Numerical Modeling of Storm Surge Effect of MRGO Closure

Summary

An examination of the effect of a closure of the MRGO on storm surge elevations was conducted using the ADCIRC model. Nine scenarios consisting of combinations of slow, medium, fast forward speeds with weak, moderate, and strong intensities were run twice with identical input parameters except for the geometry of the MRGO near the La Loutre ridge where a hypothetical closure dike was placed for one set of runs and absent for the other set of runs. Hurricane Betsy wind fields were also run twice with the same grids. The difference in maximum storm surge elevation between the paired runs for the open MRGO and the MRGO with a closure was generally small. The maximum difference between the with and without MRGO closure was 0.54 feet.

Purpose

The purpose of this report is to present the results of the ADCIRC model runs made to assess the impact of the MRGO upon storm surge still water elevations. This includes a description of the model and the input parameters, a discussion of the reasons for selecting the ADCIRC model and the credentials of the independent contractor who made the model runs and the independent technical review committee.

Model Description

ADCIRC is an advanced circulation model specifically written for shelves, coasts and estuaries. ADCIRC is a two-dimensional depth integrated finite element based hydrodynamic circulation code. ADCIRC has the capability of modeling very large domains. The domain modeled in this study was all of the waters of the North Atlantic west of 60 West longitude including all of the Caribbean Sea and the Gulf of Mexico. The finite element grid allows for coarse resolution in open waters far from the area of interest and for finer grid resolution in the study area. The finite element grid allows for the model boundary to accurately follow the coast line and for narrow channels to be realistically incorporated into the grid.

ADCIRC has an efficient solution scheme that allows for very large domains. It is a very computationally intensive computer code. For the 600,000 plus element ADCIRC-NO grid used in this study being run on 128 processors on the Cray T3E, one day of simulation requires 2.1 hours of computer time. Thus, a simulation of 28 days, including tidal spin up, takes over 54 hours of computer time.

The details of the numerical scheme used in the ADCIRC model along with accuracy testing are provided in a series of reports and papers (Luettich et al., 1991b, 1994; Kolar et al., 1994a, 1994b, 1996; Westerink et al. 1992c, 1994b).

The ADCIRC code has been modified for use in southern Louisiana to handle the highly intricate flows that occur when southern Louisiana is flooded. New features include wetting and drying of elements, internal and external weir type barrier boundaries to represent the levees and raised roads, a riverine radiation boundary condition to allow river flow and surge propagation without surge reflection, as well as a spatially variable weighting parameter in the Generalized Wave Continuity Equation (GWCE) that is critical for handling the highly intricate finite element grids necessary for this application.

ADCIRC has also been implemented in parallel using domain decomposition, a conjugate gradient solver and MPI based message passing. When a relatively low ratio of interface to processor partition nodes is maintained, linear or even super-linear speedups are achieved. Thus, the wall clock time is reduced by a factor equal to or greater than the number of processors that the code is being run on. Super-linear speed-ups are possible since the problem sizes are reduced such that the portion of the simulation being run on each processor can take advantage of the on chip caching available on RISC (reduced instruction set computer) based chips used in parallel computers. Benchmarks have been run on a variety of platforms with up to 128 processors. The runs for this study were done using 128 processors on the Cray T3E at the High Performance Computing Center in Vicksburg.

The ADCIRC computer model is the best tool for evaluating storm surge in southern Louisiana for a number of reasons. First, the finite element grid allows for explicit representation of all of the major waterways, channels, levees and other features of the region. Second, the large domain allows for the application of boundary conditions where there is no need for a priori knowledge of the surge conditions. Third, the model has been tested and reviewed by a technical review committee and has been extensively published in peer reviewed journals. These reasons for choosing the ADCIRC model are further discussed below in the sections on the grid, the boundary conditions, and the model verification.

Modeled Scenarios

Nine storm scenarios were tested. These nine storms were the combinations of a weak, moderate, or strong intensity in combination with either a slow, moderate, or fast forward speed approaching the Louisiana coast. The same track was used for all nine combinations. Figure 1 show the track of the storms which came ashore west of the Mississippi River such that the maximum winds to the east of the northward moving storm would be blowing northward along the axis of the MRGO. The track maximizes the winds parallel to the MRGO channel yet minimizes the eastern winds across the Mississippi Sound into Lake Borgne. Each of the nine storms was tested for existing conditions and with a closure in the MRGO. The MRGO closure was located at the Bayou LaLoutre ridge. Figures 2a and 2b show the depth contours for the existing MRGO conditions and for the closure of the MRGO at the Bayou LaLoutre ridge. Parametric information about the nine storms is given in Table 1.

In addition to the nine storm scenarios listed in Table 1, the ADCIRC model was also run for the historical Hurricane Betsy that came ashore in Louisiana in September 1965. The track of Hurricane Betsy is also shown in Figure 1. The Betsy computer runs were performed using the best reconstructed wind fields as produced by the Hurricane Research Division of NOAA (Dunion and Powell, 2003).

Storm Number	Forward Speed (knots)	Maximum Wind (knots)
1		65
2	5	100
3		124
4		65
5	13	100
6		124
7		65
8	20	100
9		124

Table 1: Nine storms – Forward Speeds and Maximum Winds

Principle Investigators

An independent contractor, Westerink and Luettich Consulting, located in South Bend Indiana, performed the numerical modeling of the storms using the ADCIRC model. Dr. Joannes Westerink and Dr. Richard Luettich have been involved in the development of the ADCIRC model from its inception. They have also been involved with the New Orleans District in the development of the ADCIRC-NO hurricane storm surge model grid for Southern Louisiana.

Dr. Joannes J. Westerink has been on the Notre Dame Civil Engineering faculty since 1990. Prior to that he taught at Princeton University and Texas A&M University. He has a Ph.D. from M.I.T. He is the author of several textbook chapters on numerical modeling and the application of finite element models to ocean circulation. He is the author of numerous publications in the fields of finite element modeling techniques, wind stresses, and ocean and estuarine circulation.

Dr. Richard A. Luettich is currently professor of Marine Science and Environmental Sciences and Engineering at the University of North Carolina at Chapel Hill. He has a doctorate from M.I.T. He has written numerous scientific papers and reports on tidal and storm surge circulation, numerical modeling techniques, and wind forced aquatic systems.

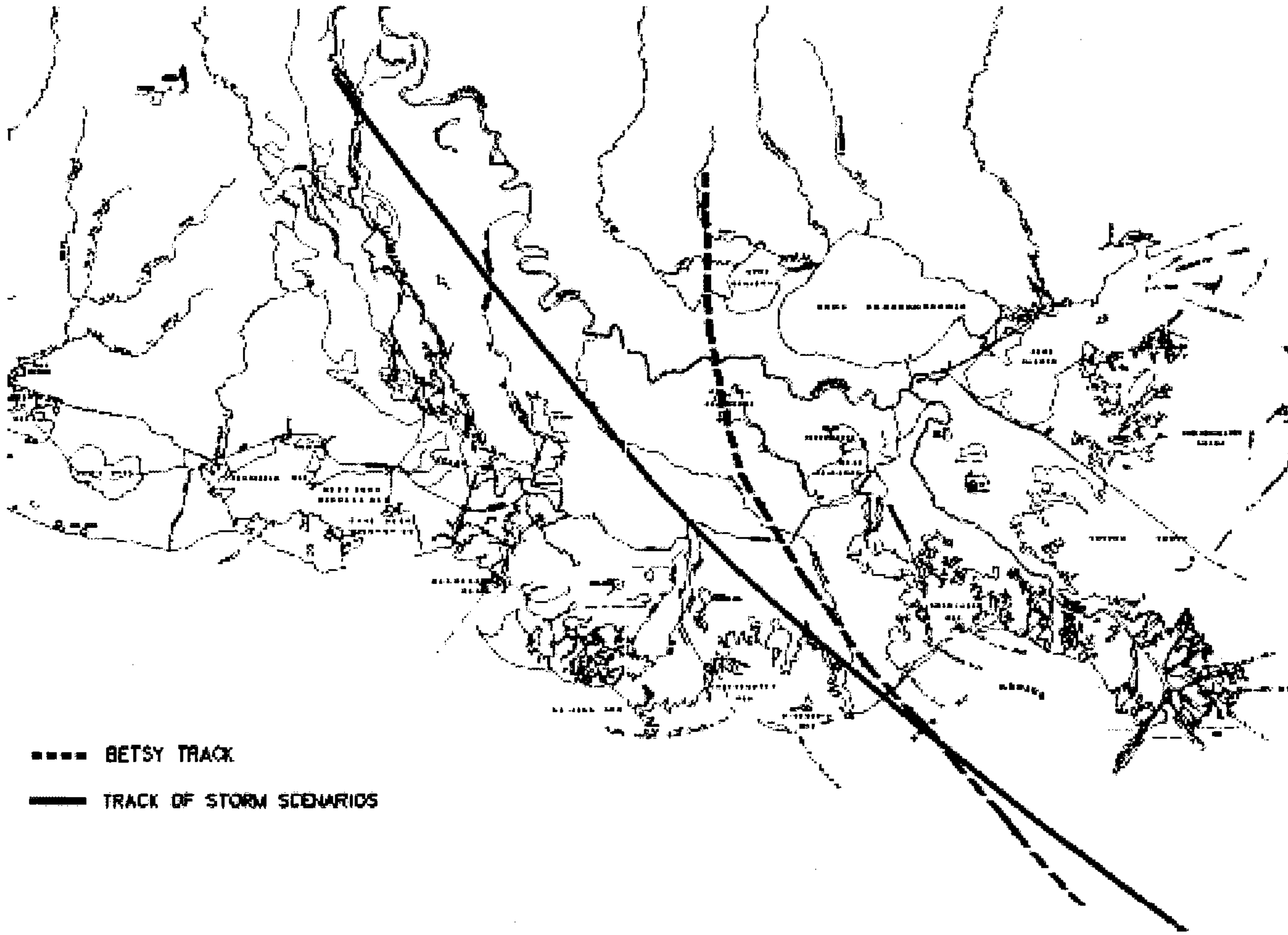

Figure 1: Storm tracks used in the MRGO closure analysis.

The ADCIRC-NO Southern Louisiana grid used in the MRGO closure study has over 314,000 nodes and over 600,000 elements, eighty-five percent of which are in southern Louisiana and the surrounding nearshore waters. Elements are triangles connecting three nodes. Figure 3 shows the entire grid of connected elements. Specifically the grid incorporates all waters of the western North Atlantic Ocean, the Gulf of Mexico and the Caribbean Sea west of longitude 60 degrees West into the computational domain. The 60 degree West longitude runs from Nova Scotia in the north to Venezuela in the south. This allows storms to be seamlessly tracked into the Gulf of Mexico and brought into southern Louisiana without requiring guesswork to define the necessary boundary conditions for hurricane storm surge and/or tides. The current ADCIRC-NO has an open ocean resolution as great as 50 kilometers but grid sizes less than 50 meters in southern Louisiana.

All Federal levee system design grades have been incorporated into the grid. Levees are represented as internal barrier boundaries or, when they are at the edge of the domain, as external barrier boundaries. Internal barrier boundaries are accommodated in the ADCIRC code as dry land outside of the computational domain. If the water level rises to a height above the internal boundary it is treated as a weir allowing both supercritical and sub-critical flow across the weir/island depending on water elevations at node pairs on opposite sides of the island. All other significant non-Federal levee systems, elevated roads, and railways have been specifically incorporated into the domain as either internal or external barrier boundaries.

Bathymetry and topography were obtained from a variety of sources. Typically, the ETOPO5 database was used to supply bathymetric values in deep waters as well as in all Mexican and Cuban waters (National Geophysical Data Center, 1988). Within the U.S. continental shelf waters, the NOAA depth-sounding database was used (National Ocean Service Hydrographic Survey Digital Database, 1997). Within the regions of southern Louisiana and the northern extent of the Atchafalaya basin, available topographic survey data were used.

Model Verification

The ADCIRC-NO model was initially verified using historical simulations of Hurricanes Andrew and Betsy including tides using the appropriate levee system grids. Further verification runs were performed with other historical storms that impacted the Louisiana coastal areas. The wind fields for these historical storms were hindcast using measured storm parameters and a planetary boundary layer (PBL) wind model. The wind field for hurricane Andrew was validated against measured data. Surface water elevations were compared to measured hydrographs at numerous locations throughout southern Louisiana. These historical model runs show that the ADCIRC-NO model is able to accurately simulate the physics of storm surge flooding scenarios throughout Southern Louisiana.

The hurricane storm wind and pressure field simulators applied in this study are the Planetary Boundary Layer (PBL) (Cardone et al., 1979, 1992, 1994; Thompson and Cardone, 1996) and the NOAA Hurricane Research Division best actual wind field for Hurricane Betsy (Dunion and Powell, 2003). The PBL model was validated against measured data for Hurricane Andrew, which indicated excellent wind and pressure field predictions for open water and land regions within the vicinity of water. PBL winds for regions well inland such as Baton Rouge were somewhat over-predicted. However, this was modified through the application of a land roughness reduction factor.

The PBL model specifies a hurricane surface wind field by applying a dynamic numerical model of the planetary atmospheric boundary layer. The model is based on the horizontal equations of motion that are vertically averaged through the planetary boundary layer. It is able to represent effects of friction, latitude, storm motion, and the shape and intensity of the sea level pressure pattern in generating an asymmetrical, vertically integrated flow in the planetary boundary layer. Asymmetrical flow around the eye can also be controlled with the use of a steering parameter. Model inputs are the position and central pressure of the hurricane eye and the maximum winds. The PBL model provides accurate wind velocity and pressure fields over open waters, near-shore regions, and over coastal landforms. A description of the PBL model is provided by Cardone et al. (1979; 1992; 1994) and Thompson and Cardone (1996).

Independent Technical Review

The simulations of the verification runs were extensively reviewed by an independent technical review committee comprised of three world renown experts in numerical simulation of ocean circulation, coastal processes and hurricane winds. An iterative process between modelers and reviewers enabled a better product and insured a quality driven product.

Professor Robert O. Reid is currently Distinguished Professor Emeritus in the Department of Oceanography at Texas A&M University. He has written textbook chapters on the subjects of numerical modeling of ocean and estuarine circulation. Noteworthy among these is the chapter on Tides and Storm Surges in the Handbook of

Coastal and Ocean Engineering. He has over 80 publications ranging from analytical and numerical studies of ocean circulation, storm surges, tides and tsunamis, to surface waves dynamics, estuarine circulation, and modeling of dense plumes.

Dr. Robert G. Dean is currently Emeritus Graduate Research Professor at the University of Florida. He is a world-renowned expert in the areas of coastal engineering. He has written a book on Beach Nourishment and along with Robert A. Dalrymple has written two textbooks; the first titled "Water Wave Mechanics for Engineers and Scientist" and recently "Coastal Processes with Engineering Applications." He has developed and participated in the application of storm surge models for establishing hazard zones for 24 coastal counties in Florida.

Dr. Mark D. Powell is an Atmospheric Scientist at the NOAA Hurricane Research Division. He is an expert on hurricane winds. He has written numerous scientific papers on the subjects of coastal meteorology, hurricane wind fields, marine boundary layers, and wind drag coefficients. He has written a textbook chapter on "Tropical Cyclones During and After Landfall"

Boundary Conditions

There is a dictum in modeling that boundary conditions need to be sufficiently far away from the area of interest so that the prescribed conditions do not dictate the solution. For this reason, the open water boundary was placed in the deep Atlantic Ocean where tides are linear and slowly varying and where hurricane storm surge surface elevation response consists of a simple inverted barometer corresponding to the atmospheric pressure field deficit. Furthermore, the deep Atlantic Ocean boundary is well away from resonant basins such as the Gulf of Mexico where boundary condition specification can lead to model inaccuracies.

The use of the 60 degree west longitude boundary avoids the problems associated with the use of a small, localized domain placed on the adjacent continental shelf. For example, although it is known that hurricane storm surge builds up significantly on the shelf, it is not possible a priori to accurately specify the storm surge elevations at the shelf boundary. The spatial variation of tidal response increases on the shelves and neither global tidal models nor satellite based tidal databases provide good boundary conditions in these areas. Shelf-to-adjacent basin physics are represented much better when the boundary is in deep-water because a small domain cannot capture the resonant modes that are potentially generated within the Gulf of Mexico (Blain et al., 1994a); however, these are appropriately represented when using a large domain.

The use of a domain encompassing all of the Gulf of Mexico, using the Strait of Florida and the Yucatan Channel as boundaries, avoids many of the potential shelf to adjacent basin issues but will not adequately represent basin-to-basin interactions that can be important when modeling the Gulf of Mexico. The Gulf of Mexico is a highly sensitive resonant basin, and although a domain limited to the Gulf may generate the correct primary storm surge, it can have serious errors in the Gulf's resonant modes. Specifically, the Gulf of Mexico is sensitive to the generation of artificial long wave modes by inaccurate port boundary conditions (Blain et al., 1994a). In addition, these boundaries have high tidal flows that are difficult to accurately specify.

In summary, by using the 60 degree west longitude boundary located in the deep Atlantic Ocean, the most accurate representation of water levels in the study area during a hurricane storm surge event is obtained. Using this boundary condition minimizes or avoids all of the problems associated with the use of a small, localized domain or a domain limited to the Gulf of Mexico, and therefore yields superior, reliable results.

Results

The storm simulations were run without any tidal effects, thus the water levels obtained in the model runs could be higher or lower by an amount equal to the tide range. Tidal effects would not appreciably change the model results, since we are interested in the difference between the high water level for the open and the closed case for the same tidal conditions. The discussion below about the results of the storm surge modeling for open and closed conditions for the MRGO is for areas along the MRGO that are outside of the hurricane protection levees.

The model runs of the nine storm scenarios did not show any differences in storm surge levels outside of the area of the MRGO and the IHNC area. There was no noticeable difference in the hydrographs for Delacroix or for Lake Pontchartrain. The differences along the MRGO at four stations are summarized for the four extremes (the combinations of the slow and fast forward speeds coupled with the weak and strong winds) of the storm scenarios in Table 2. Hurricane Betsy is also included in Table 2.

Storm	IHNC Lock	Paris Road	Bayou Dupre	Shell Beach
Fast-124 knot wind	0.156	0.19	0.16	0.53
Fast-65 knot wind	0.3	0.33	0.54	0.37
Slow-124 knot wind	0.11	0.13	0.14	0.26
Slow-65 knot wind	-0.028	-0.023	-0.022	-0.016
Betsy	-0.032	0.010	-0.021	0.297

Table 2: Differences in Maximum Storm Surge in Feet for Open MRGO Versus Closed MRGO.

The slow moving weak storm did not show very much difference between the open and closed cases. In fact the slow moving weak storm did not show any reduction in the maximum surge elevation at any of the four gage locations listed in Table 2. Figure 4 shows the location of the four gages station at the IHNC Lock, Paris Road, Bayou Dupre Flood Gate and Shell Beach. Figures 5, 6, 7 and 8 show the hydrographs for the slow moving weak storm (maximum wind speed of 65 knots) at the IHNC Lock, Paris Road Bridge, Bayou Dupre Flood Gate and Shell Beach.

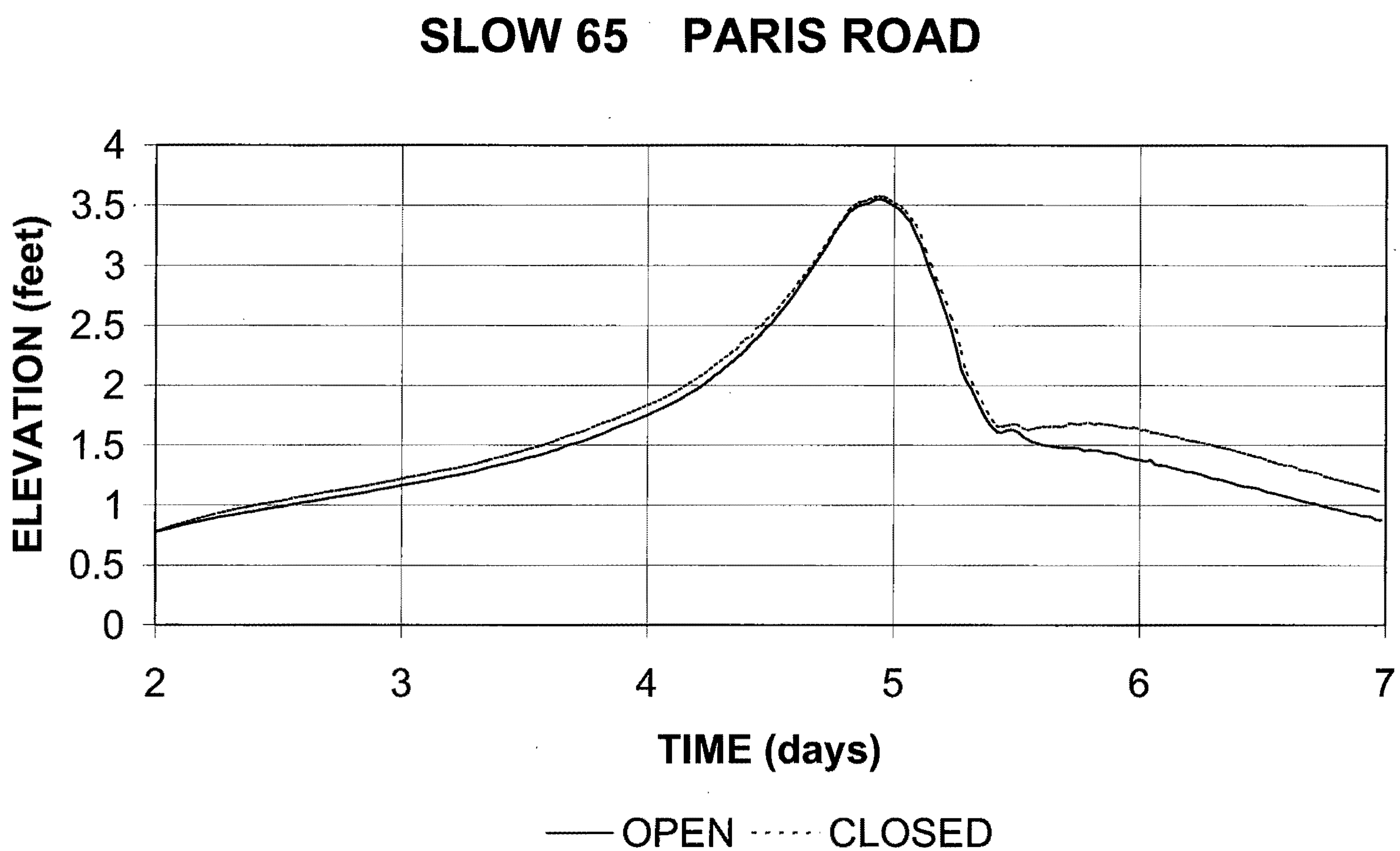

Figure 6: Hydrographs at Paris Road Bridge for open and closed MRGO for the slow moving weak storm condition.

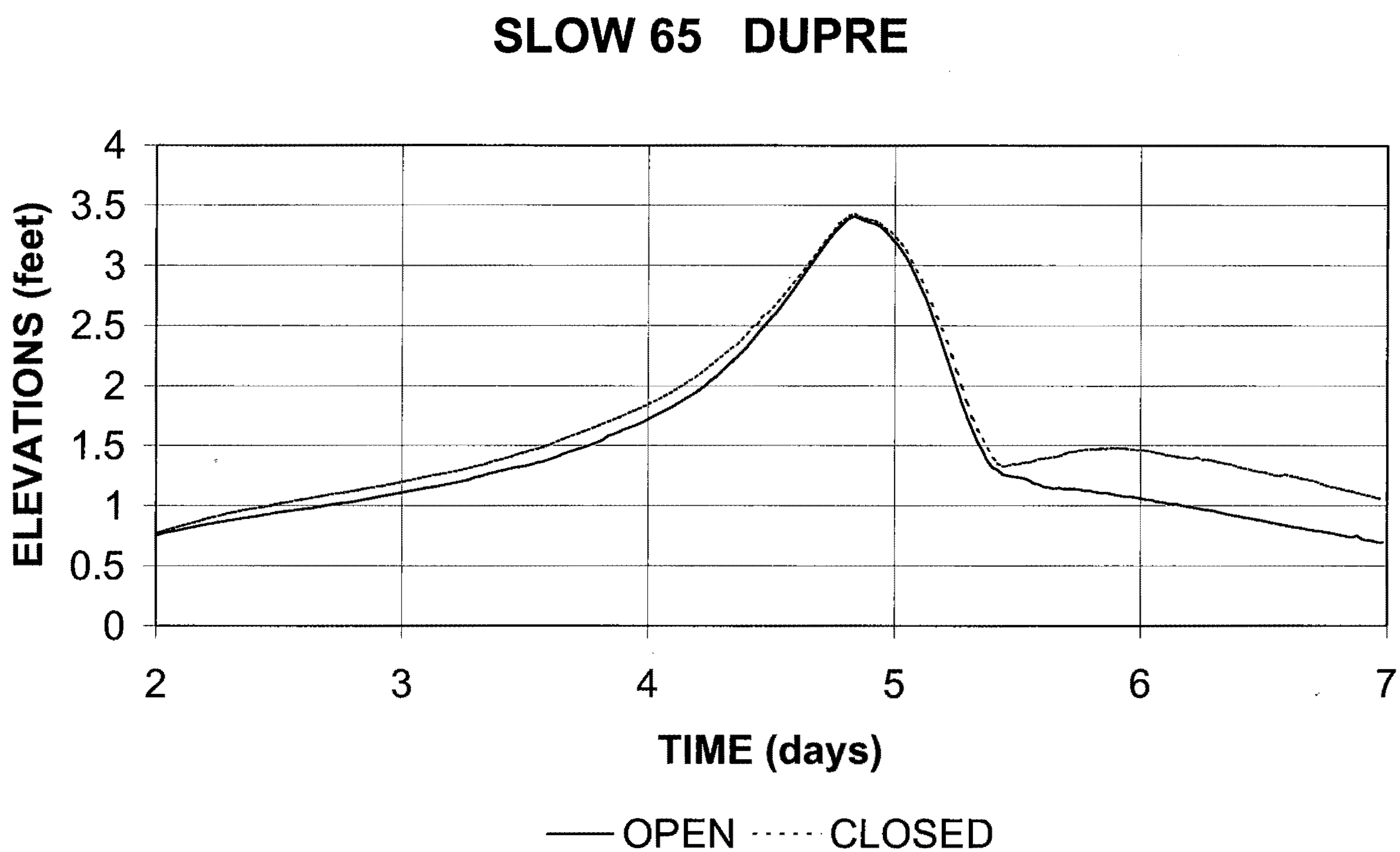

Figure 7: Hydrographs at Bayou Dupre Floodgate for open and closed MRGO for the slow moving weak storm condition.

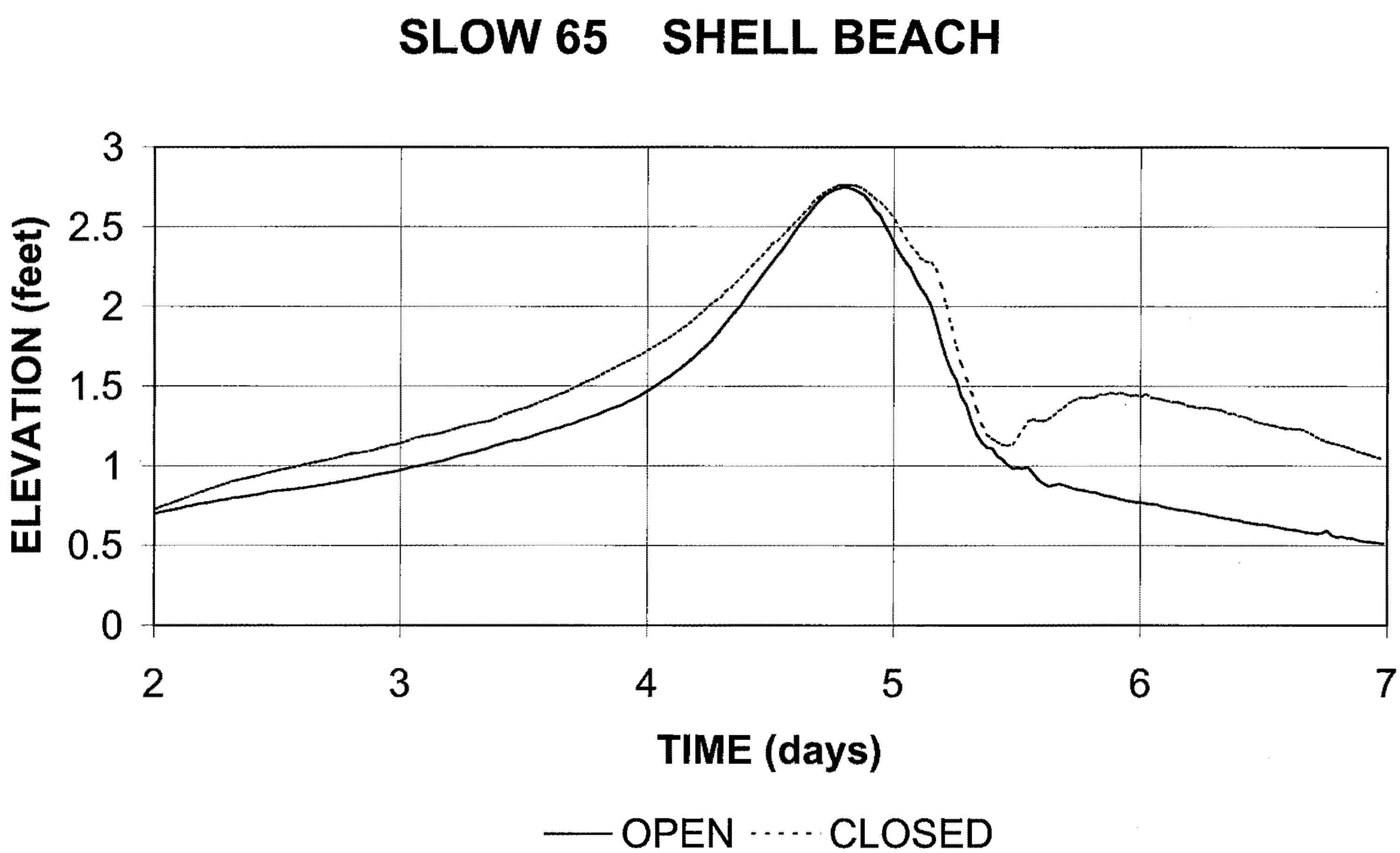

Figure 8: Hydrographs at Shell Beach for open and closed MRGO for the slow moving weak storm condition.

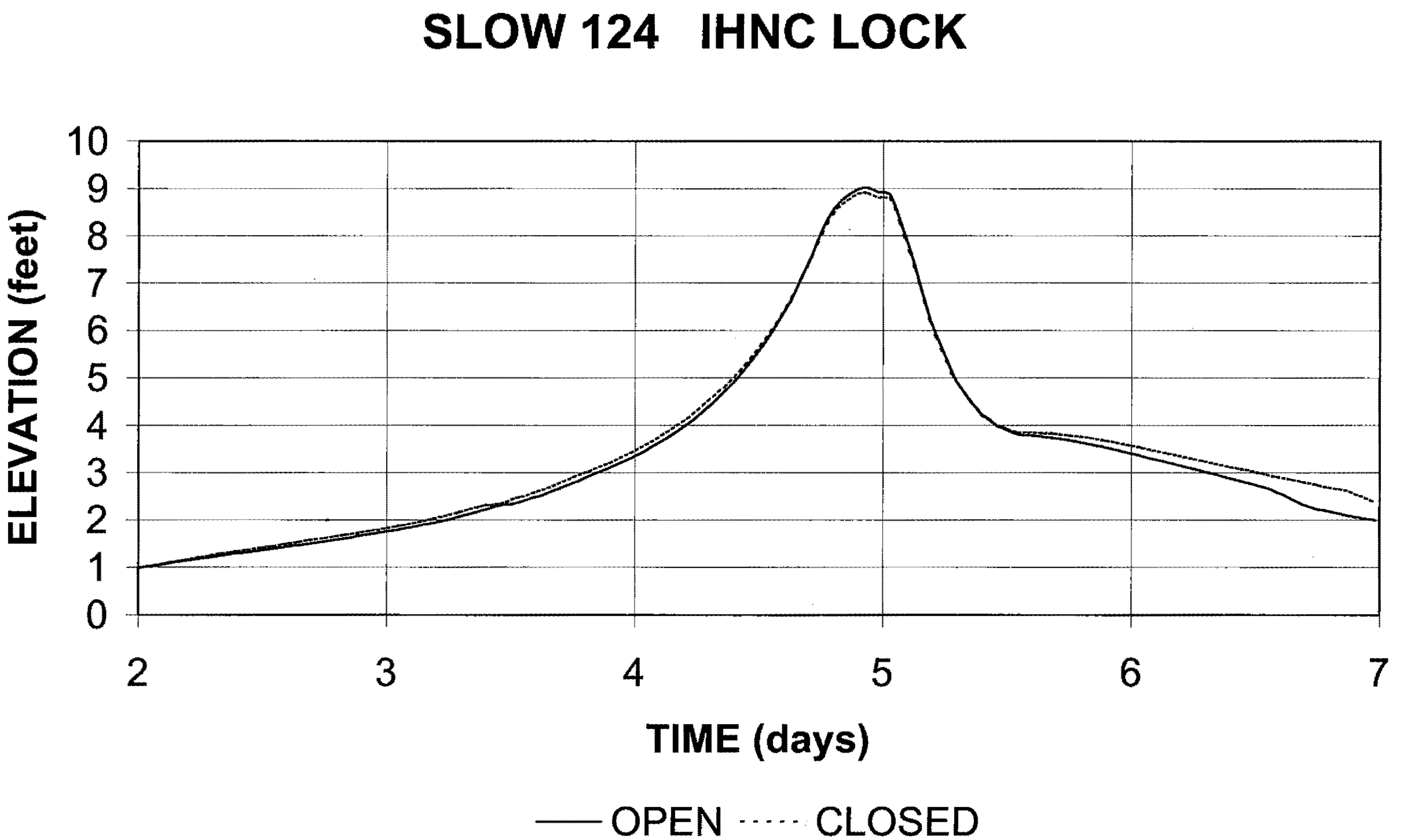

Figure 9: Hydrographs at the IHNC Lock for open and closed MRGO for the slow moving strong storm condition.

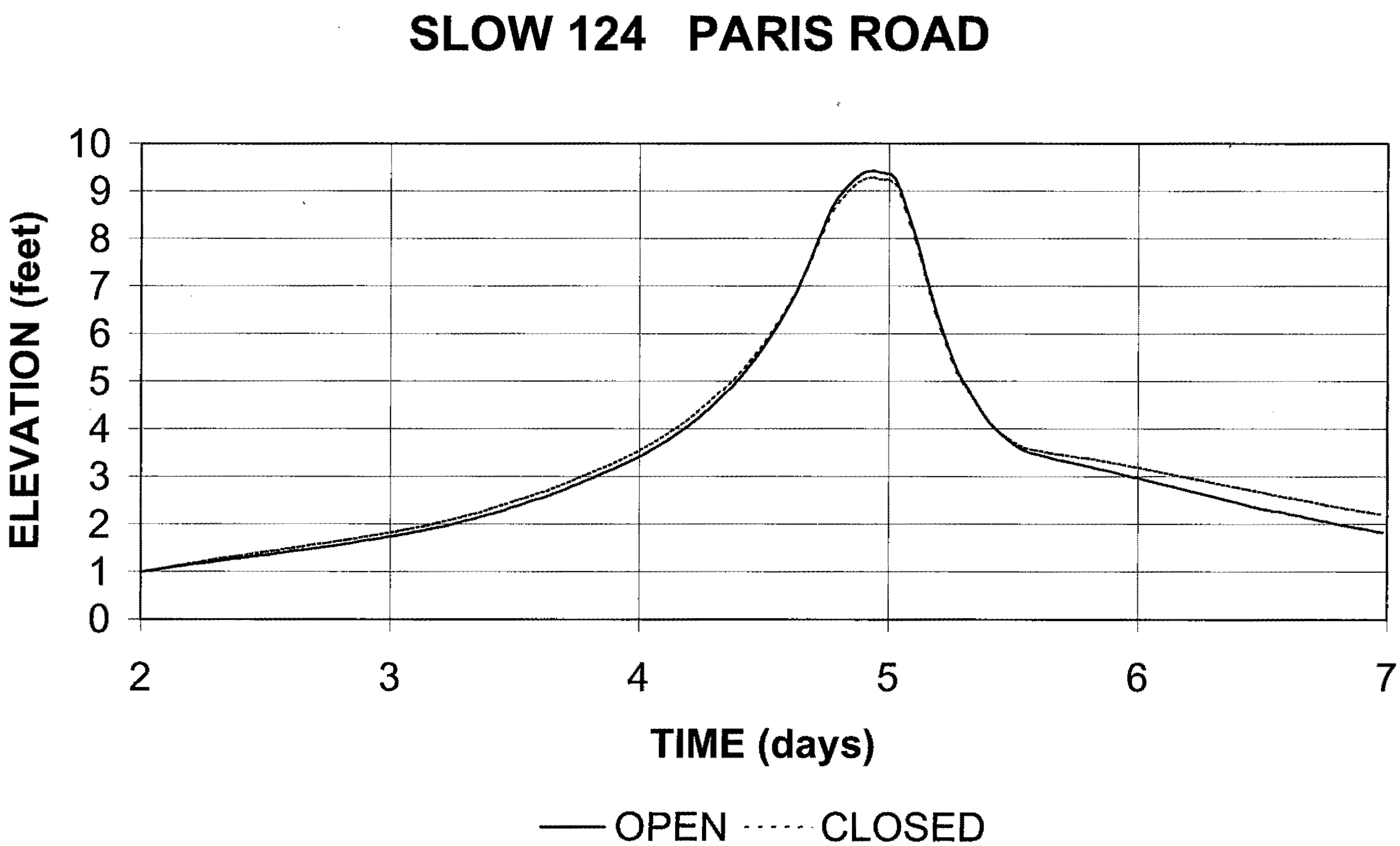

Figure 10: Hydrographs at the Paris Road Bridge for open and closed MRGO for the slow moving strong storm condition.

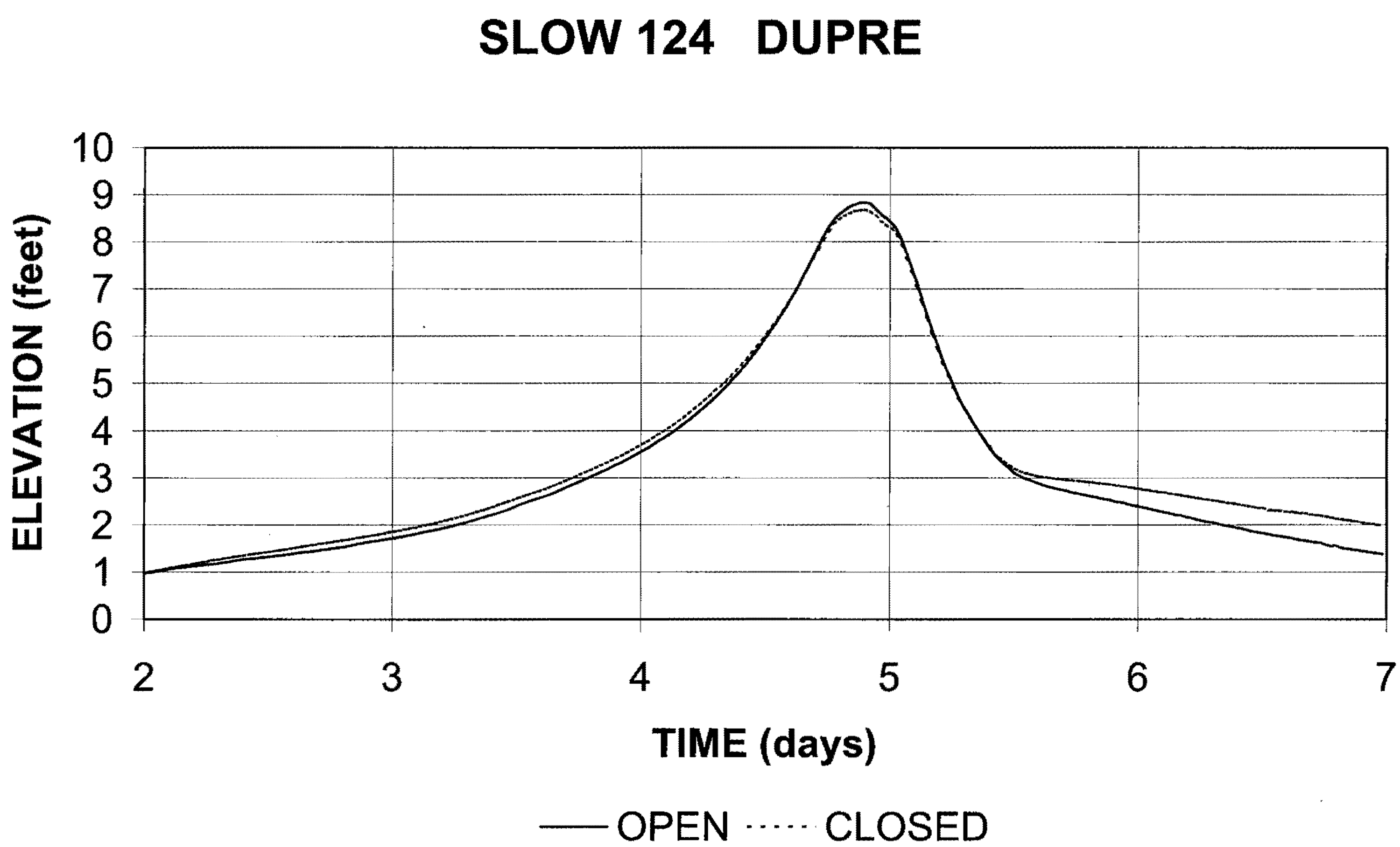

Figure 11: Hydrographs at the Bayou Dupre floodgate for open and closed MRGO for the slow moving strong storm condition.

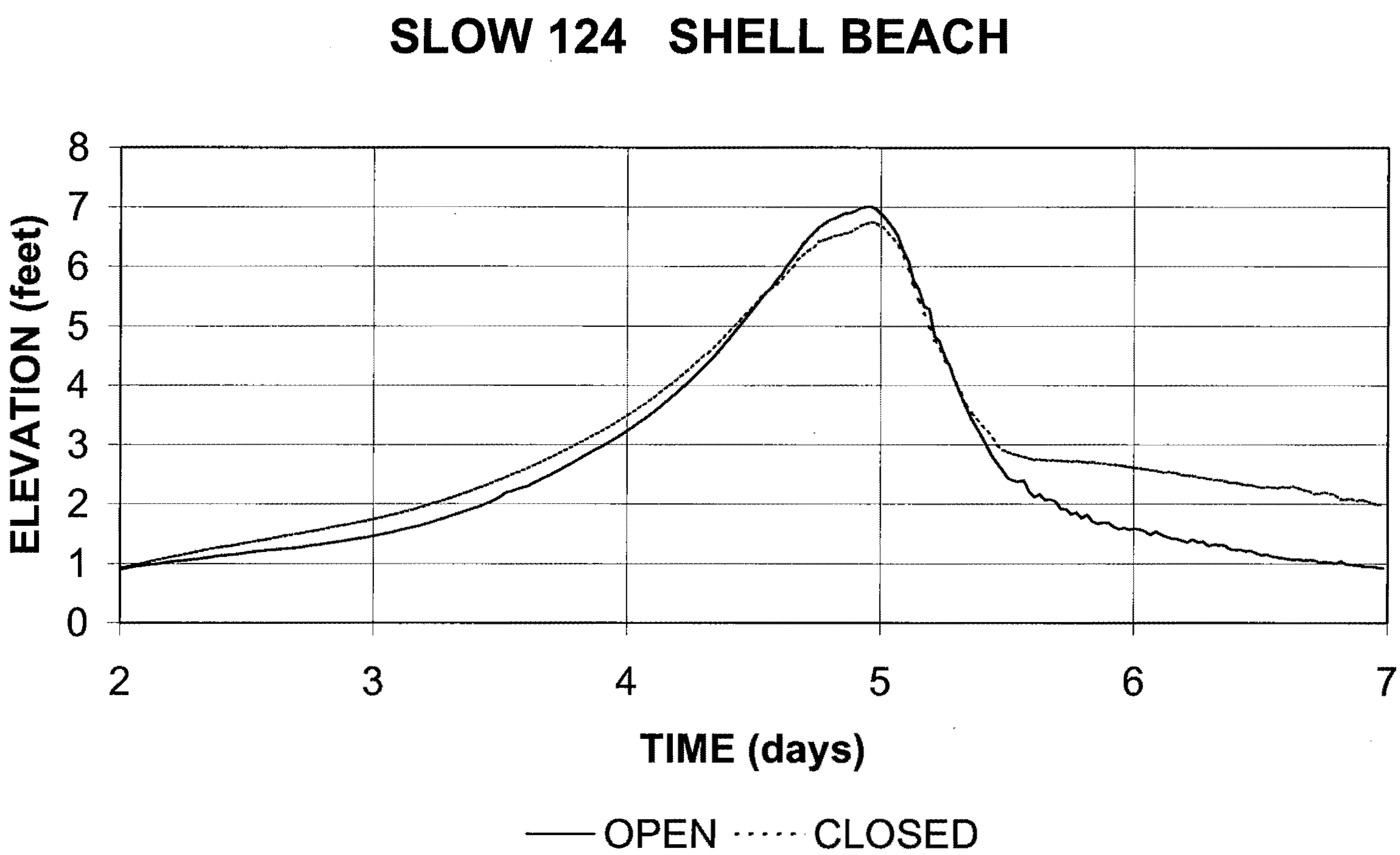

Figure 12: Hydrographs at Shell Beach for open and closed MRGO for the slow moving strong storm condition.

Again, with the slow moving strong storm, there is no significant difference in the timing or the magnitude of the peak value. The effect is local as is shown in Figure 13, which shows the contours of the maximum difference between the closed and open MRGO runs for the slow moving strong storm. Although the scale is not very legible in the graphic output from the computer program, the values are in meters and range form an increase of approximately 0.25 meters (approximately 0.80 feet) immediately north of the closure to -0.25 meters (approximately -0.80 feet) south of the closure. The negative difference indicates that the closed condition produced a greater surge than the open condition south of the closure.

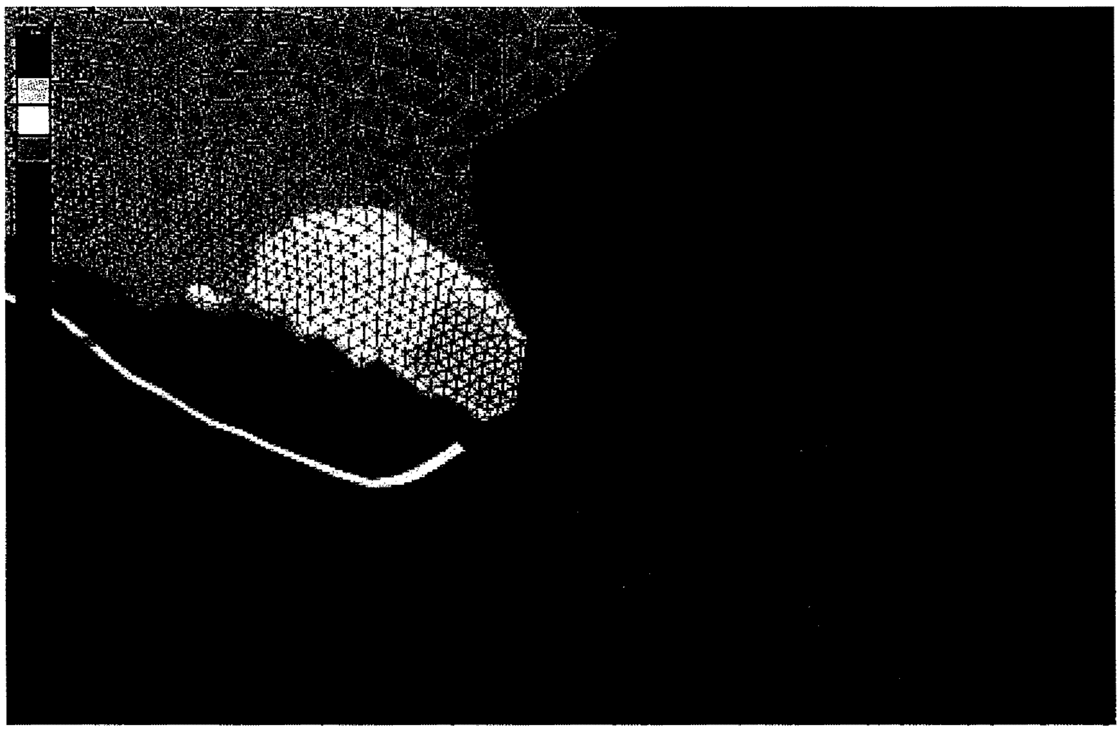

Figure 13: Contours of maximum difference between runs for open and closed condition for the slow strong storm.

Figures 14, 15, 16, and 17 show the stage hydrographs for the fast moving weak storm.

The fast moving weak storm scenario creates a second peak. This phenomenon is most pronounced at the Shell Beach location where the second peak for the closed condition is actually higher in elevation than the first peak. The double peak for the fast moving storm most likely is a result of the rapid change of wind direction coupled with some basin sloshing. The double peak is also seen for the fast moving strong storm scenario. Figures 18, 19, 20 and 21 show the stage hydrographs for the fast moving strong storm.

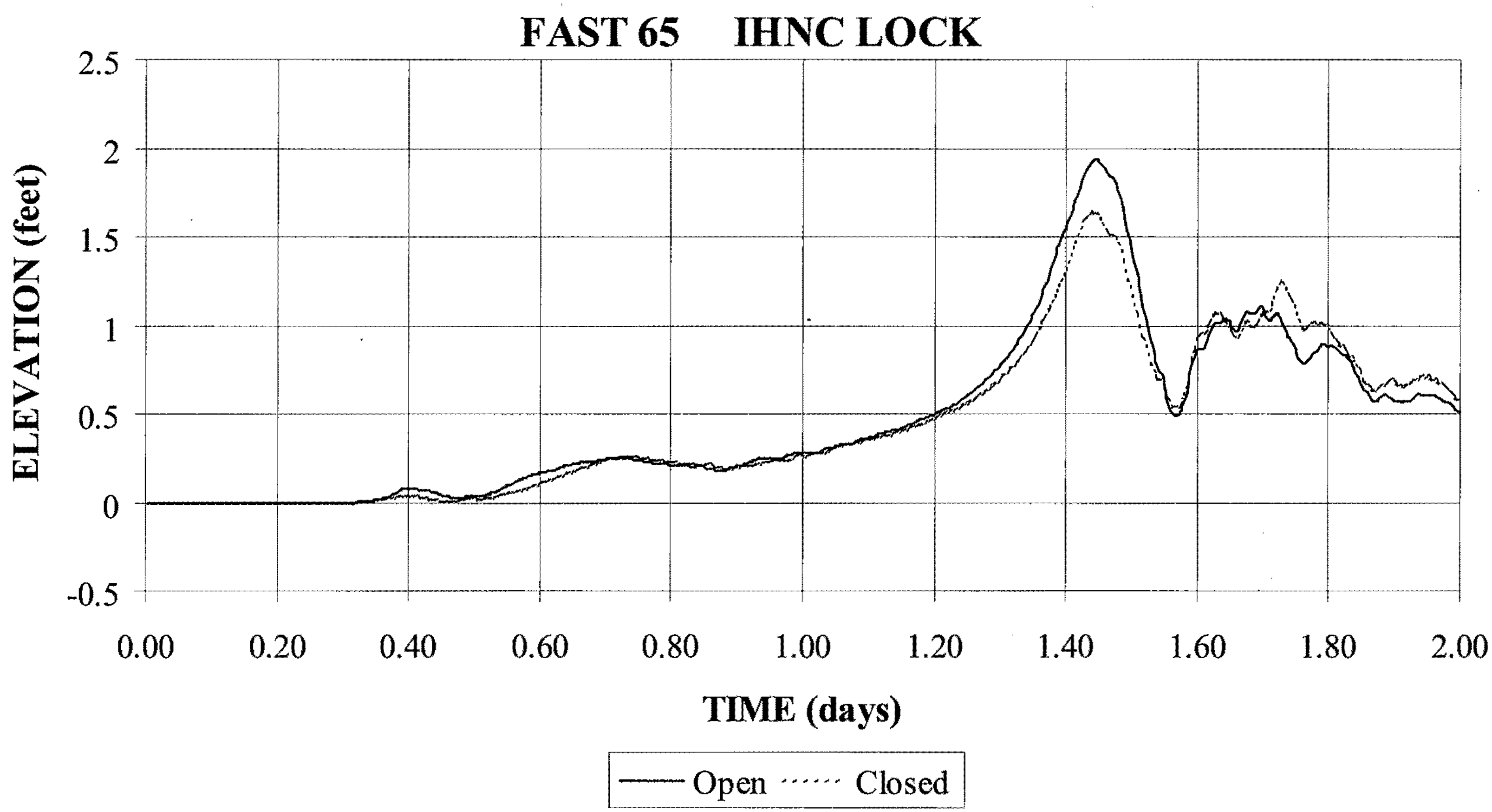

Figure 14: Hydrographs at the IHNC Lock for open and closed MRGO for the fast moving weak storm condition.

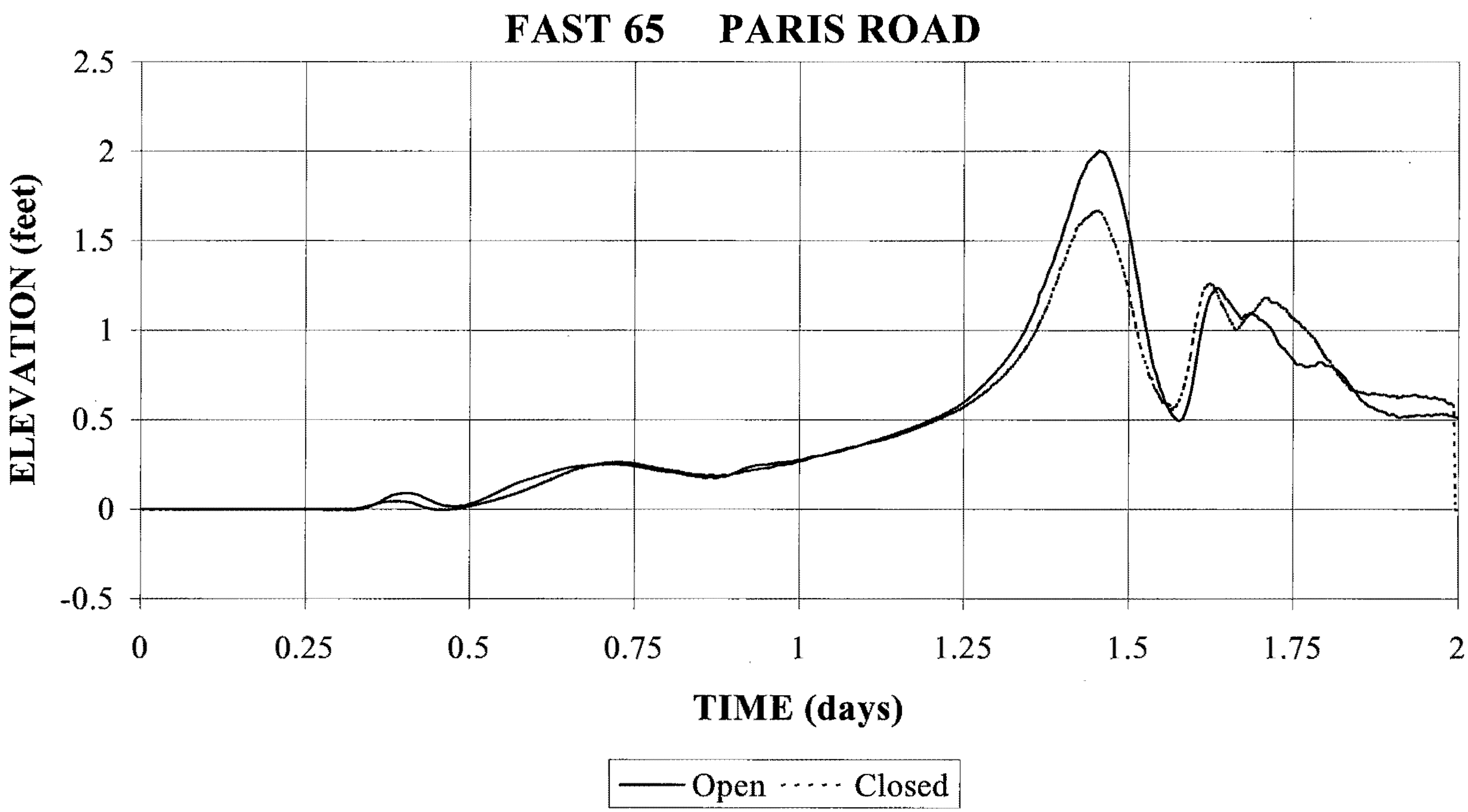

Figure 15: Hydrographs at the Paris Road Bridge for open and closed MRGO for the fast moving weak storm condition.

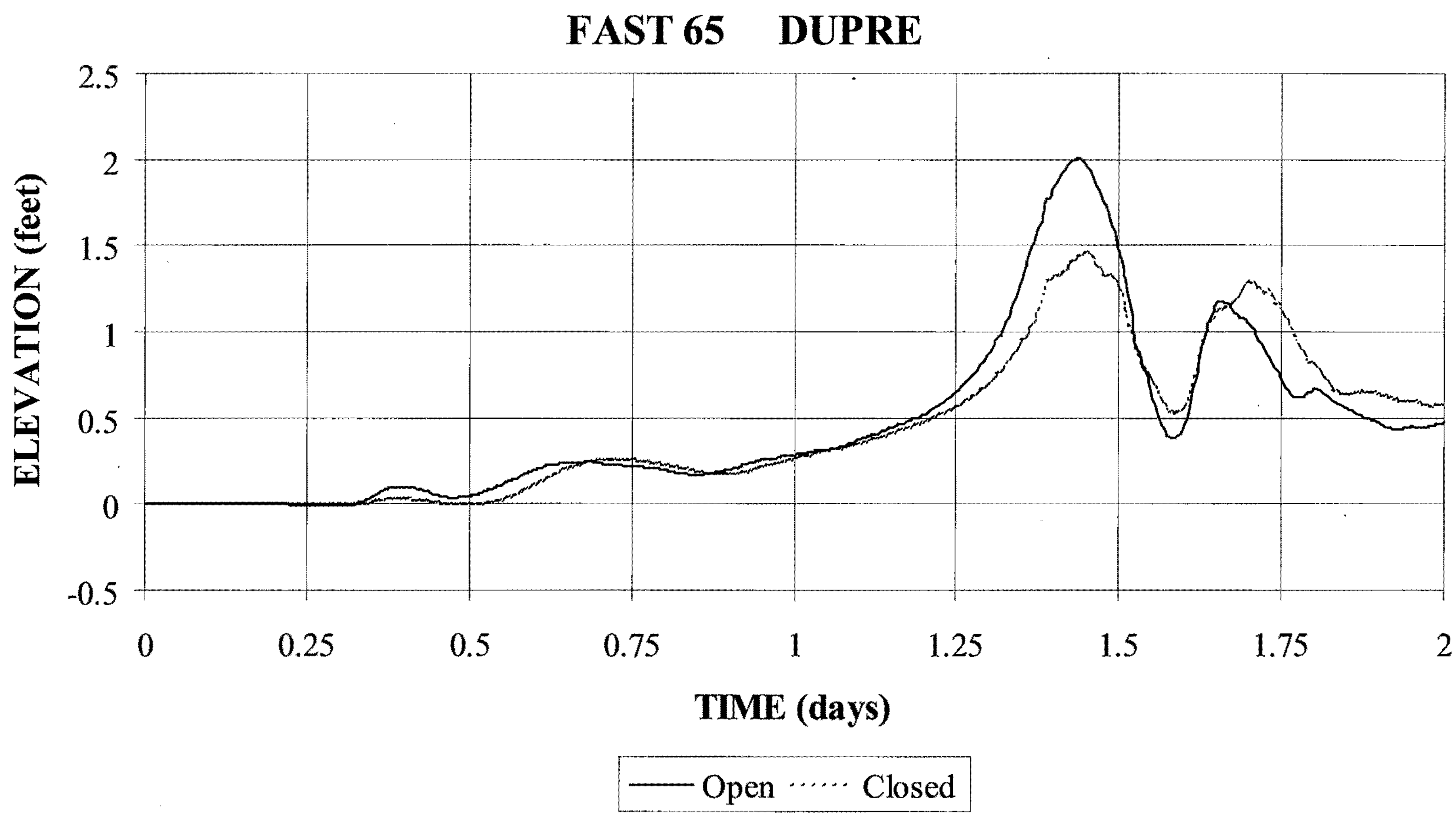

Figure 16: Hydrographs at the Bayou Dupre floodgate for open and closed MRGO for the fast moving weak storm condition.

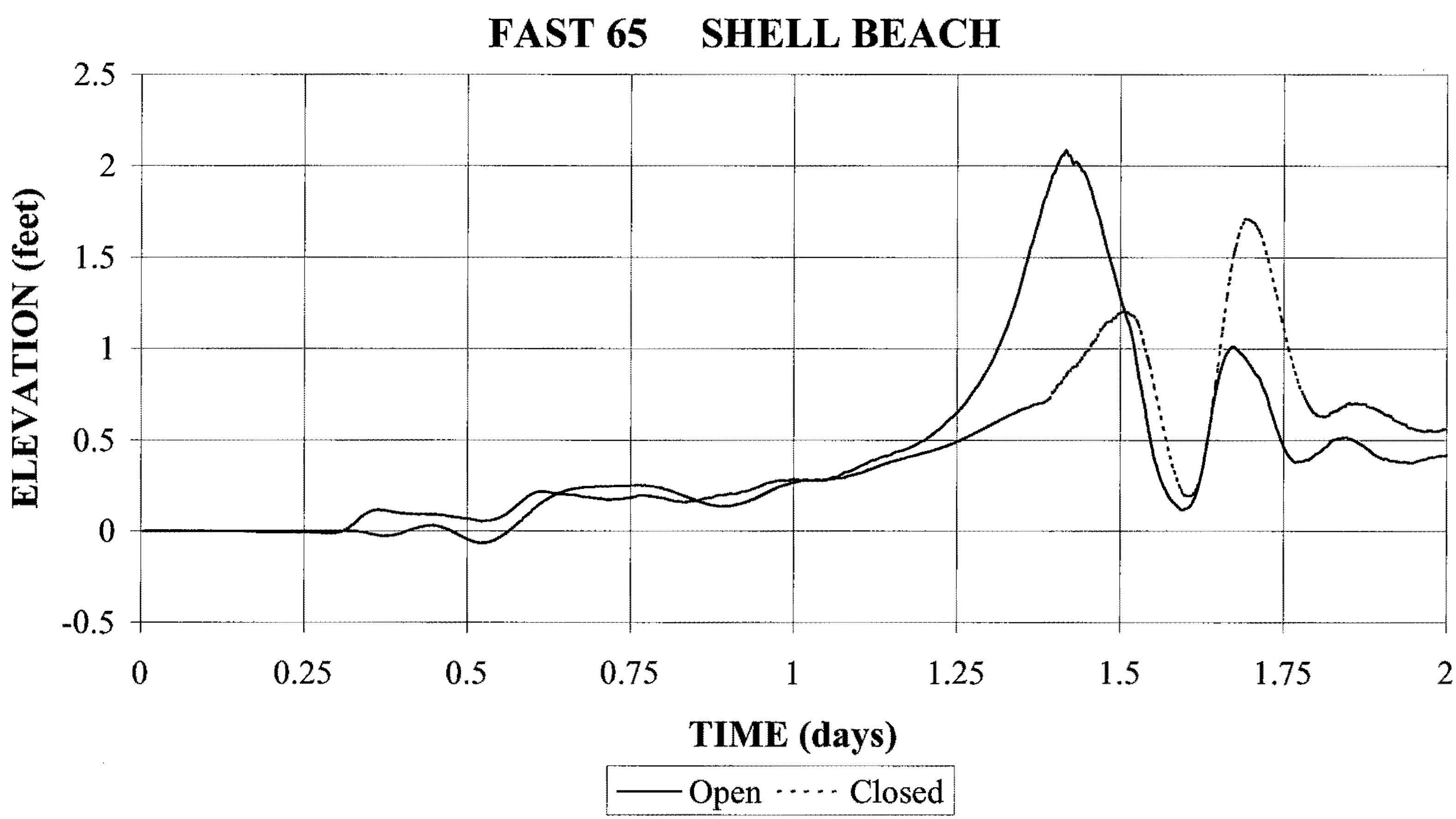

Figure 17: Hydrographs at Shell Beach for open and closed MRGO for the fast moving weak storm condition.

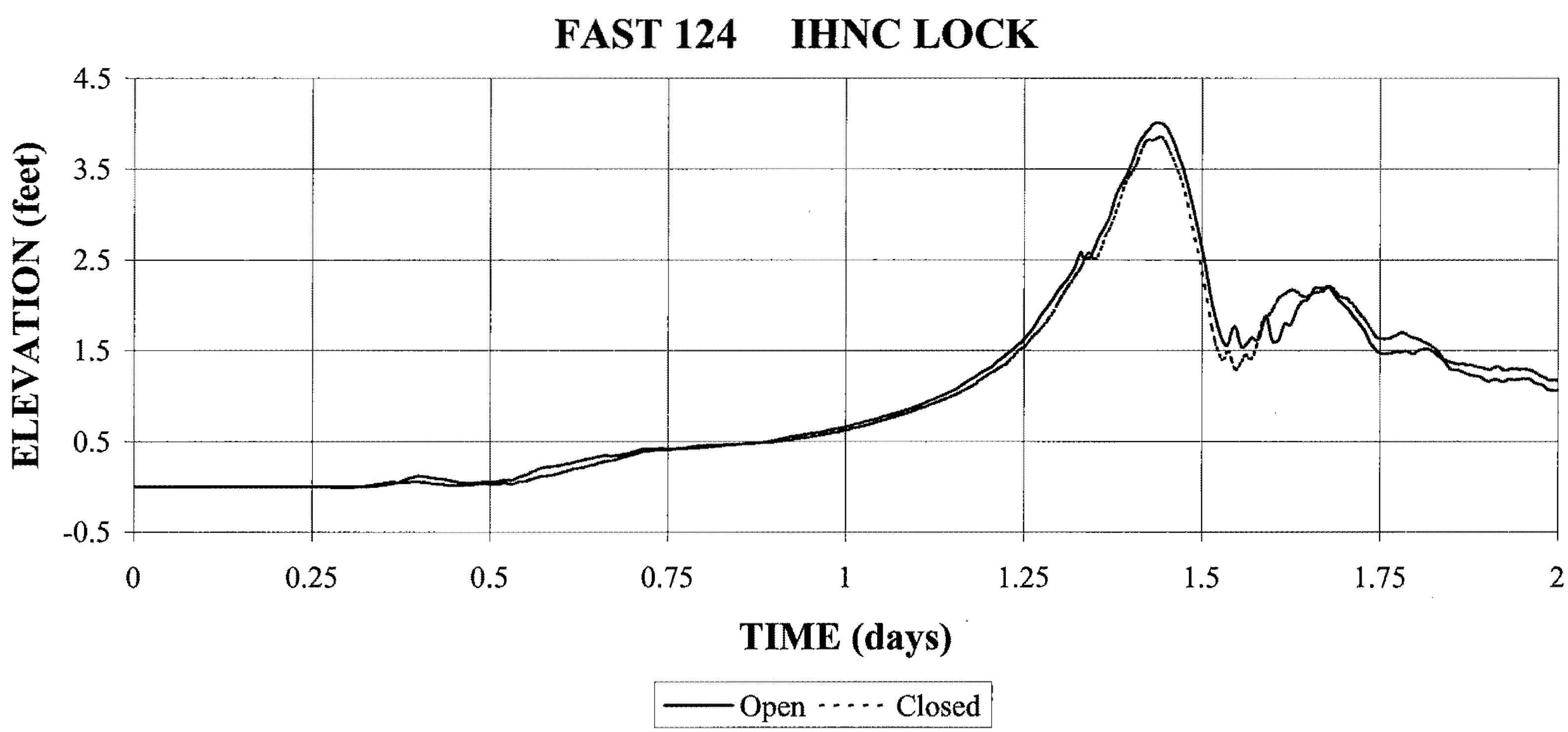

Figure 18: Hydrographs at the IHNC Lock for open and closed MRGO for the fast moving strong storm condition.

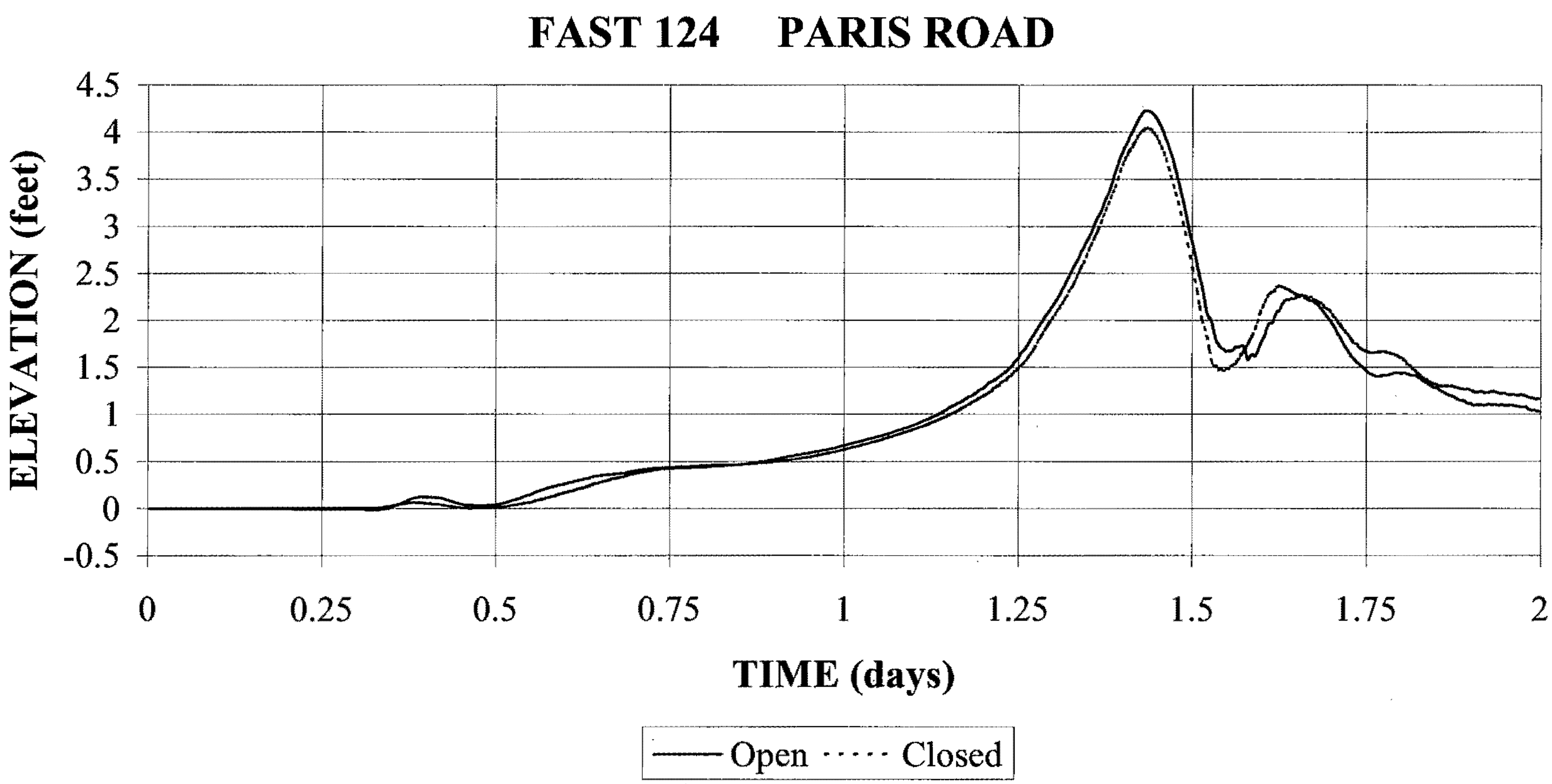

Figure 19: Hydrographs at the Paris Road Bridge for open and closed MRGO for the fast moving strong storm condition.

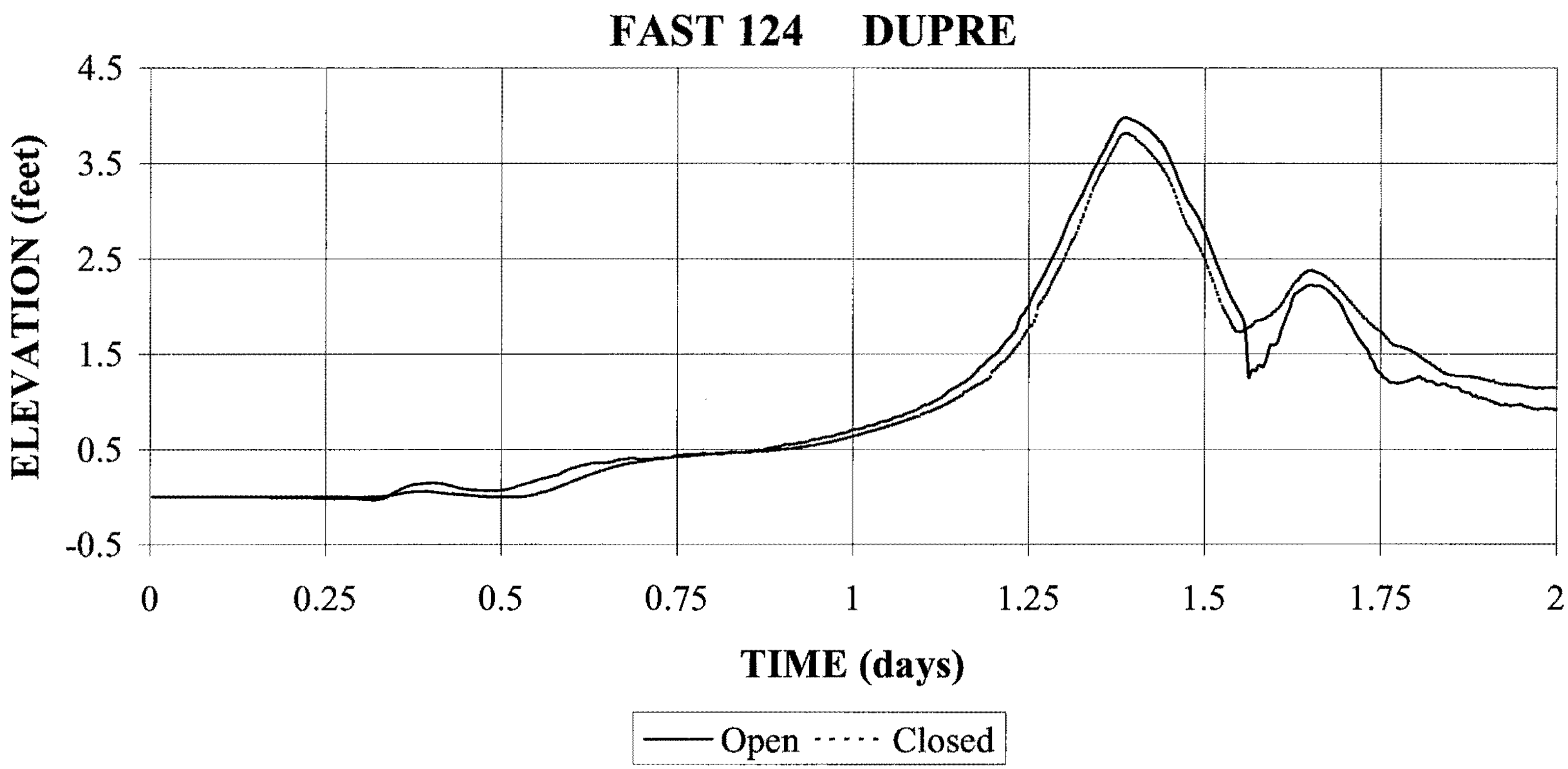

Figure 20: Hydrographs at the Bayou Dupre floodgate for open and closed MRGO for the fast moving strong storm condition.

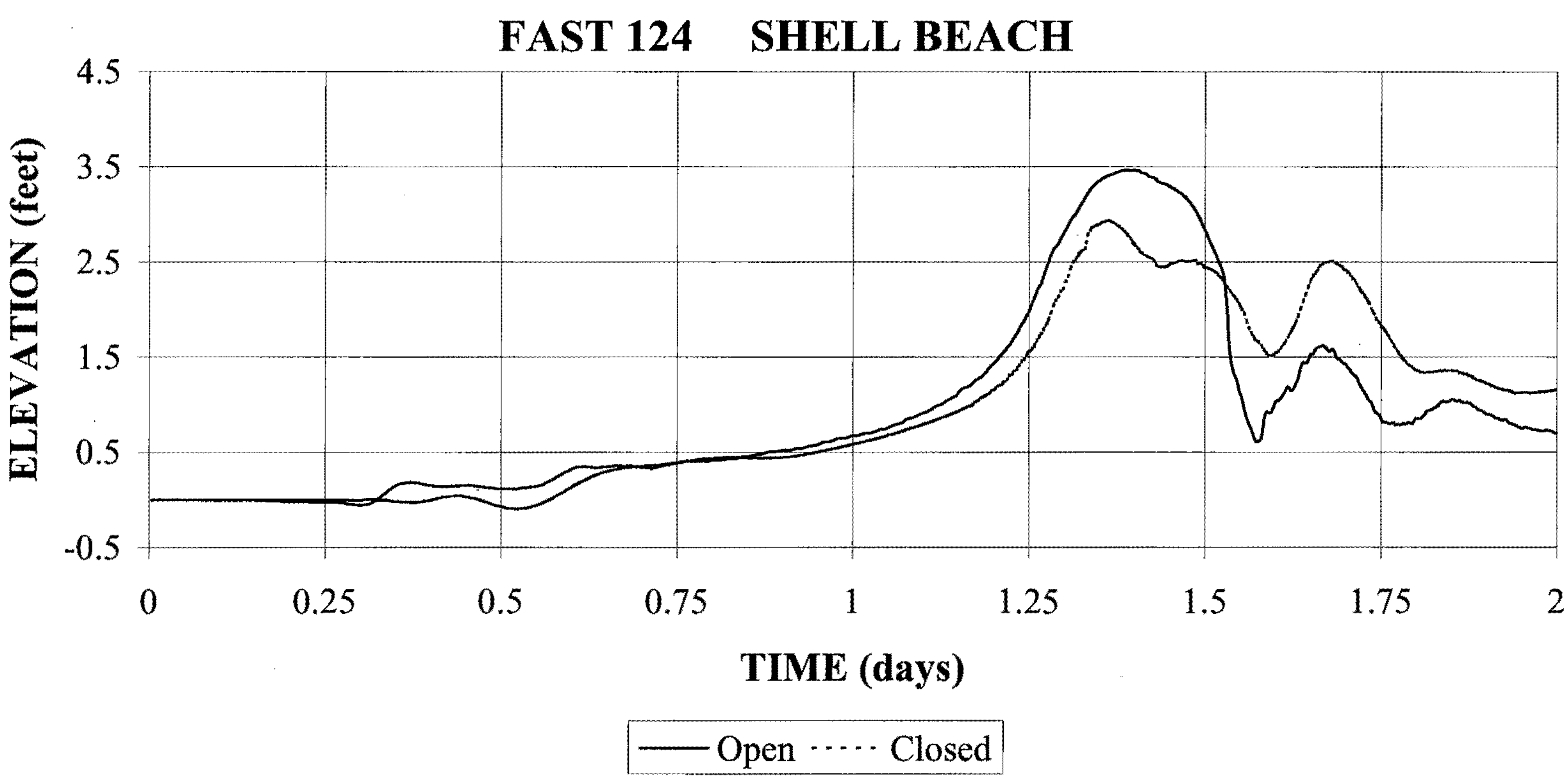

Figure 21: Hydrographs at Shell Beach for open and closed MRGO for the fast moving strong storm condition.

The results for Hurricane Betsy are shown in Figures 22 through 25 respectively for the four stations of the IHNC Lock, the Paris Road Bridge, Bayou Dupre floodgate and Shell Beach. Except for Shell Beach, where the difference in maximum elevation was 0.30 feet, the results for Hurricane Betsy showed very little difference in the maximum surge elevations for the open and closed cases. The Hurricane Betsy runs were done with the same open and closed grids as the nine storm scenarios. However, there was one difference. Hurricane Betsy was run with tides whereas the other runs did not have tides. The tides were the actual tides for August and September 1965. When running with tides, it is necessary to run the model for approximately 18 days in order to allow the start-up transients to die out and thus give a realistic simulation of actual tides. This is why the Hurricane Betsy plots start at simulation day 18. It is noteworthy that the tidal signal for the few days preceding the storm is not noticeably changed at the INHC Lock or at Paris Road (nor is the surge hydrograph). At Bayou Dupre, the tidal signal is somewhat altered by the closure of the MRGO, although there is no noticeable difference in the surge. At Shell Beach, the tide signal is noticeably altered. The high tide is slightly higher for the closed condition (.05 feet) but is nearly three hours delayed. The low tide for the closed condition is not as low as for the open condition (about .35 feet) and is nearly six hours later than for the open condition. This result for Shell Beach is not surprising since the MRGO is a very efficient ebb channel. The fact that the low tide for the closed condition is not as low as for the open condition is the same phenomenon as the reduced drainage at the tail end of the hydrographs for the hypothetical storm scenarios.

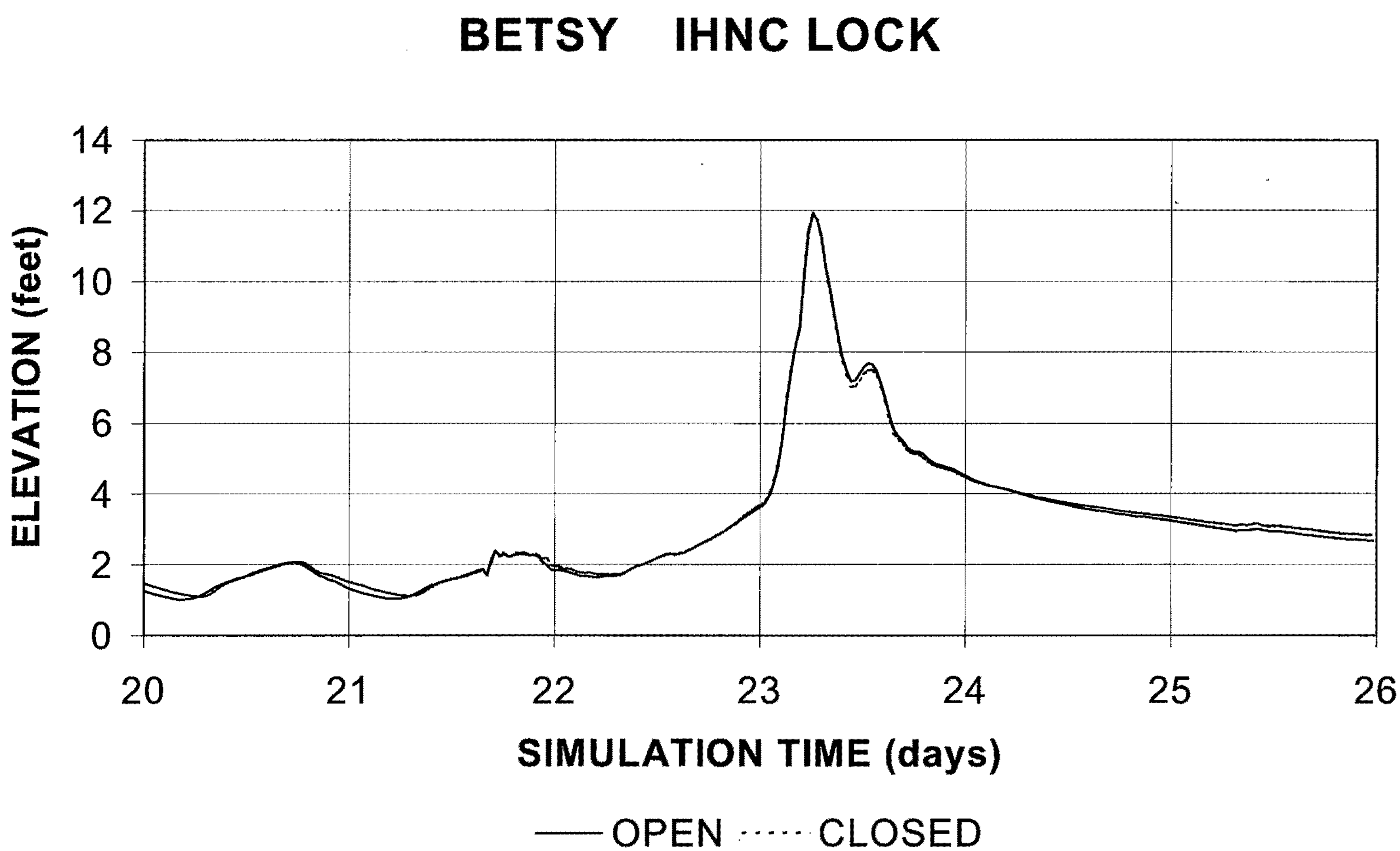

Figure 22: Hydrographs at IHNC Lock for open and closed MRGO for Hurricane Betsy.

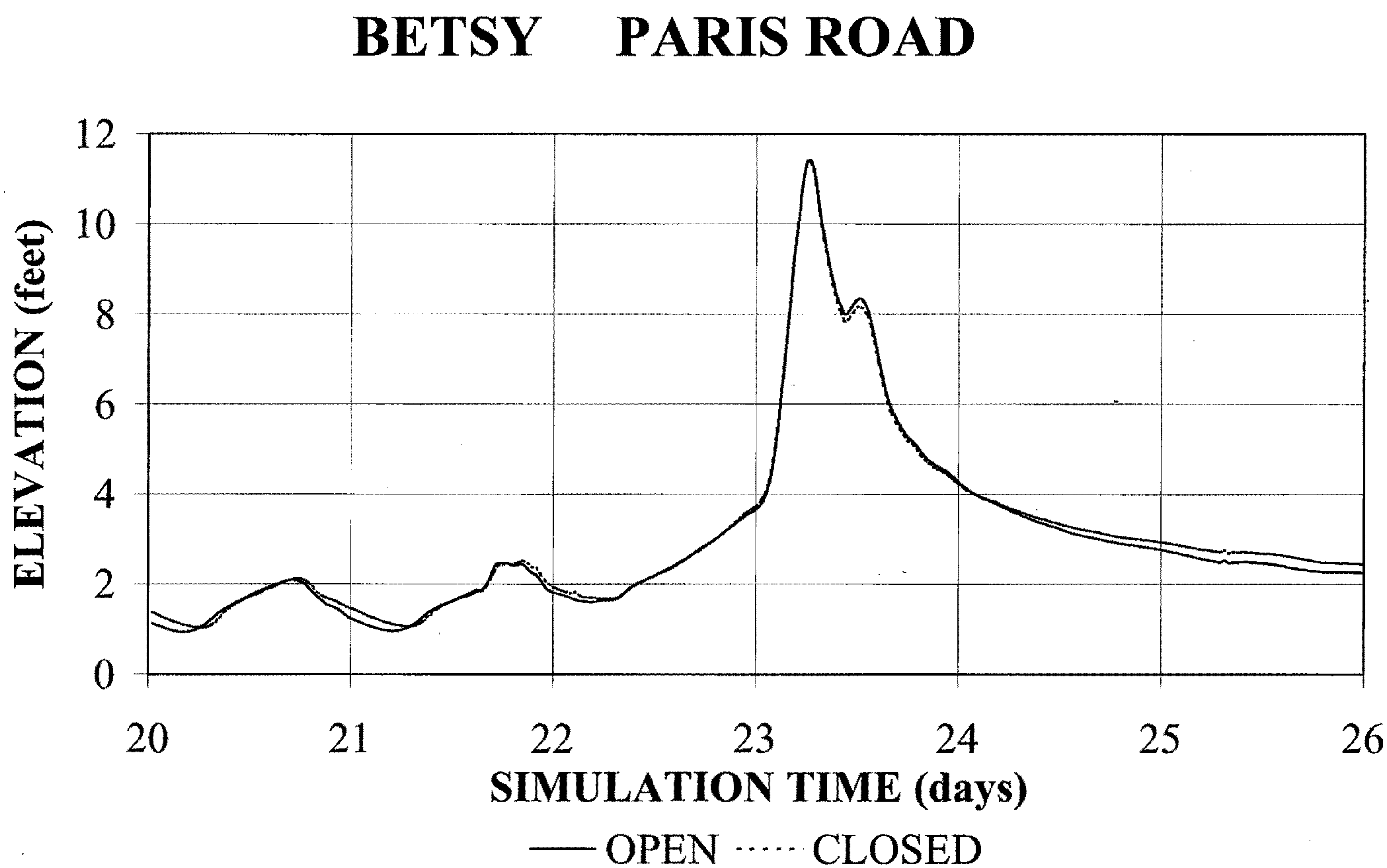

Figure 23: Hydrographs at Paris Road Bridge for open and closed MRGO for Hurricane Betsy.

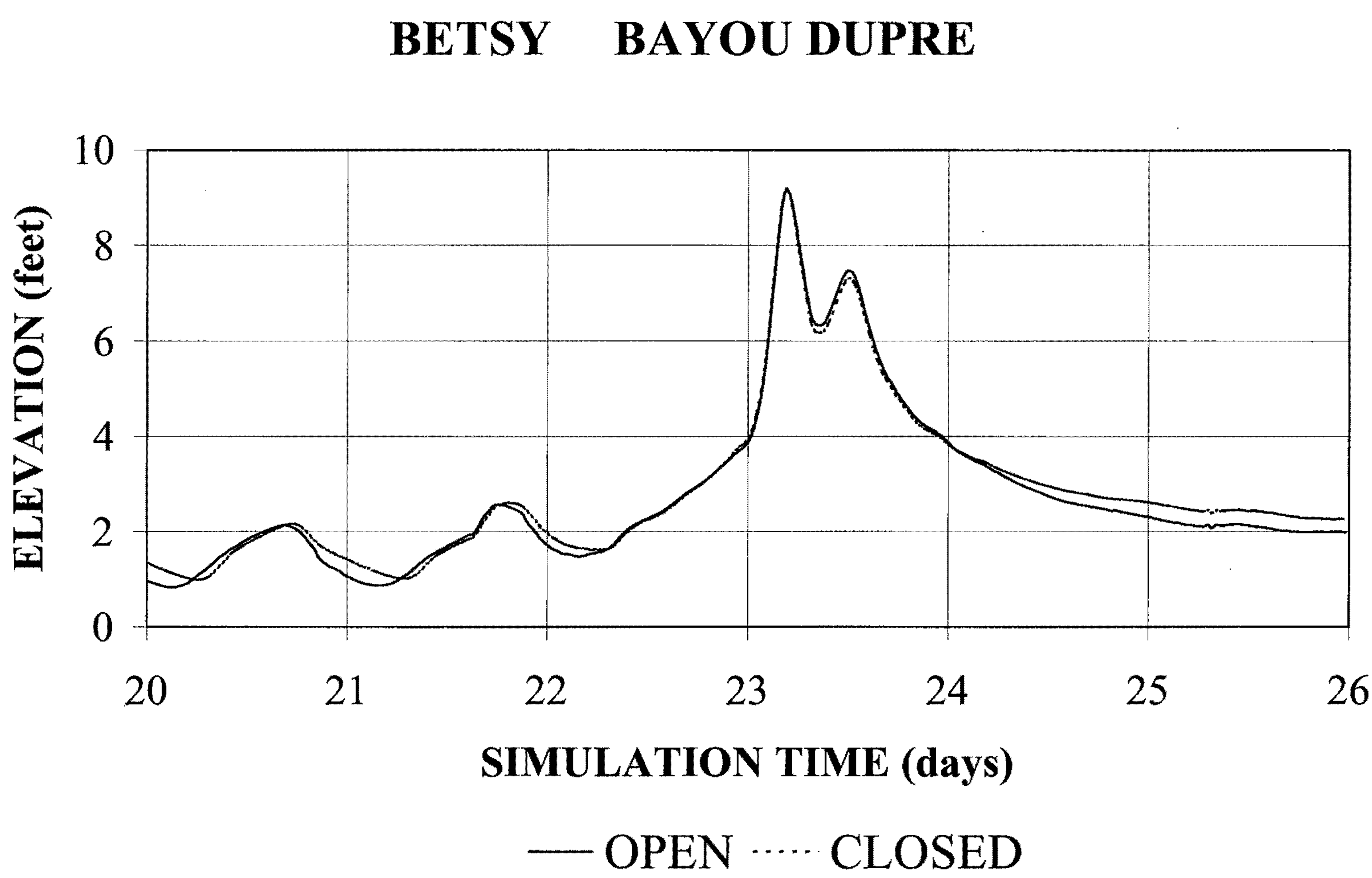

Figure 24: Hydrographs at Bayou Dupre for open and closed MRGO for Hurricane Betsy.

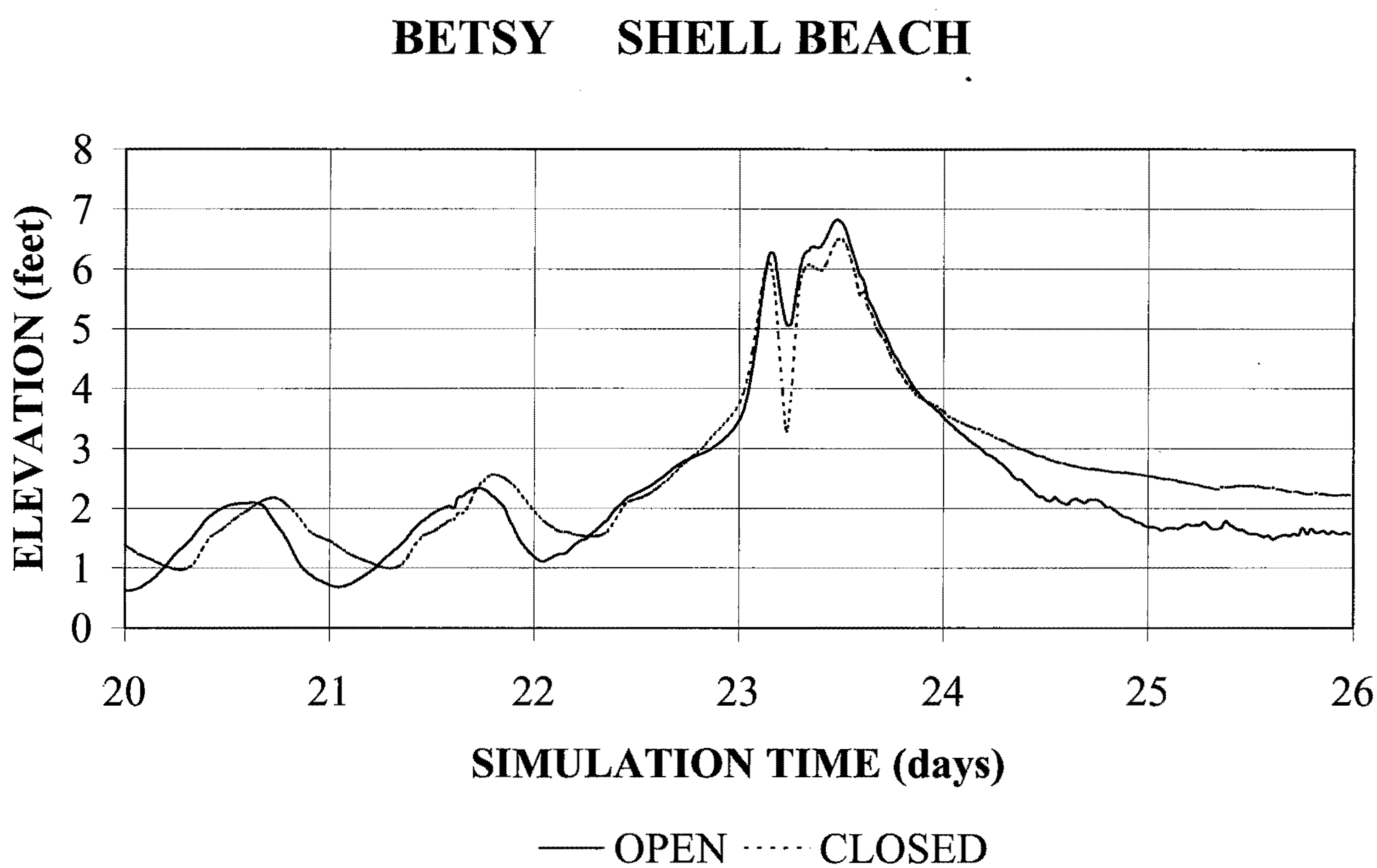

Figure 25: Hydrographs at Shell Beach for open and closed MRGO for Hurricane Betsy.

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Hypothetical storm parameters

Single Critical Track for all Runs		Forward speed	Central Pressure	Storm
Longitude	Latitude	Knot	Hg	Number
-88.56	27.58	20	29.2	1
-88.62	27.65			
-88.69	27.71			
-88.75	27.78			
-88.82	27.84		28.2	2
-88.88	27.91			
-88.95	27.98			
-89.01	28.04			
-89.07	28.11			
-89.14	28.18		27.6	3
-89.20	28.24			
-89.27	28.31			
-89.33	28.37			
-89.40	28.44			
-89.46	28.51	15	29.2	4
-89.52	28.57			
-89.59	28.64			
-89.65	28.70			
-89.72	28.77			
-89.78	28.84			
-89.84	28.90		28.2	5
-89.91	28.97			
-89.97	29.04			
-90.04	29.10			
-90.10	29.17			
-90.17	29.23		27.6	6
-90.23	29.30			
-90.28	29.37			
-90.34	29.44			
-90.39	29.51	5	29.2	7
-90.44	29.58			
-90.49	29.65			
-90.54	29.73			
-90.56	29.80		28.2	8
-90.58	29.88			
-90.60	29.97			
-90.62	30.06			
-90.64	30.13			
-90.65	30.21			
-90.65	30.30		27.6	9
-90.65	30.38			
-90.65	30.47			
-90.65	30.55			

MRGO input files

All nine storm events have the same track. There are three central pressures which we will categorize as strong, medium and weak hurricanes (central pressures of 934, 955, and 989 – this corresponds (if we take the best fit) to maximum winds of 65, 100 and 124 knots) with these three strengths are three forward speeds slow medium and fast. The storms are named as in the table below along side the input file name (input to the PBL)

MRGO001	slow-124.txt
MRGO002	slow-100.txt
MRGO003	slow-65.txt
MRGO004	med-124.txt
MRGO005	med-100.txt
MRGO006	med-65.txt
MRGO001	fast-124.txt
MRGO008	fast-100.txt
MRGO009	fast-65.txt

For the 124 knot and 100 knot storms, the intensity was kept the same up till landfall and then diminished. For the slow moving storms the reduction to a 65 knot storm was over two 6 hour time steps in the PBL input file. For the fast moving storm the reduction was over one 6 hour time interval.

Date: 27 AUG - 03 SEP 1992
Hurricane MRGO001

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.58	-82.56	08/27/00Z	124	934	HURRICANE-1
2	21.98	-82.96	08/27/06Z	124	934	HURRICANE-1
3	22.38	-83.36	08/27/12Z	124	934	HURRICANE-1
4	22.78	-83.76	08/27/18Z	124	934	HURRICANE-1
5	23.18	-84.16	08/28/00Z	124	934	HURRICANE-1
6	23.58	-84.56	08/28/06Z	124	934	HURRICANE-1
7	23.98	-84.96	08/28/12Z	124	934	HURRICANE-1
8	24.38	-85.36	08/28/18Z	124	934	HURRICANE-1
9	24.78	-85.76	08/29/00Z	124	934	HURRICANE-1
10	25.18	-86.16	08/29/06Z	124	934	HURRICANE-1
11	25.58	-86.56	08/29/12Z	124	934	HURRICANE-1
12	25.98	-86.96	08/29/18Z	124	934	HURRICANE-1
13	26.38	-87.36	08/30/00Z	124	934	HURRICANE-1
14	26.78	-87.76	08/30/06Z	124	934	HURRICANE-1
15	27.18	-88.16	08/30/12Z	124	934	HURRICANE-1
16	27.58	-88.56	08/30/18Z	124	934	HURRICANE-1
17	27.98	-88.95	08/31/00Z	124	934	HURRICANE-1
18	28.37	-89.33	08/31/06Z	124	934	HURRICANE-1
19	28.77	-89.72	08/31/12Z	124	934	HURRICANE-1
20	29.17	-90.10	08/31/18Z	124	934	HURRICANE-1
21	29.58	-90.44	09/01/00Z	100	955	HURRICANE-1
22	30.06	-90.62	09/01/06Z	65	989	HURRICANE-1
23	30.55	-90.65	09/01/12Z	65	989	HURRICANE-1
24	31.15	-90.65	09/01/18Z	65	989	HURRICANE-1
25	31.75	-90.65	09/02/00Z	65	989	HURRICANE-1
26	32.35	-90.65	09/02/06Z	65	989	HURRICANE-1
27	32.95	-90.65	09/02/12Z	65	989	HURRICANE-1
28	33.55	-90.65	09/02/18Z	65	989	HURRICANE-1
29	34.15	-90.65	09/03/00Z	65	989	HURRICANE-1
30	34.75	-90.65	09/03/06Z	65	989	HURRICANE-1

Date: 27 AUG - 03 SEP 1992
Hurricane MRGO002

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.58	-82.56	08/27/00z	100	955	HURRICANE-1
2	21.98	-82.96	08/27/06z	100	955	HURRICANE-1
3	22.38	-83.36	08/27/12z	100	955	HURRICANE-1
4	22.78	-83.76	08/27/18z	100	955	HURRICANE-1
5	23.18	-84.16	08/28/00z	100	955	HURRICANE-1
6	23.58	-84.56	08/28/06z	100	955	HURRICANE-1
7	23.98	-84.96	08/28/12z	100	955	HURRICANE-1
8	24.38	-85.36	08/28/18z	100	955	HURRICANE-1
9	24.78	-85.76	08/29/00z	100	955	HURRICANE-1
10	25.18	-86.16	08/29/06z	100	955	HURRICANE-1
11	25.58	-86.56	08/29/12z	100	955	HURRICANE-1
12	25.98	-86.96	08/29/18z	100	955	HURRICANE-1
13	26.38	-87.36	08/30/00z	100	955	HURRICANE-1
14	26.78	-87.76	08/30/06z	100	955	HURRICANE-1
15	27.18	-88.16	08/30/12z	100	955	HURRICANE-1
16	27.58	-88.56	08/30/18z	100	955	HURRICANE-1
17	27.98	-88.95	08/31/00z	100	955	HURRICANE-1
18	28.37	-89.33	08/31/06z	100	955	HURRICANE-1
19	28.77	-89.72	08/31/12z	100	955	HURRICANE-1
20	29.17	-90.10	08/31/18z	100	955	HURRICANE-1
21	29.58	-90.44	09/01/00z	65	989	HURRICANE-1
22	30.06	-90.62	09/01/06z	65	989	HURRICANE-1
23	30.55	-90.65	09/01/12z	65	989	HURRICANE-1
24	31.15	-90.65	09/01/18z	65	989	HURRICANE-1
25	31.75	-90.65	09/02/00z	65	989	HURRICANE-1
26	32.35	-90.65	09/02/06z	65	989	HURRICANE-1
27	32.95	-90.65	09/02/12z	65	989	HURRICANE-1
28	33.55	-90.65	09/02/18z	65	989	HURRICANE-1
29	34.15	-90.65	09/03/00z	65	989	HURRICANE-1
30	34.75	-90.65	09/03/06z	65	989	HURRICANE-1

Date: 27 AUG - 03 SEP 1992
Hurricane MRG0003

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.58	-82.56	08/27/00Z	65	989	HURRICANE-1
2	21.98	-82.96	08/27/06Z	65	989	HURRICANE-1
3	22.38	-83.36	08/27/12Z	65	989	HURRICANE-1
4	22.78	-83.76	08/27/18Z	65	989	HURRICANE-1
5	23.18	-84.16	08/28/00Z	65	989	HURRICANE-1
6	23.58	-84.56	08/28/06Z	65	989	HURRICANE-1
7	23.98	-84.96	08/28/12Z	65	989	HURRICANE-1
8	24.38	-85.36	08/28/18Z	65	989	HURRICANE-1
9	24.78	-85.76	08/29/00Z	65	989	HURRICANE-1
10	25.18	-86.16	08/29/06Z	65	989	HURRICANE-1
11	25.58	-86.56	08/29/12Z	65	989	HURRICANE-1
12	25.98	-86.96	08/29/18Z	65	989	HURRICANE-1
13	26.38	-87.36	08/30/00Z	65	989	HURRICANE-1
14	26.78	-87.76	08/30/06Z	65	989	HURRICANE-1
15	27.18	-88.16	08/30/12Z	65	989	HURRICANE-1
16	27.58	-88.56	08/30/18Z	65	989	HURRICANE-1
17	27.98	-88.95	08/31/00Z	65	989	HURRICANE-1
18	28.37	-89.33	08/31/06Z	65	989	HURRICANE-1
19	28.77	-89.72	08/31/12Z	65	989	HURRICANE-1
20	29.17	-90.10	08/31/18Z	65	989	HURRICANE-1
21	29.58	-90.44	09/01/00Z	65	989	HURRICANE-1
22	30.06	-90.62	09/01/06Z	65	989	HURRICANE-1
23	30.55	-90.65	09/01/12Z	65	989	HURRICANE-1
24	31.15	-90.65	09/01/18Z	65	989	HURRICANE-1
25	31.75	-90.65	09/02/00Z	65	989	HURRICANE-1
26	32.35	-90.65	09/02/06Z	65	989	HURRICANE-1
27	32.95	-90.65	09/02/12Z	65	989	HURRICANE-1
28	33.55	-90.65	09/02/18Z	65	989	HURRICANE-1
29	34.15	-90.65	09/03/00Z	65	989	HURRICANE-1
30	34.75	-90.65	09/03/06Z	65	989	HURRICANE-1

Date: 27 ? 30 AUG 1992
Hurricane MRG0004

ADV	LAT	LON	TIME	WIND	PR	STAT
1	20.93	-81.91	08/27/00Z	124	934	HURRICANE-1
2	21.88	-82.86	08/27/06Z	124	934	HURRICANE-1
3	22.83	-83.81	08/27/12Z	124	934	HURRICANE-1
4	23.78	-84.76	08/27/18Z	124	934	HURRICANE-1
5	24.73	-85.71	08/28/00Z	124	934	HURRICANE-1
6	25.68	-86.66	08/28/06Z	124	934	HURRICANE-1
7	26.63	-87.61	08/28/12Z	124	934	HURRICANE-1
8	27.58	-88.56	08/28/18Z	124	934	HURRICANE-1
9	28.51	-89.46	08/29/00Z	124	934	HURRICANE-1
10	29.44	-90.34	08/29/06Z	100	955	HURRICANE-1
11	30.55	-90.65	08/29/12Z	65	989	HURRICANE-1
12	31.90	-90.65	08/29/18Z	65	989	HURRICANE-1
13	33.25	-90.65	08/30/00Z	65	989	HURRICANE-1
14	34.60	-90.65	08/30/06Z	65	989	HURRICANE-1
15	35.95	-90.65	08/30/12Z	65	989	HURRICANE-1

Date: 27 ? 30 AUG 1992
Hurricane MRG0005

ADV	LAT	LON	TIME	WIND	PR	STAT
1	20.93	-81.91	08/27/00Z	100	955	HURRICANE-1
2	21.88	-82.86	08/27/06Z	100	955	HURRICANE-1
3	22.83	-83.81	08/27/12Z	100	955	HURRICANE-1
4	23.78	-84.76	08/27/18Z	100	955	HURRICANE-1
5	24.73	-85.71	08/28/00Z	100	955	HURRICANE-1
6	25.68	-86.66	08/28/06Z	100	955	HURRICANE-1
7	26.63	-87.61	08/28/12Z	100	955	HURRICANE-1
8	27.58	-88.56	08/28/18Z	100	955	HURRICANE-1
9	28.51	-89.46	08/29/00Z	100	955	HURRICANE-1
10	29.44	-90.34	08/29/06Z	65	989	HURRICANE-1
11	30.55	-90.65	08/29/12Z	65	989	HURRICANE-1
12	31.90	-90.65	08/29/18Z	65	989	HURRICANE-1
13	33.25	-90.65	08/30/00Z	65	989	HURRICANE-1
14	34.60	-90.65	08/30/06Z	65	989	HURRICANE-1
15	35.95	-90.65	08/30/12Z	65	989	HURRICANE-1

Date: 27 ? 30 AUG 1992
Hurricane MRG0006

ADV	LAT	LON	TIME	WIND	PR	STAT
1	20.93	-81.91	08/27/00Z	65	989	HURRICANE-1
2	21.88	-82.86	08/27/06Z	65	989	HURRICANE-1
3	22.83	-83.81	08/27/12Z	65	989	HURRICANE-1
4	23.78	-84.76	08/27/18Z	65	989	HURRICANE-1
5	24.73	-85.71	08/28/00Z	65	989	HURRICANE-1
6	25.68	-86.66	08/28/06Z	65	989	HURRICANE-1
7	26.63	-87.61	08/28/12Z	65	989	HURRICANE-1
8	27.58	-88.56	08/28/18Z	65	989	HURRICANE-1
9	28.51	-89.46	08/29/00Z	65	989	HURRICANE-1
10	29.44	-90.34	08/29/06Z	65	989	HURRICANE-1
11	30.55	-90.65	08/29/12Z	65	989	HURRICANE-1
12	31.90	-90.65	08/29/18Z	65	989	HURRICANE-1
13	33.25	-90.65	08/30/00Z	65	989	HURRICANE-1
14	34.60	-90.65	08/30/06Z	65	989	HURRICANE-1
15	35.95	-90.65	08/30/12Z	65	989	HURRICANE-1

Date: 27 AUG - 03 SEP 1992
Hurricane MRGO007

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.00	-82.00	08/27/00Z	124	934	HURRICANE-1
2	22.50	-83.50	08/27/06Z	124	934	HURRICANE-1
3	24.00	-85.00	08/27/12Z	124	934	HURRICANE-1
4	25.50	-86.50	08/27/18Z	124	934	HURRICANE-1
5	27.00	-88.00	08/28/00Z	124	934	HURRICANE-1
6	28.51	-89.46	08/28/06Z	124	934	HURRICANE-1
7	30.21	-90.65	08/28/12Z	65	989	HURRICANE-1
8	32.21	-90.65	08/28/18Z	65	989	HURRICANE-1
9	34.21	-90.65	08/29/00Z	65	989	HURRICANE-1

Date: 27 -29 AUG 1992
Hurricane MRGO008

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.00	-82.00	08/27/00Z	100	955	HURRICANE-1
2	22.50	-83.50	08/27/06Z	100	955	HURRICANE-1
3	24.00	-85.00	08/27/12Z	100	955	HURRICANE-1
4	25.50	-86.50	08/27/18Z	100	955	HURRICANE-1
5	27.00	-88.00	08/28/00Z	100	955	HURRICANE-1
6	28.51	-89.46	08/28/06Z	100	955	HURRICANE-1
7	30.21	-90.65	08/28/12Z	65	989	HURRICANE-1
8	32.21	-90.65	08/28/18Z	65	989	HURRICANE-1
9	34.21	-90.65	08/29/00Z	65	989	HURRICANE-1

Date: 27 ? 29 AUG 1992
Hurricane MRGO009

ADV	LAT	LON	TIME	WIND	PR	STAT
1	21.00	-82.00	08/27/00Z	65	989	HURRICANE-1
2	22.50	-83.50	08/27/06Z	65	989	HURRICANE-1
3	24.00	-85.00	08/27/12Z	65	989	HURRICANE-1
4	25.50	-86.50	08/27/18Z	65	989	HURRICANE-1
5	27.00	-88.00	08/28/00Z	65	989	HURRICANE-1
6	28.51	-89.46	08/28/06Z	65	989	HURRICANE-1
7	30.21	-90.65	08/28/12Z	65	989	HURRICANE-1
8	32.21	-90.65	08/28/18Z	65	989	HURRICANE-1
9	34.21	-90.65	08/29/00Z	65	989	HURRICANE-1

Chalmette Loop Design Grades

14.0	11+59 to 280+57 (IHNC Lock to Paris Road)
17.5	290+73 to 1191+95 Paris Road to Flood wall
17.0	1194+25 to pipelines at appox. 1331+50
16.5	1331+50 to 1518+75
13.5	1518+75 to fllodwall at 1560+31

LAT	LON	MAX WIND KNOTS
10.9	50.5	25
11.1	52.1	30
11.4	53.5	30
11.6	54.5	30
12.0	55.8	30
13.0	57.8	30
14.0	59.8	30
15.3	61.4	30
16.2	62.1	30
17.4	62.6	30
19.2	63.4	35
20.5	64.3	40
21.2	64.7	65
21.8	65.1	65
22.4	65.5	65
22.6	65.6	65
22.7	65.7	65
22.7	65.8	65
22.5	66.1	70
22.5	66.0	70
22.5	66.1	75
22.3	66.6	75
22.2	67.5	80
22.3	68.0	70
22.5	68.5	80
22.6	69.3	90
22.8	70.2	105
23.4	70.9	105
24.1	71.3	110
24.7	72.1	110
25.3	72.9	110
26.3	73.7	115
26.9	74.3	120
27.3	74.7	120
28.1	75.3	120
28.6	75.6	115
28.8	75.4	110
29.0	75.3	110
29.0	75.3	105
28.6	75.4	100
28.0	75.4	95
27.5	75.8	100
26.9	76.3	100
26.2	76.5	100
25.8	76.7	100
25.6	76.9	105
25.3	77.2	110
25.3	77.9	110
25.2	78.5	110
25.1	79.5	110
25.1	80.7	110
25.3	82.2	105
25.5	83.6	110
25.9	85.3	115
26.4	86.9	120
27.3	88.1	125
28.3	89.2	135

29.6	90.7	90
30.8	91.8	65
32.3	92.0	55
33.0	92.0	35
34.0	91.5	30
34.6	91.0	30
35.5	90.2	25
36.3	88.4	20
37.0	87.5	20
38.0	86.5	20
39.0	85.0	20
39.0	83.0	20

Station	Longitude	Latitude	Gage ID	Location
1	-93.8383	29.6909	!	SABINERIVER
2	-93.3461	29.7750	!AJ73650	CAMERON@CALCASIEU
3	-93.3328	29.8283	!A08017115	EAST FORK TRIBUTARY NEAR CAMERON
4	-93.2994	30.0317	!A08017095	NORTH CALCASIEU LAKE NEAR HACKBERRY
5	-93.3155	30.0759	!76880	CALCASIEULOCK
6	-92.9887	29.7398	!J70900	GRANDCHENIER
7	-92.8407	29.8631	!70675	CATFISHPTCTRLSTRUCTURE; moved 9/08/99
8	-92.7724	30.0035	!70600	MERMR@LACASSINE
9	-92.8786	30.0700	!A08012470	BAYOU LACASSINE NR LAKE ARTHUR
10	-92.5903	30.1897	!A08012150	MERMENTAU RIVER AT MERMENTAU
11	-92.3058	29.5525	!AJ76593	FRESHWATERBLOCK
12	-92.3053	29.5550	!A76590	FRESHWATER CANAL ABOVE BEEF RIDGE
13	-92.2633	29.7578	!A76600	SCHOONERB_CTRLSTR
14	-92.1944	29.7833	!AJ76720	ICW AT LELAND BOWMAN LOCK (EAST AUTO)
15	-92.1267	29.8392	!A67875	VERMILION RIVER NEAR BANCKER
16	-92.1561	29.9511	!A07386980	VERMILION RIVER AT PERRY
17	-92.1391	29.9760	!67675	VERRIV@ABBEVILLE(VERMILION RIVER)
18	-91.8089	29.4775	!	MARSHISLAND; moved 9/08/99
19	-91.8817	29.7156	!A07387040	CYPREMONTPOINT; moved 5/20/99
20	-91.8185	30.0078	!	BTECHE@NEWIBERIA
21	-91.5446	29.5965	!AB88800	LUKE'SLANDING; moved 6/17/99
22	-91.4625	29.6760	!76560	WAXLAKE_WEST
23	-91.6094	29.7558	!B	MUD LAKE
24	-91.4989	29.7917	!A07385800	BAYOU TECHE NR FRANKLIN
25	-91.5417	29.8231	!AJ64450	CHARENTONDRGCANAL AT BALDWIN
26	-91.4224	29.5853	!A03830	WAX_LAKE_OUTLET
27	-91.3728	29.6978	!A07381590	WAX LAKE OUTLET AT CALUMET
28	-91.3686	29.7025	!A03720	WAX LAKE OUTLET AT CALUMET
29	-91.3753	29.7036	!A64650	BAYOU TECHE AT W. CALUMET FLOODGATE
30	-91.3911	29.7646	!A03645	6MLLK@ATCHBASIN; moved 7/25/01
31	-91.3228	29.6408	!A76440	WAX_LAKE_EAST
32	-91.3817	29.3792	!AJ88600	EUGENEISLAND
33	-91.3411	29.4508	!A88550	ATCHAFALAYA BAY NR EUGENE ISLAND
34	-91.2675	29.4783	!AJ03850	ROUND_BAYOU_AT_DEER ISLAND; moved 5/20/99
35	-91.2447	29.5517	!A07381650	LW ATCH R BELOW SWEET BAY LK NR M C
36	-91.1736	29.6831	!A76360	BAYOU_BOEUF_LOCK
37	-91.2108	29.6944	!ABJ03780	MORGAN_CITY
38	-91.2247	29.7181	!A03750	LOWER ATCH. R. AT BERWICK LOCK WEST
39	-91.5256	29.8917	!A64400	CHARENTON DRAINAGE CNL NR FLOODGATE
40	-91.5239	29.9056	!A03555	GRAND LAKE AT CHARENTON
41	-91.2636	29.9451	!49645	OLDRIVER@ATCHBASI
42	-91.4856	30.0608	!A03465	CHICOT PASS AT WEST FORK CHICOT PASS
43	-91.5883	30.2247	!A03210	BAYOU LA ROMPE AT LAKE LONG
44	-91.5650	30.2406	!A03315	BLIND TENSAS CUT BELOW U. GRAND RIVER
45	-91.0983	29.6685	!A52800	BAYOU BOEUF AT AMELIA; moved 6/17/99
46	-90.9530	29.1580	!	CAILLOU_BAY
47	-90.8639	29.3368	!	South end of Bayou Dularge
48	-90.8141	29.5337	!	Intersect GIWW and Minor's Canal; moved 9/08/99
49	-90.8274	29.5596	!	Water control structure Bayou Black
50	-90.9921	29.6855	!52840	BBLACK@GIBSON; moved 8/17/01
51	-90.8189	29.7993	!82175	BLAFOURCHE@THIBODEAUX
52	-90.8028	29.8171	!	Intersect Bayou Lafourche and Bayou Terrebonne
53	-90.6300	29.1830	!	TERREBONNE_BAY
54	-90.6708	29.2335	!J76305	B_PETITE_CAILLOU; moved 9/08/99
55	-90.5830	29.2500	!	LAKE_BARRE-WEST
56	-90.5370	29.2720	!	LAKE_BARRE-NORTH
57	-90.6661	29.2993	!	Southern most part of LA 57
58	-90.7229	29.3182	!	Houma Navigation Canal near MM 18.0

112 -91.2103 30.4319 !A52415 ICW AT PORT ALLEN LOCK
113 -89.1833 29.4583 !A85222 BRETON_SND@BRETON ISLAND
114 -89.5232 29.3832 ! OSTRICA
115 -89.3186 29.6282 ! MRGO@CHANLEURSND
116 -89.5681 29.4856 !A07374529 CALIFORNIA BAY NR SUNRISE PT NE OF
NAIM
117 -89.5833 29.5167 !A07374528 NORTH CALIFORNIA BAY NR
PT-A-LA-HACHE
118 -89.6333 29.5833 !A85111 BLACK_B_NR_BRETON
119 -89.6667 29.6000 !A07374527 NE BAY GARDENE NR PT-A-LA-HACHE
120 -89.5667 29.6333 !A07374526 BLACK BAY NR SNAKE IS NR
PT-A-LA-HACHE
121 -89.9367 29.6627 ! PHOENIX
122 -89.7922 29.7639 !AJ85780 B_TERRE AUX BOEUFS AT DELACROIX
123 -89.8592 29.8479 ! TOCA
124 -90.7823 30.2750 !85255 AMITER@FRENCHSETT
125 -90.5461 30.0807 !01260 RESERVCANAL@US61
126 -90.5898 30.2076 ! LKMAURPAS@BLNDRIV; moved 9/08/99
127 -90.5618 30.2883 ! LKMAURPAS@AMITE
128 -90.5591 30.3687 !J85300 TICKFAW RIVER NR SPRINGFIELD
129 -90.4112 30.1833 ! LKPONT@RUDDOCK
130 -90.4156 30.1084 !AJ85550 LKPONT@FRENIER; 8/12/99
131 -90.3777 30.0697 ! LKPONT@BONNECARR
132 -90.3743 29.9990 ! STCHRLS_CNTR@US61
133 -90.3306 30.0289 !A85564 PIPELINE CANAL AT ILLINOIS CENTRAL RR N
134 -90.3303 30.0289 !A85566 PIPELINE CANAL AT ILLINOIS CENTRAL RR S
135 -90.2927 29.9857 ! STCHRLS_EAST@US61
136 -90.2925 30.0071 ! JEF-STCHRLS@I10; moved 7/25/01
137 -90.2779 30.0628 ! KENNER_JEFPRSHLEV
138 -90.2074 30.0454 ! CENTER_JEFPRSHLE
139 -90.1246 29.9791 ! 17STCANAL@RR
140 -90.1156 30.0217 !ABJ85625 LKPONT@WESTEND
141 -90.1027 30.0362 ! LKPONT@PONTBEACH
142 -90.0266 29.9675 !76160 IHNC@SHIPLOCK
143 -90.0208 29.9814 !A76120 IHNC@FLORIDA AVE. BRIDGE
144 -90.0328 30.0292 !AB76060 IHNC@SEABROOK
145 -89.9779 30.0008 ! CITRUSBACKLEVEE
146 -89.9347 30.0067 !AB76040 MRGO@PARISRD
147 -89.9152 29.9986 !A76025 BAYOU BIENVENUE AT FLOODGATE EAST; moved
6/17/99
148 -89.8649 30.0296 ! NOEAST_BKLEVEE; moved 9/08/99
149 -89.8400 29.9431 !AJ76010 BAYOU DUPRE AT FLOODGATE (EAST)
150 -89.8400 29.9411 !A76005 MRGO@MARTELLO (GATE CL.)/B_DUPRE W
151 -89.6836 29.8617 !ABJ85800 MRGO_AT_SHELL_BEACH; moved 5/12/99
152 -89.6486 29.8709 !B OLDSHELLBEACH; moved 9/08/99
153 -89.9464 29.9819 !A76020 BAYOU BIENVENUE AT PARIS ROAD
154 -89.9882 30.0587 ! CITRUS_LKFRTLEVEE
155 -89.9118 30.1188 ! NOEASTLKFRTLEVEE
156 -89.8692 30.1461 !A85675 "LKPONT@SPT (SOUTH SHORE, IRISH BAYOU)"
157 -89.8553 30.0956 ! SPT-US90LEVEE
158 -89.8486 30.0786 ! US90_NOESTBKLEVEE
159 -89.8061 30.0681 !A85750 CHEFMENTR@US90; moved 8/17/01
160 -89.7307 30.1181 ! LKSTCATHERINE; moved 9/08/99
161 -89.6768 30.1410 !85725 RIGOLETSNRLBORGNE; moved 9/08/99; moved
8/17/01
162 -90.4003 30.2814 !A85420 PSMANCHAC@I55
163 -90.3027 30.2937 ! LKPONT@PSMANCHAC
164 -90.1258 30.1878 !AB85600 CAUSEWAY@MDLK
165 -90.0958 30.3586 !ABJ85575 CAUSEWAY@NRTHSHORE (MANDEVILLE)
166 -89.9532 30.2525 ! LKPONT@BLACOMBE; moved 9/08/99
167 -89.8687 30.2474 ! LKPONT_BBONFUCA; moved 9/08/99
168 -89.8301 30.1772 ! LKPONT@US11
169 -89.7921 30.2057 ! LKPONT_EDENISLES

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170      -89.7673        30.1928 !       LKPONT_TREASUREIS;  moved 9/08/99
171      -89.7369        30.1672 !ABJ85700        RIGOLETS@US90
172      -89.7222        30.1685 !A0738023365     THE RIGOLETS NEAR SLIDELL;  moved
6/17/99
173      -89.6206        30.2822 !       PEARLINGTON
174      -89.3084        30.2991 !       BAYSTLOUIS
175      -89.0944        30.3601 !       GULFPORT
176      -88.8287        30.3820 !AB88200         BILOXI
177      -88.5715        30.3450 !       PASCAGOULA
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