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BONNET CARRÉ FRESHWATER DIVERSION, LAKE PONTCHARTRAIN,  
LAKE BORGNE, BILOXI MARSHES, MRGO AND THE IHNC

AN EVALUATION BY THE COMMITTEE ON TIDAL HYDRAULICS

OCTOBER 1995

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EXECUTIVE SUMMARY

The USACE New Orleans District has been authorized by Congress to construct a structure at the Bonnet Carré floodway to divert Mississippi River water into Lake Pontchartrain in order to reduce salinities in the Mississippi-Louisiana estuarine area. The project involves consideration of the roles that the Mississippi River Gulf Outlet (MRGO) and Inner Harbor Navigation Canal (IHNC) play in the system's salinities, and the District asked the Committee on Tidal Hydraulics to review information on the Bonnet Carré Freshwater Diversion project and answer the questions listed below.

a. *Can the contribution of the MRGO-IHNC to the increase in salinity in Lake Pontchartrain and adjacent waterways be economically controlled by reducing either:*

(1) *The volume of MRGO flow into the Lake, or*

(2) *The salinity concentration of the MRGO flow into the Lake?*

b. *If so, can the Bonnet Carré freshwater diversions be reduced in magnitude while still producing:*

(1) *The desired freshening effect in project wetlands and marshes, and*

(2) *The target salinities for increased oyster production?*

This report by the Committee on Tidal Hydraulics provides the following conclusions and recommendations:

a. The Inner Harbor Navigation Canal (IHNC) contributes about 5 percent of the Lake Pontchartrain tidal prism, but about 9 percent of the salt flux into the lake.

b. The Mississippi River-Gulf Outlet (MRGO) contributes about six times as much salt to Lake Borgne as the IHNC contributes to Lake Pontchartrain.

c. Salinity intrusion to Lake Pontchartrain cannot be significantly reduced by controlling flows at the IHNC connection to the lake, but construction of a sill-weir combination might alleviate the hypoxia zone that forms in Lake Pontchartrain near the airport. Further field data are needed to determine how effective such a structure would be. X

d. Salinity reduction in Lakes Pontchartrain and Borgne and the nearby Biloxi Marshes might be achieved by controlling flows in the multiple connections between the MRGO and Lake Borgne and/or artificially mixing stratified waters in the MRGO. These alternatives offer the possibility that diversions through the Bonnet Carré structure could be reduced from the original design capacities without compromising the project's salinity reduction goals.

e. Salinity reduction efforts by other means might be enhanced by comparatively small Mississippi River water diversions through the IHNC lock to the Mississippi River.

f. Items (c)-(e) above should be the subjects of engineering studies to determine their feasibility.

g. The ongoing numerical modeling of the system should be continued, with verification and then testing of various alternatives, including those listed here. Additional field observations in support of the modeling may be required.

## 1 INTRODUCTION

### Background

1. The Bonnet Carré Spillway, located on the Mississippi River about 27 miles (43 km) upstream from New Orleans, was completed in 1931 for the purpose of providing a controlled discharge of a portion of above flood stage flows of the Mississippi River into Lake Pontchartrain, in order to reduce flooding of New Orleans and other down river communities. The spillway structure consists of 350 gate bays, and was intended to be used only for extreme flood conditions. In the 64 years since its construction, the spillway has only been used for its designed purpose during seven years (1937, 1945, 1950, 1973, 1975, 1979, and 1983).
2. Figure 1 is a map of Lake Pontchartrain and adjacent waterways, showing the various locations discussed in this report.
3. The Mississippi River Gulf Outlet (MRGO) canal is a man-made navigation waterway for ship and barge traffic, which extends some 76 miles (122 km) from deep water in the Gulf of Mexico northwestward to New Orleans. The MRGO, completed to its designed dimensions of 36 ft (11 m) by 500 ft (152 m) in 1965, includes a land cut 38 miles (61 km) long passing through marsh and shallow water areas. At its landward end the MRGO joins the Gulf Intracoastal Waterway (GIWW) for about five miles before ending in a turning basin within the Inner Harbor Navigation Canal (IHNC). The project was constructed in stages, and attained dimensions of 36 ft (11 m) by 250 feet (76 m) over the full reach from the GIWW to open waters in the Gulf in early July of 1963. Since completion to project dimensions the unstable marsh bank lines have eroded along the length of the land cut.
4. During the construction of the MRGO the U.S. Army Engineer Waterways Experimental Station (WES) conducted tests in an hydraulic model which included, at a horizontal scale of 1:2000 and a vertical scale of 1:100, all of Lake Pontchartrain, all of Lake Borgne, a part of Mississippi Sound, the full reach of the MRGO, the GIWW, and the IHNC, and all of the passes between these several waterways. This study (WES, 1963) predicted that the completion of the MRGO would result in significant increases in the salinities in Lake Pontchartrain, Lake Borgne, the IHNC, and in the passes interconnecting these water bodies. The average increase (low fresh water flow and high fresh water inflow years combined) in the salinities in Lake Pontchartrain as given by these hydraulic model tests was 5.03 ppt, from 1.15 ppt without MRGO to 6.18 ppt with MRGO installed in the model.
5. More recently Sikora and Kjerfve (1985) published a paper giving the results of an analysis of a record of daily salinity observations made at two stations in Lake Pontchartrain, and one station each in The Rigolets, in Chef Menteur, and in Pass Manchac. These data, collected by the U.S. Army Engineer District, New Orleans, extended over the 36 year period from 1946 through 1981. This data set and its analysis by Sikora and Kjerfve are described in detail in Appendix A, which includes an evaluation of this paper by the Committee. For the purposes of this introduction, the important conclusions reached by Sikora and Kjerfve are listed below:
  - a. For each of these five stations the post-MRGO (after 1963) record length mean salinity exceeds the pre-MRGO (before 1963) record length mean salinity, but by an increment much smaller than the 5.03 ppt increase predicted for Lake Pontchartrain using data collected in the 1963 WES hydraulic model. The maximum post-MRGO minus pre-MRGO salinity difference within Lake Pontchartrain as computed by Sikora and Kjerfve using the subject

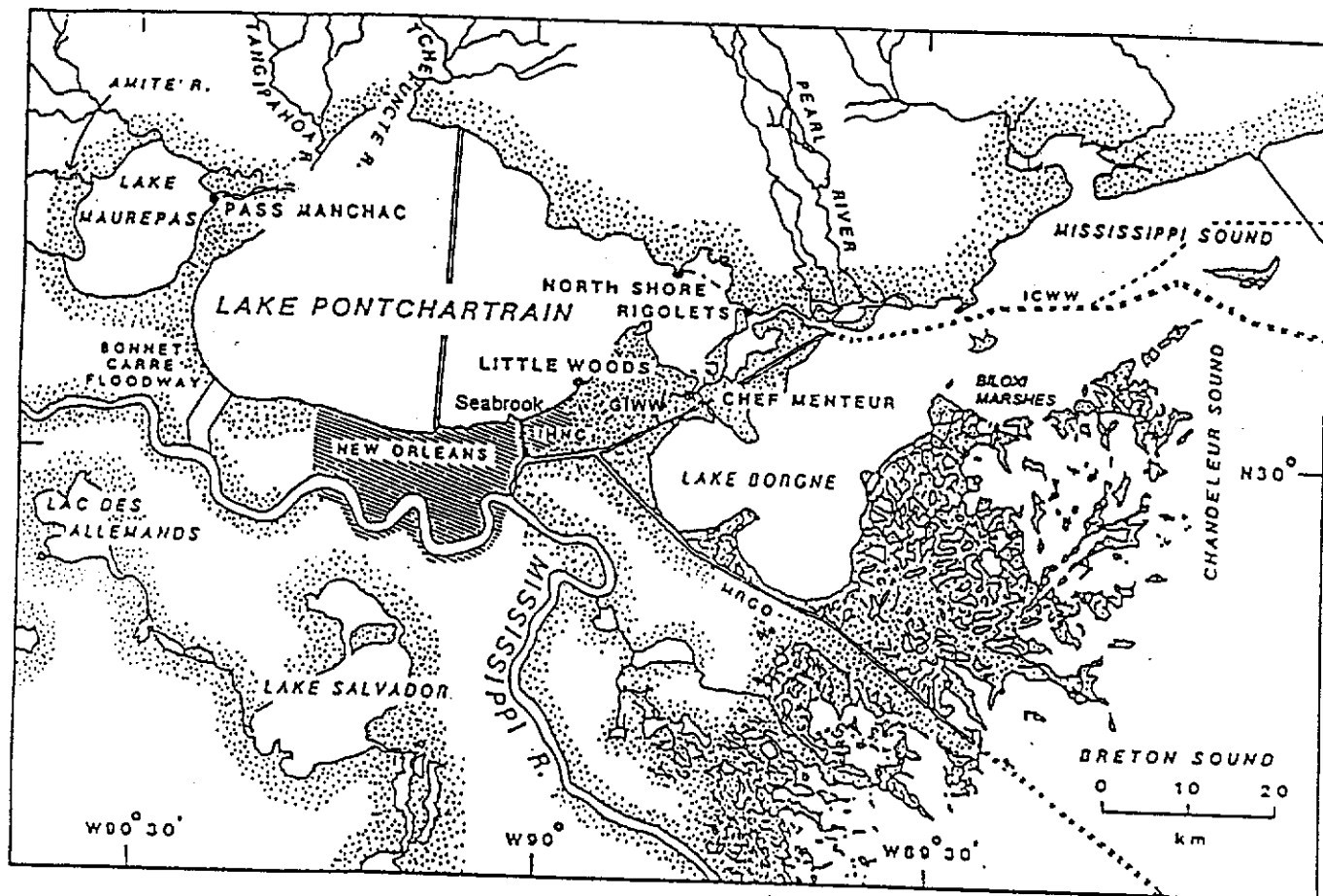


Figure 1. Map of Lake Pontchartrain and adjacent waterways. MRGO indicates the Mississippi River Gulf Outlet; IHNC indicates the Inner Harbor Navigation Canal; GIWW indicates the Gulf Intracoastal Waterway.

prototype data set was 1.6 ppt for the Little Woods station, located just off the southwestern shore of the Lake.

b. The subject data set is marked by large variances for each station at all time scales. Sikora and Kjerfve state that because of these large variances the computed values of the pre-MRGO to post-MRGO increases in salinities are statistically insignificant. These authors do not present any description of the statistical measures used to reach this conclusion.

6. Since the publication of the Sikora and Kjerfve paper, the U.S. Army Engineer District, New Orleans (USAENOD), used that same data base to analyze the pre-MRGO to post-MRGO monthly mean salinity differences for four of the five stations listed in the previous paragraph (USAENOD, 1984). This analysis by the District gave values for the pre-MRGO to post-MRGO record length mean salinity increases quite close to the values given in the paper by Sikora and Kjerfve. In addition, The District analysis included the computation of the characteristic seasonal variation in the pre-MRGO and post-MRGO mean salinities for each month, and in the month by month differences in these monthly average salinities. In the document the District did not discuss the statistical significance of the results of their analysis.

7. Prior to the completion of MRGO there was evidence of a loss of fresh water marshes throughout the Lake Pontchartrain Basin. Such loss probably resulted from the combined long term effects of subsidence, sea level rise, and the loss of sediment input to the Lake from overflow of the Mississippi River, which had been effectively eliminated over the last 100 years by improvements to the levees along the River. Exceptions to this last statement are of course the purposeful diversions of flood waters through the Bonnet Carré Spillway. When it was realized that the opening of the MRGO would likely result in some increase in the salinity of the Lake waters, there was concern expressed by various parties that the loss of freshwater wetlands would be accelerated. Also, the production of oyster seed on beds in the Biloxi Marshes on the east side of Lake Borgne is adversely impacted by salinities consistently greater than about 15 ppt as a result of the invasion of the oyster drill at these salinities. The U.S. Army Engineer District, New Orleans, and the State of Louisiana have undertaken projects, including freshwater diversions, to offset or at least reduce the loss of fresh water wetlands in other marsh areas as well as around Lake Pontchartrain, and to improve oyster seed production. A fresh water diversion has been constructed at Caernarvon; one is under construction at Davis Pond; and a third has been authorized for Bonnet Carré.

8. In 1988 the U.S. Congress authorized the expenditure of funds to modify the Bonnet Carré Spillway to provide for a controlled diversion of flow from the Mississippi River into Lake Pontchartrain under non-flood river stages. The purpose of this Bonnet Carré Diversion Project was to provide some mitigation for an increase in the salinity of Lake Pontchartrain, Lake Borgne, and in the Biloxi Marshes which had resulted since the opening of the Mississippi River-Gulf Outlet Canal in 1963. Although the MRGO was not completed to full project dimensions until 1965, its impact on the salinities of Lake Pontchartrain appears to have been felt beginning in the middle of 1963, when the Canal dimensions were 36 ft by 250 ft. The Bonnet Carré diversion project would provide for the diversion of Mississippi River water into western Lake Pontchartrain through the existing Bonnet Carré spillway, using a new control structure and a new channel within the spillway. This new control structure would allow diversions of up to 30,000 cfs (850 m<sup>3</sup>/sec.) The economic justification for the project is the reduction in the salinities in the Biloxi Marshes, which lie between Lake Borgne and Chandeleur Sound along the Louisiana-Mississippi boundary, for the purpose of increasing the production of oyster seed. Benefits from the project would also include the

reduction of salinities in the marshes surrounding Lake Pontchartrain and Lake Borgne.

9. The project's oyster production benefits have been tied to achieving a target range of salinities in the Biloxi Marshes. The targets, called the Chatry-Dugas Salinities, consist of an annual cycle of salinities that have been found to result in a superior oyster harvest the following year. It is claimed that if these targets are met one year in three, a two fold increase in oyster production would be achieved. To insure that the project would result in sufficient oysters in the seed grounds, the Corps designed the diversion structure for a maximum flow of 30,000 cfs with a 50 percent flow duration in the Mississippi River for April.

10. Since 1932 some 66,000 acres of marsh have been lost in the Pontchartrain Basin, and another 63,000 acres are expected to be lost in the next 50 years if no remedial action is taken. As noted above, some of these losses are the result of subsidence and sea level rise, as well as the loss of sediment replenishment, which previously occurred due to frequent natural flooding of the Basin from the Mississippi River. In addition to providing sediment replenishment, such past natural flow of Mississippi River water into Lake Pontchartrain significantly increased the annual input of fresh water to Lake Pontchartrain over that provided by the rivers and streams which enter directly to the lake, and consequently provided for lower salinities in the Lake than occurred after the levees closed off the supply of fresh water from the Mississippi River. The salinity increases resulting from the MRGO are considered to have increased the loss of fresh water marshes along the shores of western Lake Pontchartrain. The Bonnet Carré diversion project was designed to offset these processes by diverting fresh water into Lake Pontchartrain. This diversion would also push lower salinity water through the passes and into Lake Borgne.

11. Some of the commercial and sport fisheries which are now important in Lake Pontchartrain are favored by the higher salinities which have occurred there since the opening of the MRGO. A group of commercial and sports fisherman, together with other opponents of the project, have joined together under the umbrella of the Lake Pontchartrain Basin Foundation. This organization has asserted that introduction of Mississippi River water containing pollutants and excess nutrients will harm Lake Pontchartrain, leading to algal blooms, sediment resuspension and turbidity, and fisheries displacement. Federal and state agencies support the Bonnet Carré project.

12. Under the urging of some members of the Louisiana Congressional delegation, and representatives of the Governor's office, various state and federal agencies, including the U.S. Army Corps of Engineers, formed a Steering/Review Panel to oversee a Technical Team's reanalysis of the project. Included in the various findings and recommendations of the Technical Team and the Steering/Review Panel, under the general heading "ITEM 4 OTHER FINDINGS AND RECOMMENDATIONS BEYOND THE ORIGINAL CHARGE", was the following statement: "3. The Steering Panel requests Congress to pass additional authorization necessary to construct a sill or other barrier across the IHNC, as soon as possible."

13. As a result of the deliberations of the above described Steering/Review Panel, and the recommendations of its Technical Team, the New Orleans District asked the Committee on Tidal Hydraulics to review the available material on the effects of the opening and ultimate completion of the MRGO on the temporal and spatial variations in salinity within Lake Pontchartrain, Lake Borgne, the various passes and navigation projects connecting these waterways, and the marshes adjacent to them, and to answer several questions posed by the District.

Purpose

14. The purpose of this report is to answer the following questions posed by the New Orleans District:

a. Can the contribution of the MRGO-IHNC to the increase in salinity in Lake Pontchartrain and adjacent waterways be economically controlled by reducing either:

(1) The volume of MRGO flow into the Lake, or

(2) The salinity concentration of the MRGO flow into the Lake?

b. If so, can the Bonnet Carré freshwater diversions be reduced in magnitude while still producing:

(1) The desired freshening effect in project wetlands and marshes, and

(2) The target salinities for increased oyster production?

15. In view of the quoted statement given in Paragraph 12, the Committee interprets question a. (1) above to include the construction of a lock or a submerged weir at or near Seabrook at the northern end of the IHNC.



## 2 PROCEDURE

16. To develop the basis for answers to the questions posed by the New Orleans District, the Committee found it necessary to first resolve certain matters related to but not directly a part of these questions. The Committee used published and unpublished documents and data to attempt to resolve these matters. The following is a list of these subjects that the Committee felt it necessary to consider prior to dealing with the questions posed by the District. Each item on this list is preceded by a brief introductory statement:

a. The paper by Sikora and Kjerfve raised questions concerning the statistical significance of the computed values of the pre-MRGO to post-MRGO increase in salinities of Lake Pontchartrain and adjacent waterways, but these authors did not present information on the statistical tests which led them to reach this conclusion. Although the District used the same data base to recalculate the pre-MRGO to post-MRGO difference in the annual average salinities, and in addition determined the pre-MRGO to post-MRGO change in the monthly mean salinities, the question of statistical significance was also not addressed. Therefore, the Committee has undertaken a determination of the probabilities that the available data support the statement that the post-MRGO salinities are in fact greater than the pre-MRGO salinities, and to determine the confidence limits around the computed salinity increases.

b. Several different estimates of the fraction that is provided by the IHNC of the tidal prism of Lake Pontchartrain, and of the total flux of salt to Lake Pontchartrain, were contained in the various published papers and reports provided to the Committee for use in the preparation of this report. The Committee considers it necessary to resolve these uncertainties since the benefits that a complete closure or partial control of the flow from the IHNC to Lake Pontchartrain depend on the relative contribution of this source of salt to the Lake.

c. Early in the study of various documents provided by the District and by WES dealing with the construction of the MRGO, and with the various modeling efforts made to evaluate the impact of the MRGO on the salinity in Lake Pontchartrain and the adjacent waterways, the Committee found several references to the possible input of high salinity waters directly from the MRGO to Lake Borgne via inlets which constitute the mouths of the several bayous which intersect and cross the MRGO. These inlets are particularly evident along the southern and southeastern shores of the Lake Borgne where the MRGO passes within a few hundred feet from the Lake shore over a reach of several miles. It appeared to the Committee that this source of salt to Lake Borgne could constitute a significant cause for the increases in the salinities over the oyster seed beds in the Biloxi Marshes. The Committee believed it was necessary to expend considerable effort to search for any existing data on the size of these inlets and on the tidal and subtidal flows between the MRGO and Lake Borgne via these bayou crossings. The committee has used the data it has found to estimate the salt flux to Lake Borgne directly from the MRGO.

17. In the next section of this report (Section 3), brief statements will be presented giving the results of the Committee's attempts to resolve the subjects listed in the above paragraph. More detailed descriptions of the basis for the Committee's conclusions regarding the three subjects listed in Paragraph 16 are given in Appendices A, B, and C. In Section 4 of this report, the Committee's answers to the questions posed by the District are given. Included in that section are brief descriptions of the basis for the

Committee's answers. Finally, Section 5 contains the Committee's recommendations to the District.

### 3 CONCLUSIONS ON THE THREE PRELIMINARY SUBJECTS TO BE RESOLVED

#### On the Statistical Significance of the Pre-MRGO to Post-MRGO Salinity Differences

18. A detailed description of the procedures employed in the resolution of this matter is given in Appendix A. The Committee undertook an independent analysis of the pre-MRGO to post-MRGO salinity increases using the same data set used by Sikora and Kjerfve (1985) and by the District in their analysis. For comparison, the following Table 3-1 lists the post-MRGO record length mean salinity minus the pre-MRGO record length mean salinity for each of the stations used by Sikora and Kjerfve, by the District, and by the Committee.

TABLE 3-1 COMPARISON OF ANALYSIS OF CHANGES IN SALINITIES FROM BEFORE TO AFTER MRGO CONSTRUCTION, PPT			
STATION	SIKORA & KJERFVE	USAENOD	Committee (Appendix A)
Rigolets	2.0	Not Published	Not Published
Chef Menteur	2.6	2.4	2.1
Little Woods	1.6	1.8	1.7
North Shore	1.3	1.3	1.1
Pass Manchac	0.2	0.4	0.3

The differences in the listed values for each station result from differences in the procedures used by each of the three groups in treating the transition year, 1963, and in dealing with missing data for one to three months in an otherwise complete year of monthly mean salinity values. The District and also the Committee (Appendix A) computed monthly mean salinity differences, pre-MRGO to post-MRGO, with very similar results. Table A1 of Appendix A lists the pertinent parameters used in and the computed results produced by the Committee's analysis. The following paragraphs briefly state the Committee's conclusions regarding the characteristics of the data set and the statistical significance of the computed values of the pre-MRGO to post MRGO salinity differences, both for annual averages and for monthly averages.

19. The data base of pre-MRGO and post-MRGO observed salinities at locations in Lake Pontchartrain and in the adjacent passes suffers from the shortness of the data record, particularly for the pre-MRGO period. Two of the four Pre-MRGO data sets contained salinity observations for just six years. One of these two stations had salinity data for the post-MRGO period covering only 12 years. The small data base is coupled with a large variability in the salinity values at all time scales (daily, and weekly, monthly and yearly averages), such that, considering each station independently from the others, there is a large range of uncertainty about the computed values of the post-MRGO minus pre-MRGO differences.

20. Even so, for the annual averaged data sets, the probability that the post-MRGO salinities exceed the pre-MRGO salinities is very high, being  $>0.995$  for the three higher salinity stations, and only slightly lower (0.992) for the station in Pass Manchac. It would thus appear that Sikora and Kjerfve were using the term "statistically insignificant" from a subjective standpoint and not from an objective, quantitative standpoint. For the case of monthly averaged data sets, the probabilities that the post-MRGO salinities exceed pre-MRGO salinities are smaller, and for two of the stations, very much smaller, than for the annually averaged data. For the station at Little Woods, which was the station for which there was the largest data set, and for which the data was the most evenly divided between pre- and post-MRGO periods, the values of the probability that the post-MRGO salinities are greater than the pre-MRGO salinities were sufficiently high for all months to justify the statement that the differences based on monthly data are significant. Although the values of the probability that the subject difference is positive for all 12 months for the station in the Chef Menteur are somewhat less than those for Little Woods, they are adequately high to also state that the case for the contention that the post-MRGO monthly mean salinities are greater than the pre-MRGO monthly mean salinities is essentially proven for this station. For the station at North Shore, and even more so for the station in Pass Manchac, the data do not provide a strong basis in support of the contention that post-MRGO monthly mean salinities are higher than pre-MRGO monthly mean salinities.

21. The 95% confidence limits about the mean difference, post-MRGO minus pre-MRGO, computed by the Committee from the annual average data sets, indicate a reasonably high degree of confidence in these differences for Little Woods and Chef Menteur. For Little Woods, the range of the 95% confidence limits is  $\pm 0.35$  ppt, or  $\pm 21\%$  of the mean difference. For Chef Menteur, the range in the 95% confidence limits is  $\pm 0.5$  ppt, or  $\pm 24\%$  of the mean difference. For the station at North Shore, the range of the 95% confidence limits about the mean difference is  $\pm 46\%$  of the mean, while at the station in Pass Manchac, it is  $\pm 67\%$  of the mean. The subject differences for the individual monthly average salinities are known with considerably less certainty. Even for Little Woods, one month had a lower 95% limit of  $-0.1$  ppt and an upper 95% limit of  $+3.0$  ppt. The average values over the 12 months for the lower limit was  $0.1$  ppt and for the upper limit  $3.0$  ppt. These values represent a range of  $\pm 85\%$  of the average mean difference of  $1.7$  ppt. For the station in the Chef Menteur, the average of the monthly values of the upper and lower 95% confidence limits is  $\pm 93\%$  of the average mean difference. For the North Shore, this range is  $\pm 160\%$  of the 12 month mean difference, while for the station in the Pass Manchac,  $\pm 238\%$  of the mean difference.

22. The above statements are made for the case of treating each station individually. Several comments have been included in earlier paragraphs noting that the seasonal variation shown by the monthly values of both the pre-MRGO and post-MRGO salinities, and the month to month variation in the post-MRGO minus the pre-MRGO differences, are quite consistent among the four stations, and particularly among the 3 higher salinity stations. These observations suggest that the confidence which could be placed in the computed values of the pre- to post-MRGO differences is greater than indicated by the simple statistical analysis described above. It was also noted that the difference in the mean values of the pre-to post-MRGO salinities, for both annual and monthly data sets, increased with increasing salinity. Otherwise, the statistical parameters, such as the standard deviation, of the distribution of the monthly mean salinities, appear to be the same, at least for the three higher salinity stations. These observations then suggest that combined data sets for these three stations could be formed by adjusting the data from two of the stations so that these data sets had the same record length mean as the third station. Thus, for the station in the Chef Menteur

serving as the master data set, the monthly mean salinities for, say, the station at Little Woods would be multiplied by a factor equal to the record length mean of the Chef Menteur monthly mean salinities divided by the record length mean of the Little Woods monthly mean salinities. The data set for the station at North Shore would be similarly treated, and a composite data base formed from the data set for the Chef Menteur and the modified data sets for the other two stations.

23. The Committee performed such an exercise, the results of which are shown in Table A2 of Appendix A. This analysis indicates that in fact the values of the post-MRGO minus the pre-MRGO salinities for the annual averaged data are quite well known. The range in the 95% confidence limits given by this analysis for the Chef Menteur and the Little Woods stations is just  $\pm 16\%$  of the mean difference, and for the North Shore station, just  $\pm 17\%$ . The average range of the confidence limits for the monthly differences was  $\pm 52\%$  of the mean difference for all three stations. This is a considerably narrower confidence band than was found from considering each station individually.

#### On the Question of the Several Estimates of the Tidal Prism of Lake Pontchartrain

24. The details of the Committee's analysis of the several estimates of the tidal prism of Lake Pontchartrain found in the various reference materials available to the Committee, and the Committee's conclusion as to the best estimate of the tidal prism, are given in Appendix B. At the start of this investigation the Committee had available three estimates of the tidal prism of the Lake. One of these was a value contained on a the cover sheet to an informal briefing document provided by the District. This value of  $3.0 \times 10^9 \text{ m}^3$  was not accompanied by any supporting data or any references to reports or publications supporting this estimate. A second estimate was a value of  $2.55 \times 10^9 \text{ m}^3$  contained in WES Technical Report No. 2-636, dated November, 1963. The third estimate of the tidal prism initially evaluated by the Committee was based on information contained in a WES Letter Report to the U.S. Army Engineer District, New Orleans, dated April 1976, and entitled "Reduction in Lake Pontchartrain Tidal Prism Caused by Hurricane Barriers." This report gave values of the flood and ebb tidal averaged volume fluxes through each of the three passes to the Lake based on velocity measurements made in the 1963 hydraulic model of the subject waterways. Details of the Committee's analysis of these flux values as estimates of the tidal prism of the Lake are given in paragraph B2 of Appendix B. The estimate of the tidal prism based on these data is  $1.44 \times 10^9 \text{ m}^3$ . These three estimates thus range from  $1.44 \times 10^9 \text{ m}^3$  to  $3.0 \times 10^9 \text{ m}^3$ . Considering the importance of narrowing the uncertainty of these estimates in order to evaluate the consequences of the construction of a structure to effectively close off the exchange of water and salt between the IHNC and the Lake, the Committee considered it necessary to search for other data which could be used as a basis for the computation of the tidal prism.

25. The tidal prism of a semi-enclosed coastal water body having a connection via one or more passes or entrance channels to the adjacent open coastal waters is the average difference between the maximum volume and the minimum volume of the water body over a tidal cycle, under conditions that the variations in volume is the result of the astronomical tide. That is, the effects of meteorological forced changes in water level within the subject water body are not included in the calculations. The simplest algorithm expressing this definition is that the tidal prism is equal to the product of the range of the tide times the surface area of the subject water body. This statement is correct only if the tide in the water body is a standing wave, that is, the phase lag of the tide is constant over the surface of the water

body. Corrections for the effect of varying phase lags across the water body can be made by subdividing the area of the water body into segments for which a constant value of the phase lag is assigned. In the case of Lake Pontchartrain it can be shown that the effect of a varying phase lag reduces the computed value of the tidal prism compared to that calculated using the simple algorithm by less than 1%. In any case, the product of mean tide range times the surface area of the Lake gives the maximum possible value of the tidal prism of the Lake.

26. The Committee found several slightly different values for the surface area of Lake Pontchartrain quoted in the various documents provided by the District and in referenced publications. The Committee chose to use a value of  $1.644 \times 10^3 \text{ km}^2$  given by Poirrier (1973), which is intermediate to the other values found in the reference material. Using data from six tide gages deployed by the District over a 182 day period described by Outlaw (1982), Swenson and Chuang (1983) computed the mean range of the tide in Lake Pontchartrain to be 10.88 cm. Based on these values of Lake surface area and tide range, the maximum tidal prism of Lake Pontchartrain is  $1.79 \times 10^9 \text{ m}^3$ . The slight correction for the fact that there is some variation in the phase lag of the tide wave within the Lake results in a best estimate for the tidal prism of Lake Pontchartrain of  $1.78 \times 10^9 \text{ m}^3$ .

27. A second procedure for determining the tidal prism of a water body involves the use of measurements of current velocities taken at a number of points in a transect across the pass, or passes, which connect the subject water body to the adjacent open coastal waters which constitute the proximate source of the tidal energy in the water body. In the case of Lake Pontchartrain, the ideal application of this procedure would be the deployment of a number of vertical moorings across a transect in each of the three passes, with each mooring containing up to five current meters in the vertical. The instruments should be capable of *in situ* recording or the transmission of data to a surface buoy or to a shore station. These arrays should be deployed for periods of 35 days or longer. The number of moorings required to obtain good estimates of the volume flux would depend on the geometric complexity of the pass, and the number of current meters in the vertical would depend on the depth of the water and the vertical structure of the velocity distribution. The sampling rate of the current meters would depend on the amplitude of short term time variations in the local velocity. Longer time intervals between recordings of current meter readout can be utilized if the current meter is capable of taking vector averages of the velocity signal over the interval between recordings.

28. In the real world the cost of instrumentation has precluded the attainment of this ideal deployment of current meters. An alternate approach is to use survey vessels equipped with current meters having sensor packages which can be lowered and raised rapidly through the water column and having deck mounted readout units (or acoustic Doppler current profiling (ADCP) instruments.) The survey vessels moves rapidly from station to station back and forth across the transect. The rate at which measurements are to be made at each station should be no less than once an hour, and preferably once each 30 minutes, so that the number of stations that can be occupied in the transect depends on the width of the waterway. Where the width of the pass is such that fewer than three stations could be occupied within 30 minutes to an hour, the use of multiple survey vessels should be considered. The cost and availability of suitably equipped survey vessels and trained field parties preclude the use of this moving vessel procedure for long periods. Measurements in the passes to Lake Pontchartrain using this procedure have been limited to a duration of 25 hours, or just one diurnal tidal cycle.

29. A procedure of combining the use of long term moored current meter arrays (35 days) with the use of moving survey vessels over short time periods (25 hours), could provide lower costs without causing serious degradation in the results. The idea is to use fewer moorings, with each mooring having fewer than the ideal number of current meters in the vertical, and to calibrate the volume flux values calculated from this reduced array with data obtained using the moving survey vessel procedure during several 25-hr surveys during the longer term period of current meter deployment.

30. The Committee located three additional data sets which could be used to compute the tidal prism of Lake Pontchartrain. Each of these data sets was used by the Committee to obtain estimates of the tidal volume flux per tidal cycle through the three passes to the Lake. One of these data sets was from the paper by Swenson and Chuang (1983). The other two data sets were from the document by Outlaw (1982). Details of the Committee's analysis of the data provided by these three sources are given in Appendix B, paragraphs B5 through B8. The three values of the tidal prism of Lake Pontchartrain obtained by the Committee in its analysis of the data from these three data sets were  $1.56 \times 10^8 \text{ m}^3$ ,  $1.54 \times 10^8 \text{ m}^3$ , and  $1.72 \times 10^8 \text{ m}^3$ .

31. It would appear that the  $3.0 \times 10^8 \text{ m}^3$  estimate of the tidal prism need not be considered further. The WES (1963) report, which was the source of the statement that the tidal prism of Lake Pontchartrain is  $2.55 \times 10^8 \text{ m}^3$ , does not provide information on the procedures used to obtain this value. Of the other five estimates, one is based on the tidal range times surface area concept, one is based on the use of current velocity measurements made in the 1963 hydraulic model, and three are based on current velocity measurements in the prototype. The value based on the tide range times the surface area concept,  $1.78 \times 10^8 \text{ m}^3$ , is considered by the Committee to be the most probable correct estimate. A common feature of the four estimates based on the measurements of tidal volume flux through the three passes,  $1.44 \times 10^8 \text{ m}^3$ ,  $1.56 \times 10^8 \text{ m}^3$ ,  $1.54 \times 10^8 \text{ m}^3$ , and  $1.72 \times 10^8 \text{ m}^3$ , is that all are less than the estimate based on the tide range times the surface area procedure. Possible reasons for what would appear to be a common error for this type of measurement include the neglect of Stokes transport, and the fact that current meters using rotor or propeller based speed sensors are subject to decay in response due to biological fouling. Also, in most cases, navigation requirements precluded the deployment of long term moorings in main shipping channels, where maximum tidal currents are usually located. Unfortunately, no single major cause of this apparent underestimation of the flux through the passes has been identified, and no firm basis for applying a correction term to these estimates has been put forward.

#### On the Relative Contributions Through the IHNC to the Tidal Prism of Lake Pontchartrain.

32. As noted earlier in this report, several of the documents made available to the Committee, or obtained from the published literature, state that about 60% of the tidal prism of Lake Pontchartrain passes into and out through the Rigolets, 30% through the Chef Menteur, and 10% through the IHNC at Seabrook. The origin of these figures appears to be the published paper by Swenson and Chuang (1983). The emphasis on the word about is the Committee's. Swenson and Chuang do use this caveat, but without emphasis, in the referenced statement. However, these authors give the actual numerical values of the tidal flux through each of the passes that they determined from their analysis of the current meter records. They state that "A calculation of the tidal prism volume for each pass yields values of  $9.7 \times 10^7$ ,  $5.2 \times 10^7$  and  $7.0 \times 10^6 \text{ m}^3$  for The Rigolets, Chef Menteur and the IHNC, respectively". Based on these values, the relative contributions of each pass to the total tidal prism of

the Lake is 62.2% for the Rigolets, 33.3% for Chef Menteur, and 4.5% for the IHNC. ~~The value of 10% given by these authors for the relative contribution of the IHNC appears to have been the result of a rather gross round off procedure. 62.2% rounds to about 60%, and 33.3% rounds to about 30%. The remaining 10% was then stated to apply to the contribution of the IHNC without actually using their data to obtain the correct percentage. As noted in paragraph B5, the total tidal volume flux of  $1.56 \times 10^8 \text{ m}^3$  is probably too small by about  $0.21 \times 10^8 \text{ m}^3$ . If all of this uncertainty is attributable to the measurements of the tidal volume flux through the IHNC, the percent relative contribution of this pass to the tidal prism of the Lake would increase to 7.9%. It does not seem likely that measurements of the tidal volume flux in the IHNC should be less accurate than such measurements in the two larger passes.~~

33. Paragraphs B11 and B12 of Appendix B give further details which support the contention that although the total tidal volume flux through the passes as estimated by Swenson and Chuang is probable too small, the values for the relative contributions of the various passes to the actual total tidal flux are not seriously in error. Also included in the Swenson and Chuang paper, and described in some detail in paragraph B13 of Appendix B, are estimates of the subtidal volume flux through the three passes. This analysis shows that the subtidal volume exchanges into and out of the passes are quite large, indicating the importance of coastal meteorologic forcing of variations in coastal sea level, which are in turn readily transmitted into the Lake through the passes. The net subtidal volume fluxes indicate that the Rigolets is flood dominated and both the Chef Menteur and the IHNC are ebb dominated, with the total net subtidal volume flux directed into the Lake. This is opposite to the direction required to discharge a volume of water through the passes equal to the inflow of fresh water to the Lake from the tributary rivers. Assuming that the fresh water inflow to the Lake during the period in which the current meters were deployed by Swenson and Chuang was the mean annual river discharge, then the deficit in ebb directed subtidal volume flux through the passes as determined by Swenson and Chuang would represent about 7.5% of the total ebb subtidal volume flux, a value perhaps indicative of the uncertainty in this type of measurement.

34. In view of questions raised by this analysis of the Swenson and Chuang paper, and because of the importance of the best estimates possible of the relative contribution of the IHNC to the tidal exchange of water and salt through the several passes to Lake Pontchartrain, the Committee concluded that a search should be conducted to find other data sets which could be used to obtain estimates of the relative contribution of each of the passes to the combined tidal volume flux through the three passes. One of the sources found was the WES Letter Report dated April 1976 referred to in paragraph 24 above, and described in detail in paragraphs B2 and B14 of Appendix B. This report included estimates of the tidal cycle average of the flood and ebb volume exchanges into and out of the Lake through each of the three passes. The tidal volume flux values obtained by taking the average of the absolute values of the flood and ebb volume exchanges were  $8.74 \times 10^7 \text{ m}^3$  for the Rigolets;  $4.45 \times 10^7 \text{ m}^3$  for the Chef Menteur; and  $1.24 \times 10^8 \text{ m}^3$  for the IHNC; for a total tidal volume flux through the three passes of  $1.44 \times 10^8 \text{ m}^3$ . The relative contribution of the IHNC to the total tidal volume flux through the three passes given by this analysis is 8.4%, a value nearly twice as large as that computed from the Swenson and Chuang results. Paragraph B14 of Appendix B presents detailed arguments as to why lower confidence should be placed on this estimate of the contribution of the IHNC to the total tidal volume flux through the passes. Included in these arguments is the fact that the estimates in this paragraph are based on data obtained from the 1963 hydraulic model, which was built and verified before the MRGO was completed.



35. The two other data sets used by the Committee to evaluate the probable relative contribution to the tidal volume flux through the three passes to the Lake are the two data sets from Outlaw (1982) already mentioned in paragraph 30 above and described in detail in paragraphs B6 through B8, and paragraphs B15 through B17, of Appendix B. The estimates of the relative contribution of the IHNC to the total tidal volume flux through the three passes obtained by the Committee in its analysis of these two important data sets were 3.5% and 4.8%. More reliance should be placed on the second of these estimates, since it is based on current meter measurements in the three passes which returned good records with record lengths varying from 27 days to 47 days. The value of 3.5% listed above was obtained by an analysis of a 25-hr long study using survey boat based measurements at two stations in transects in each pass. This data set is valuable in that the measurements were made at three depths at two stations in each transect, but its length of just one tidal cycle places a higher uncertainty on the tidal flux calculations.

36. There were thus four estimates of the relative contribution of the IHNC to the total tidal volume flux through the three passes, and hence of the relative contribution of the IHNC to the tidal prism of Lake Pontchartrain, obtained in the Committee's analysis of the several data sets described in previous paragraphs. These estimates are: 4.5% from the analysis by Swenson and Chuang (1983); 8.4% from the analysis contained in the WES 1976 Letter Report, in which data from the 1963 hydraulic model study were utilized; 3.5% from the 25-hr data set tabulated in Outlaw (1982); 4.8% from the intensive 50 day survey data set given in Outlaw (1982). See Table B1 in Appendix B for a listing of the six estimates of the tidal prism of Lake Pontchartrain and of the four estimates of the tidal volume flux values through each of the passes. It appears unlikely that the relative contribution of the IHNC to the tidal prism of Lake Pontchartrain exceeds 5%.

On the Relative Contributions Through the IHNC to the Total Tidal Salt Flux into Lake Pontchartrain.

37. The proper procedure for the determination of the flux of salt through the passes connecting Lake Pontchartrain to the adjacent coastal waters involves the simultaneous measurements of current velocity and salinity at a number of points in a cross section in each of the three passes. These ranges should contain at least three stations distributed across each of the passes, and measurements should be made at up to five positions in the vertical. Current velocity and salinity measurements should be made at time intervals of between 30 minutes and one hour over a period of about 35 days, in order to obtain measurements at all epochs of the diurnal tidal cycle, at each measurement position in the vertical at each station in the range. The number of positions in the vertical at which measurements should be made depends on the vertical variation of the current velocity and salinity, while the number of stations in each range depends upon the lateral variation in current velocity and salinity, and also upon the width of the pass at the range selected for measurement.

38. One procedure for obtaining such a data set is to deploy vertical taut wire moorings at each station, on which are mounted *in situ* recording current meters and salinometers. The salinometers may be part of the current meter package or contained in a separate package which can be mounted close to each current meter. No such ideal data set has been obtained for the three passes of concern here. An alternate procedure for obtaining the desired data set is to use a survey vessel equipped with a current meter and a salinometer, the sensor packages of each having the capability of being lowered and raised rapidly through the water column and of transmitting data via cable or acoustically to deck mounted readout or recording units on the survey vessel.

ADCP equipment can replace the velocity part of these sensor packages, but not the salinity part. This survey vessel would move rapidly from station to station back and forth across the range. There would have to be at least one such survey vessel for each pass. The cost together with the logistic complexity of this approach has, however, generally limited such undertakings to durations of about 25 hours, or over a single diurnal tidal cycle. The Committee has located one such 25-hr data set, and made use of this data set to determine the salt flux through each of the three passes for that single diurnal tidal cycle. The procedure used in determining the tidal and subtidal salt flux over this 25-hr period is described in detail in paragraphs B21 and B22.

39. As a consequence of the lack of simultaneous measurements of current velocity and salinity at a number of positions in ranges in each of the three passes, over a number of diurnal tidal cycles, a less accurate procedure is employed that makes use of independent data sets of current velocity and salinity. The two sets of current velocity measurements which were utilized to obtain estimates of the tidal prism of Lake Pontchartrain, and of the volume flux in the three passes, as described in paragraphs 30, 32, and 32 above, and in more detail in Appendix B, were used again here. The available salinity observations for each of the three passes were used to obtain estimates to the mean salinity over the period of flood directed flow and over periods of ebb directed flow characteristic of the location and the season during which the current velocity measurements were made. The details of the procedure used to obtain estimates of the tidal and subtidal flux of salt from these data sets is described in paragraphs B20, and B24 through B27. The pertinent parameters of concern in comparing the contribution of each of the passes to the total flux of salt to Lake Pontchartrain is the net tidal and subtidal salt flux.

40. The results of use of these procedures on the 25-hr data set given in Outlaw (1982) follow: (a) For the Rigolets, the computed flood tidal salt flux was  $7.04 \times 10^8$  kg and the computed ebb directed tidal salt flux was  $-6.35 \times 10^8$  kg. (b) For the Chef Menteur, the computed flood directed salt flux was  $4.84 \times 10^8$  kg and the computed ebb directed tidal salt flux was  $-4.53 \times 10^8$  kg. (c) For the IHNC, computed flood directed tidal salt flux was  $5.23 \times 10^7$  kg and the computed ebb directed tidal salt flux was  $-4.23 \times 10^7$  kg. (d) The total computed tidal salt flux through all three passes was, for flood,  $1.24 \times 10^9$  kg, and for ebb,  $-1.13 \times 10^9$  kg. Note that by definition, the tidal volume flux is zero centered, so that there is the same absolute value of flood volume flux and the ebb volume flux. The tidal salt flux is not necessarily zero centered, since the time variations in salinity is a determining factor whether the flood directed or the ebb directed tidal salt flux will be the larger. For the case of an estuary, in which higher salinity water occurs toward the sea, the flood tidal salt flux will usually be larger than the ebb tidal salt flux, since the salinity during flood will usually be larger than the salinity during ebb. The net tidal salt flux, which is the difference between the flood tidal salt flux and the ebb tidal salt flux is the required quantity to consider here. (e) The computed net salt flux through the Rigolets for this data set was  $6.89 \times 10^7$  kg; through the Chef Menteur,  $3.12 \times 10^7$  kg; and through the IHNC,  $9.96 \times 10^6$  kg; the total net tidal salt flux was then  $1.10 \times 10^8$  kg. (f) The computed percentage contribution of each pass to the total net salt flux to Lake Pontchartrain was then 62.8% for the Rigolets, 28.4% for the Chef Menteur, and 9.0% for the IHNC.

41. Based on the data set from Swenson and Chuang (1983), the Committee made estimates of the tidal salt flux through each of the passes, as described in detail in paragraphs B22 and B26 through B28, which gave the following results:

(a) For the Rigolets, the computed value of the flood tidal salt flux is  $4.80 \times 10^8$  kg, and the ebb tidal salt flux is  $-4.51 \times 10^8$  kg. For the Chef Menteur, the computed value of the flood tidal salt flux is  $2.29 \times 10^8$  kg, and the ebb tidal salt flux is  $-2.13 \times 10^8$  kg. For the IHNC, the computed value of the flood tidal salt flux is  $5.25 \times 10^7$  kg, and the ebb tidal salt flux is  $-4.76 \times 10^7$  kg. Values of the net tidal salt flux, which is the parameter of concern for this analysis, are then  $2.91 \times 10^7$  kg for the Rigolets,  $1.56 \times 10^7$  kg for the Chef Menteur, and  $4.90 \times 10^6$  kg for the IHNC, for a total net tidal salt flux through the three passes of  $4.96 \times 10^7$  kg. The relative contributions of each of the passes to the total net tidal salt flux are then, for the Rigolets, 58.7%, for the Chef Menteur, 31.5%, and for the IHNC, 9.9%. Note that all of these net tidal salt flux values are positive, or into Lake Pontchartrain.

(b) The net subtidal salt flux values computed using the procedures described earlier together with the data from Swenson and Chuang are: for the Rigolets,  $-3.04 \times 10^7$  kg; for the Chef Menteur,  $-1.73 \times 10^7$  kg; and for the IHNC,  $-5.67 \times 10^6$  kg, for a total net subtidal salt flux of  $-5.33 \times 10^7$  kg. Note that this total is negative, as are the values for each pass, indicating a net discharge of salt from the Lake due to the subtidal processes. A discharge of salt from the lake by the subtidal processes is expected, in order to balance the net tidal flux of salt into the Lake. The computed discharge of salt from the Lake by the subtidal salt flux process is greater than the computed input of salt by the net tidal salt flux process. The computed value of this net tidal plus subtidal salt flux is  $-3.69 \times 10^6$  kg.

(c) As pointed out in paragraph B23, the characteristic seasonal pattern of salinity in Lake Pontchartrain requires that during roughly half of the year there must be a net flux of salt through the passes into the Lake and for the other half of the year there must be a net flux of salt through the passes out of the Lake. The 35 day long survey period in which Swenson and Chuang deployed their current meters extended from February 23 through March 29, 1980. This is during the spring period of decreasing average salinity of the Lake. From the salinity data described in Appendix A, the salinity of Lake Pontchartrain decreased during the spring of 1980 at a rate of  $1.81 \times 10^{-3}$  kg/m<sup>3</sup>/day. Such a decrease in average salinity requires a net tidal plus subtidal salt flux through the three passes of  $-1.08 \times 10^7$  kg per tidal cycle. Although of the correct sign, this value is much larger than that of the net tidal plus subtidal salt flux given in paragraph (b) above. Note that this discrepancy has no bearing on the computed values of the relative contributions of each of the three passes to the total tidal flux of salt through the passes.

42. Based on data from the 50 day intensive survey given in Outlaw (1982), the Committee made estimates of the tidal salt flux through each of the passes as described in detail in paragraph B27, which gave the following results:

(a) For the Rigolets, the computed value of the flood tidal salt flux is  $9.06 \times 10^8$  kg, and the ebb tidal salt flux is  $-8.00 \times 10^8$  kg. For the Chef Menteur, the computed value of the flood tidal salt flux is  $4.60 \times 10^8$  kg, and the ebb tidal salt flux is  $-4.03 \times 10^8$  kg. For the IHNC, the computed value of the flood tidal salt flux is  $8.94 \times 10^7$  kg, and the ebb tidal salt flux is  $-7.29 \times 10^7$  kg. Values of the net tidal salt flux, which is the parameter of concern for this analysis, are then  $1.07 \times 10^8$  kg for the Rigolets;  $5.68 \times 10^7$  kg for the Chef Menteur; and  $1.66 \times 10^7$  kg for the IHNC; for a total net tidal salt flux through the three passes of  $1.80 \times 10^8$  kg. The relative contributions of each of the passes to the total net tidal salt flux are then, for the Rigolets, 59.3%; for the Chef Menteur, 31.5%; and for the

IHNC, 9.2%. Note that all of these net tidal salt flux values are positive, of into Lake Pontchartrain.

(b) The net subtidal salt flux values computed using the procedures described earlier together with the data from Outlaw are: for the Rigolets,  $-7.55 \times 10^7$  kg; for the Chef Menteur,  $5.74 \times 10^7$  kg; and for the IHNC,  $-2.86 \times 10^6$  kg; for a total net subtidal salt flux of  $-2.10 \times 10^7$  kg. The net subtidal salt flux values for the Rigolets and the IHNC are ebb dominated while the value for the Chef Menteur is flood dominated. However, the total flux through all three passes is negative, indicating a net discharge of salt from the Lake due to the subtidal processes. A discharge of salt from the lake by the subtidal processes is expected, in order to balance the net tidal flux of salt into the Lake. The computed discharge of salt from the Lake by the subtidal salt flux process is, however, less than the computed input of salt by the net tidal salt flux process. The computed value of this net tidal plus subtidal salt flux is  $1.59 \times 10^8$  kg, indicating that there is a net tidal plus subtidal flux of salt into Lake Pontchartrain.

(c) The months of September and October of 1978 and of August and September of 1979, when the data processed by Outlaw were obtained, are at the end of the period of the year during which the salinity of Lake Pontchartrain is increasing. There is insufficient salinity data available for these specific months to determine an applicable rate of increase of salinity. The average spring to fall salinity increase for the Lake as described in Appendix A would require a combined net tidal plus subtidal flux of salt through the three passes into the Lake of  $1.26 \times 10^8$  kg. This is only slightly less than the value of  $1.59 \times 10^8$  kg given in the just previous paragraph.

43. The Committee has thus made three estimates of the tidal and subtidal flux of salt through the three passes into Lake Pontchartrain, using three different data sets. The three estimates of the relative contribution of the IHNC at Seabrook to the combined net tidal salt flux through the three passes are 9.0%, 9.9%, and 9.2%. See Table B2 in Appendix B for a listing of the three estimates of the total net tidal salt flux into Lake Pontchartrain, and of the three estimates of the net tidal salt flux values through each of the passes.

#### On the Salt Flux to Lake Borgne from the MRGO via Three Bayou Inlets and the GIWW

44. As described in detail in Appendix C, paragraphs C3 through C9, the Committee undertook to obtain estimates of the salt flux from the MRGO into Lake Borgne via three bayou inlets. The WES report by Outlaw (1982) provides one of the data sets used for the analyses described in Appendix C. The other source of data used by the Committee in its appraisal of this route for salt flux from the MRGO is a WES report authored by Fagerburg (1990). Insight into the processes operating in the exchange of water and salt between the MRGO and Lake Borgne was provided by the WES report authored by Donnell and Letter (1991).

45. During the 50 day intensive survey period described by Outlaw (1982), current meters were deployed in three inlets at the mouths of bayous which cross the MRGO. The three bayous involved were Bayou Yscloskey which enters Lake Borgne near Mile Marker 41, Bayou Dupre which enters Lake Borgne near Mile Marker 51 at a landmark in the Lake called Martello Castle, and Bayou Bienvenue which enters Lake Borgne about 3.5 mile NNE from the Martello Castle. The current meters deployed in these three inlets returned good records for periods ranging from 27 to 32 days. Outlaw computed the significant tidal constituents for the tidal currents from these records. He also computed the record length residual mean current velocities and the root

mean square (rms) of the variations in the currents left unaccounted for by the tidal constituents. Using these tidal constituents, the Committee determined a mean diurnal tidal current amplitude for each of three inlet stations. The residual mean current plus the absolute value of the rms amplitude gives the flood directed subtidal current, while the residual mean current minus the absolute value of the rms amplitude gives the ebb directed subtidal current.

46. Fagerburg (1990) describes data collected by survey vessels in Bayou Yscloskey inlet, in Dupre Bayou inlet, and at three locations in the MRGO. These data provided estimates of the mean salinities in each of the inlets during periods of flood flow and during periods of ebb flow. Information on the depths of the inlets just lakeward from the MRGO is also given by Fagerburg. Paragraph C6 of Appendix C describes the additional sources of information used to obtain the cross-sectional areas of the inlets. This paragraph also gives the mean salinities for the flood and ebb periods as determined from the Fagerburg salinity data.

47. Using the above described data sets, the net tidal plus subtidal salt flux from the MRGO to Lake Borgne was computed to be  $4.09 \times 10^7$  kg. Since there are no continuity based constraints on the net subtidal salt flux values for these inlets as were described for the passes to Lake Pontchartrain, it is the net tidal plus subtidal salt flux values for these inlets which are the appropriate parameters to consider in comparing the input of salt to Lake Borgne from these inlets on the one hand to the input of salt to Lake Pontchartrain from the IHNC at Seabrook on the other. Of the three estimates made in Appendix B for the net tidal salt flux through the IHNC, the one most appropriate to use for this comparison is the one determined using the data set from the intensive 50 day survey given in Outlaw (1982), since this is the same source of the data used in obtaining the estimates of the salt flux through the three inlets to Lake Borgne from the MRGO. This estimate of the net tidal salt flux through the IHNC is also the largest of the three estimates made by the Committee. As given in subparagraph (a), paragraph B27, of Appendix B, the computed value of the net tidal salt flux through the IHNC, using the 50 day survey data set from Outlaw, is  $1.66 \times 10^7$  kg, a value smaller than the estimated net salt flux from the MRGO to Lake Borgne through the subject three inlets of  $4.09 \times 10^7$  kg. by a factor of about 2.5.

48. Outlaw (1982) also gives the results of computations of the significant tidal constituents for the tidal currents, as well as the record length residual mean current and the rms current amplitude, from a 32 day long record from an *in situ* recording current meter deployed in the GIWW. The current meter was moored about one km ENE from the intersection of the MRGO with the GIWW. The net subtidal volume flux at this location is directed ENE toward the intersection of the GIWW with the Chef Menteur and the Rigolets. The diurnal tidal current amplitude in the GIWW is relatively small, but the residual mean current is relatively large, and this station showed a relatively large rms amplitude.

49. Extrapolation of the salinity measurements at the three ranges in the MRGO provided an estimate of the mean salinities during the flood and ebb flow periods. Using these data with the flood and ebb volume flux values computed from the current meter data, the net tidal salt flux in the GIWW was estimated to be about  $1.44 \times 10^6$  kg, which is only 7.5% of the net tidal salt flux to Lake Borne from the MRGO through the three Bayou inlets for which current meter data is available. However, the net tidal plus subtidal salt flux through the GIWW and directed ENE is considerably larger than the net tidal salt flux alone. The calculated value is  $6.09 \times 10^7$  kg, which is larger than the either the net tidal plus subtidal salt flux through the three bayou

inlets or the net tidal salt flux to Lake Pontchartrain through the IHNC. The reason that the net subtidal salt flux is so high is that both the residual mean velocity and the rms amplitude at the current meter station in the GIWW are high compared to the value of these parameters in the IHNC and in the three bayou passes. Also, the subtidal volume flux is directed toward the Chef Menteur, while in the IHNC the subtidal volume flux, and hence the subtidal salt flux, must be directed out of Lake Pontchartrain in order to discharge a part of the fresh water which enters the Lake from tributary rivers, and in order to provide for the return out of the Lake a portion of the salt which has entered the Lake by the net tidal salt flux. Also note that even though the volume flux in the bayou passes is much smaller than the volume flux through the IHNC, the difference between the mean salinity during flood flow and the mean salinity during ebb flow is much larger in the bayou passes than in the IHNC.

50. The sum of the net tidal plus subtidal salt flux to Lake Borgne from the three bayou inlets and the GIWW is computed to be  $1.02 \times 10^8$  kg, which is about 6 times the maximum value salt flux through the IHNC to Lake Pontchartrain computed by the Committee. The intersection of the GIWW and the Chef Menteur is close to the Lake Borgne end of the Chef, and hence most of the salt flux from the GIWW will enter Lake Borgne at a location just across the Lake from the Biloxi Marshes. The following table is a summary of the averages of the various values of the tidal prism of Lake Pontchartrain and of the volume and salt fluxes computed by the Committee.

ITEM	LAKE PONTCHARTRAIN	RIGOLETS	CHEF MENTEUR	IHNC AT SEABROOK	MRGO INTO LAKE BORGNE
TIDAL PRISM	$1.77 \times 10^8$	N/A	N/A	N/A	N/A
VOLUME FLUX	N/A	$9.51 \times 10^7$ 60.7%	$5.33 \times 10^7$ 34.0%	$8.27 \times 10^6$ 5.3%	N/A
SALT FLUX	N/A	$6.82 \times 10^7$ 60.3%	$3.45 \times 10^7$ 30.5%	$1.05 \times 10^7$ 9.3%	$1.02 \times 10^8$

Total =  $1.13 \times 10^8$

51. The above observations suggest that overall salinity change questions should focus primarily on the MRGO-Lake Borgne connections. It is further noted that any future natural enlargement of those openings could increase Lake Borgne salinities further.

#### 4 ANSWERS TO THE QUESTIONS POSED BY THE DISTRICT

52. The questions as given in Section 1 under the heading Purpose have been divided into sub-questions in order to facilitate the presentation of the answers and of the supporting statements and comments. The thus modified questions and the Committee's response are given below.

Question: Can the contribution of the MRGO-IHNC to the increase in salinity in Lake Pontchartrain and adjacent waterways be economically controlled by reducing the volume of MRGO flow into the Lake?

Answer:

53. The answer to the above question will be subdivided in terms of the mechanisms which might be used to attain the reduction in volume of the MRGO flow into the Lake.

For the Case of Control of the Volume of MRGO Derived Salt Water by Construction of a Structure in the IHNC at Seabrook

54. For the case of control of the volume of MRGO flow into Lake Pontchartrain by construction of a solid barrier structure, such as a lock at Seabrook similar to the existing preliminary design, the answer to this question is no. The problem is not the physical ability to build such a structure and have it function to effectively stop the flux of MRGO derived salt water from passing through the IHNC into the Lake. The problem is, in part, that there is evidence that such a structure could not be economically justified in terms of the reduction in the mean salinity of Lake Pontchartrain and, in particular the salinities in Lake Borgne and over the Biloxi Marshes. Using five different data sets, the Committee concluded that the relative contribution of the tidal volume flux from the IHNC to the Lake is most probably less than 5% of the total tidal volume flux through all three passes, and that the relative contribution of the net tidal flux of salt from the IHNC into the Lake is most probably less than 10% of the total net tidal salt flux through all three passes. At the very most, the complete closure of the IHNC at Seabrook would reduce the salinity increase that has occurred in eastern Lake Pontchartrain since the completion of the MRGO from an average value, based on pre-MRGO to post MRGO salinities as measured at Little Woods and North Shore, of about 1.5 kg/m<sup>3</sup> (ppt), to a value of between 1.3 and 1.4 kg/m<sup>3</sup>. The District has a regression model which can be used to estimate the volume rate of fresh water input to the Lake via the proposed diversion at Bonnet Carré to provide the same decrease in the salinity of the Lake that complete closure of the IHNC at Seabrook would accomplish. The Committee has not made this detailed calculation, but a rough estimate indicates that a diversion of less than 1000 cfs ( $\approx 28 \text{ m}^3/\text{s}$ ) would be adequate.

55. In addition, the Committee concludes that the IHNC is not the only route by which MRGO derived salt can enter Lake Pontchartrain. Based on the analysis of data obtained from several sources, it appears likely that there is a net flux of salt from the MRGO directly into Lake Borgne via bayous which intercept and cross the MRGO along the reach of this waterway where it passes within a few hundred feet of the shore line of Lake Borgne. A net flux of salt directed towards the Chef Menteur and the Rigolets also occurs via the GIWW, and thus adds salt to the Chef Menteur near to its entrance into Lake Borgne. These higher salinity waters would then enter Lake Borgne, and possibly also Lake Pontchartrain, from the Chef Menteur. The Committee's calculations of the net tidal plus subtidal salt flux from the MRGO to Lake Borgne via the bayou inlets and the GIWW is considerably larger than the flux of salt into Lake Pontchartrain via the IHNC. Pre-MRGO and post-MRGO salinity