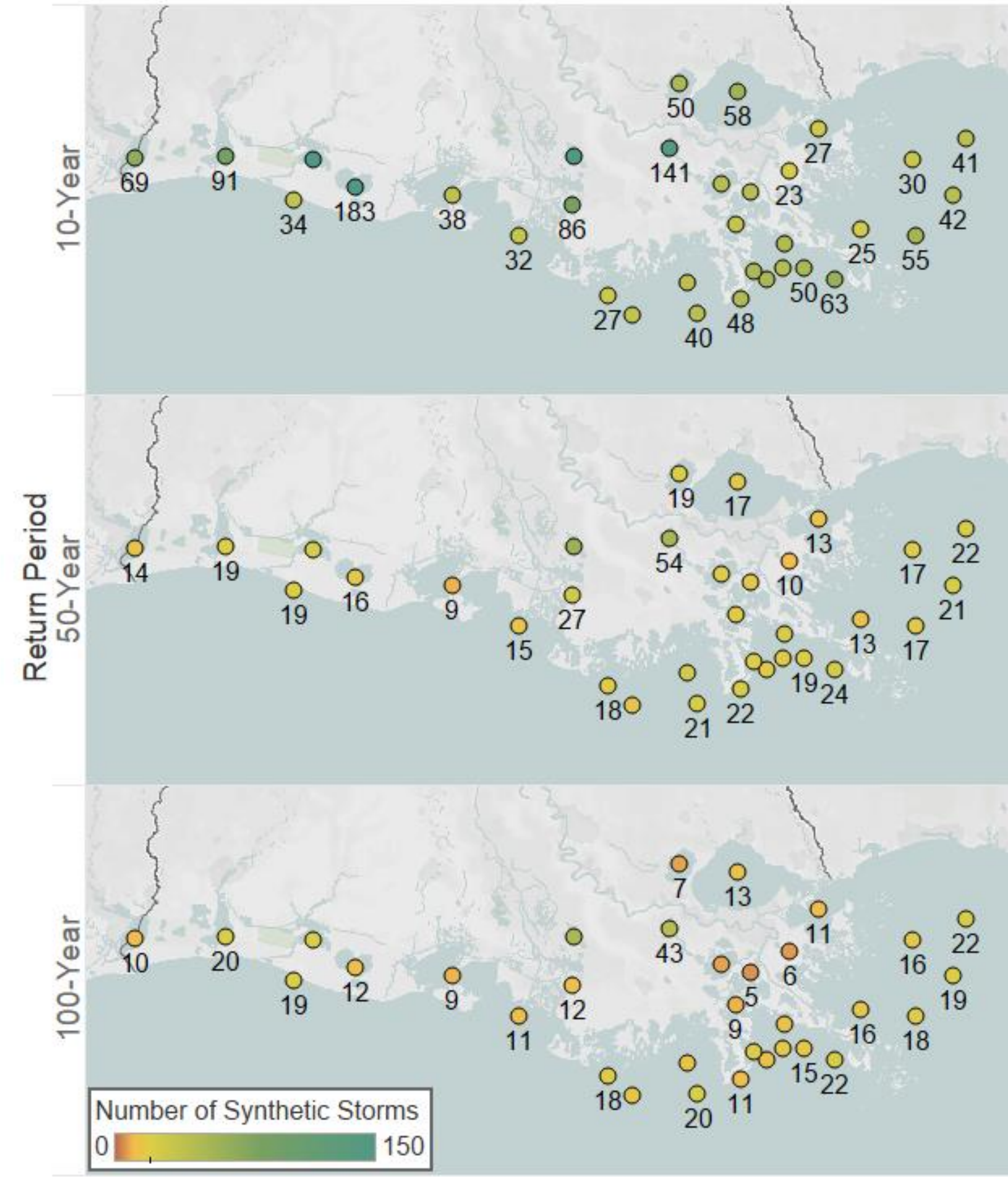

Figure 2. Number of synthetic storms matching WSE values with indicated return periods (0.5 ft tolerance).

Table 1. Storms matching target WSE exceedance values (0.5 ft tolerance) (H=historic sequence, B=balanced sequence, WSE+NAVD88 ft).

	Return Period								
	10-Year			50-Year			100-Year		
Point ID	H	B	WSE	H	B	WSE	H	B	WSE
1	6	3	4.8	1	2	7.3	1	2	8.7
2	9	4	5.0	4	1	7.3	1	2	8.7
3	0	1	6.8	3	2	11.0	0	2	12.5
4	6	3	5.6	1	2	9.1	2	2	9.9
5	6	4	6.1	3	1	10.6	0	2	11.7
6	3	1	7.3	1	1	12.3	0	1	13.7
7	8	4	4.7	2	1	7.2	1	1	8.6
8	10	6	3.9	1	1	6.0	3	2	6.6
9	9	3	4.9	1	2	7.8	2	1	8.7
10	6	2	4.8	0	0	7.9	1	1	9.0
11	6	1	4.1	2	1	6.3	1	1	7.1
12	24	3	2.8	6	3	3.5	4	4	3.8
13	8	1	4.8	0	2	7.3	1	2	7.8
14	4	2	4.8	0	2	8.1	0	2	8.5
15	12	1	3.3	3	1	4.5	2	1	5.6
16	29	6	1.7	5	3	2.3	4	3	2.5
17	4	1	5.0	1	0	8.3	0	1	9.7
18	7	1	5.1	0	0	7.9	1	1	9.5
19	19	4	1.9	1	1	4.2	0	0	4.9
20	21	6	1.8	3	1	3.8	2	1	4.3
21	6	1	3.9	7	3	6.8	4	1	8.4
22	7	2	3.0	5	1	5.0	4	2	5.6
23	7	2	3.3	2	2	6.0	3	2	6.7
24	1	1	4.5	1	1	7.5	0	1	8.5
25	5	2	4.1	0	0	6.3	2	1	7.1
26	7	2	4.1	1	1	6.6	1	2	7.4
27	6	1	4.1	2	1	6.7	1	2	7.5
28	10	5	3.6	1	2	6.2	0	1	6.7
29	7	3	3.6	1	2	5.7	1	2	6.2
30	8	2	4.0	1	2	6.1	1	1	7.0
31	8	4	4.2	3	1	6.8	0	2	7.8
32	6	5	4.4	4	2	7.3	3	3	7.8
33	7	2	4.2	4	2	6.7	0	2	7.4
Average	8.5	2.7	4.2	2.1	1.4	6.9	1.4	1.6	7.7

3.0 REFERENCES

J. Fischbach, D. Johnson, K. Kuhn, M. Pollard, C. Stelzner, R. Costello, E. Molina-Perez, R. Sanchez, J. Syme, H. Roberts, Z. Cobell. 2017. "2017 Coastal Master Plan Modeling: Attachment C3-25 – Storm Surge and Risk Assessment." Baton Rouge, Louisiana: Louisiana Coastal Protection and Restoration Au-thority.

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4.0 APPENDIX A: HISTORIC AND BALANCED STORM SEQUENCES

Table A 1. Synthetic storms most similar to historic storm events, and the balanced sequence.

HURDAT Storm ID	Year	Synthetic Storm ID	Balanced Synthetic Storm ID
131970	1970	61	544
21971	1971	68	103
51971	1971	188	38
101971	1971	170	573
111971	1971	415	415
131971	1971	556	193
111973	1973	459	515
41974	1974	241	297
101974	1974	83	83
61975	1975	95	304
181975	1975	504	639
161976	1976	531	510
21977	1977	437	437
61977	1977	503	285
151977	1977	592	414
91978	1978	474	103
41979	1979	510	510
61979	1979	242	242
111979	1979	310	296
51982	1982	357	551
171984	1984	102	629
41985	1985	263	103
121985	1985	576	414
21986	1986	141	414
31987	1987	349	615
71988	1988	298	298
41989	1989	141	141
141989	1989	341	615
41992	1992	276	276
171995	1995	544	544
51997	1997	600	197
71998	1998	305	544

HURDAT Storm ID	Year	Synthetic Storm ID	Balanced Synthetic Storm ID
81998	1998	510	510
92000	2000	250	285
122000	2000	319	319
22002	2002	190	190
92002	2002	423	423
102002	2002	592	366
132002	2002	260	302
32003	2003	510	510
92004	2004	437	437
142004	2004	399	399
12005	2005	437	437
32005	2005	407	407
122005	2005	413	180
182005	2005	355	565
92007	2007	553	150
52008	2008	68	103
72008	2008	173	414
92008	2008	131	606
112009	2009	423	423
32010	2010	90	90
52010	2010	196	196
132011	2011	489	285
92012	2012	173	197
32017	2017	355	355
92017	2017	357	357
162017	2017	413	551
72018	2018	205	205
22019	2019	75	103
172019	2019	499	302