Chapter 10

SEDIMENTATION AT THE MOUTH OF THE MISSISSIPPI RIVER

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Sedimentation at the mouth of the Mississippi River is a phenomenon that has been under study by the Corps of Engineers, Department of the Army, during the past 120 years. The primary objective in these investigations has been the determination of the most economical method of maintaining required navigation depths through the Mississippi River Passes for ocean-going vessels that serve the Ports of New Orleans, Baton Rouge, and indirectly the vast Mississippi Valley river traffic.

The objective of this paper is to summarize pertinent sediment investigations of the Mississippi River and Outlets below the latitude of Old River, Louisiana, and to discuss the complex nature of the sedimentation problem in the Mississippi River delta area. Topographic features of the region are shown on Figure 1.

INTRODUCTION

GENERAL

The Mississippi River rises in Lake Itasca, Minnesota, and flows in a general southerly direction to the Gulf of Mexico, a distance of approximately 2,434 miles. The river, with its tributaries, drains about 41 percent of the area of the United States proper. This drainage basin of 1,245,000 square miles, including all, or parts of 31 states and two Canadian provinces is shown on Figure 1. The Mississippi is navigable to ocean-going commerce as far upstream as Baton Rouge, Louisiana, 247 miles from the Gulf of Mexico via Southwest Pass.

New Orleans, one of the major ports of the country, with a population of about 600,000, is located on the river about 114 miles from the Gulf via Southwest Pass and 107 miles by South Pass. The principal industries of New Orleans are closely allied with river traffic. Manufacturing plants covering a wide range of products are located at that site in order to utilize the raw and semifinished products which are handled through the port or produced in the adjacent territory. This city is also an important terminal and point of origin for barge shipments to the east and west via the Intracoastal Waterway and north or south on the Mississippi-Ohio River system.

DESCRIPTION OF THE LOWER MISSISSIPPI RIVER

The levees of the Mississippi River below the latitude of Old River, Louisiana, are built relatively close to the banks of the river and extend downstream on the west bank to Venice, La., 10 miles above the Head of Passes, and on the east bank to Pointe-a-la-Hache, 44 miles above the Head of Passes, and thence from Mile 33 to Mile 11.5 above Head of Passes. No important tributaries enter the Mississippi River between Old River and the Head of Passes, all the drainage being carried to the Gulf by adjacent

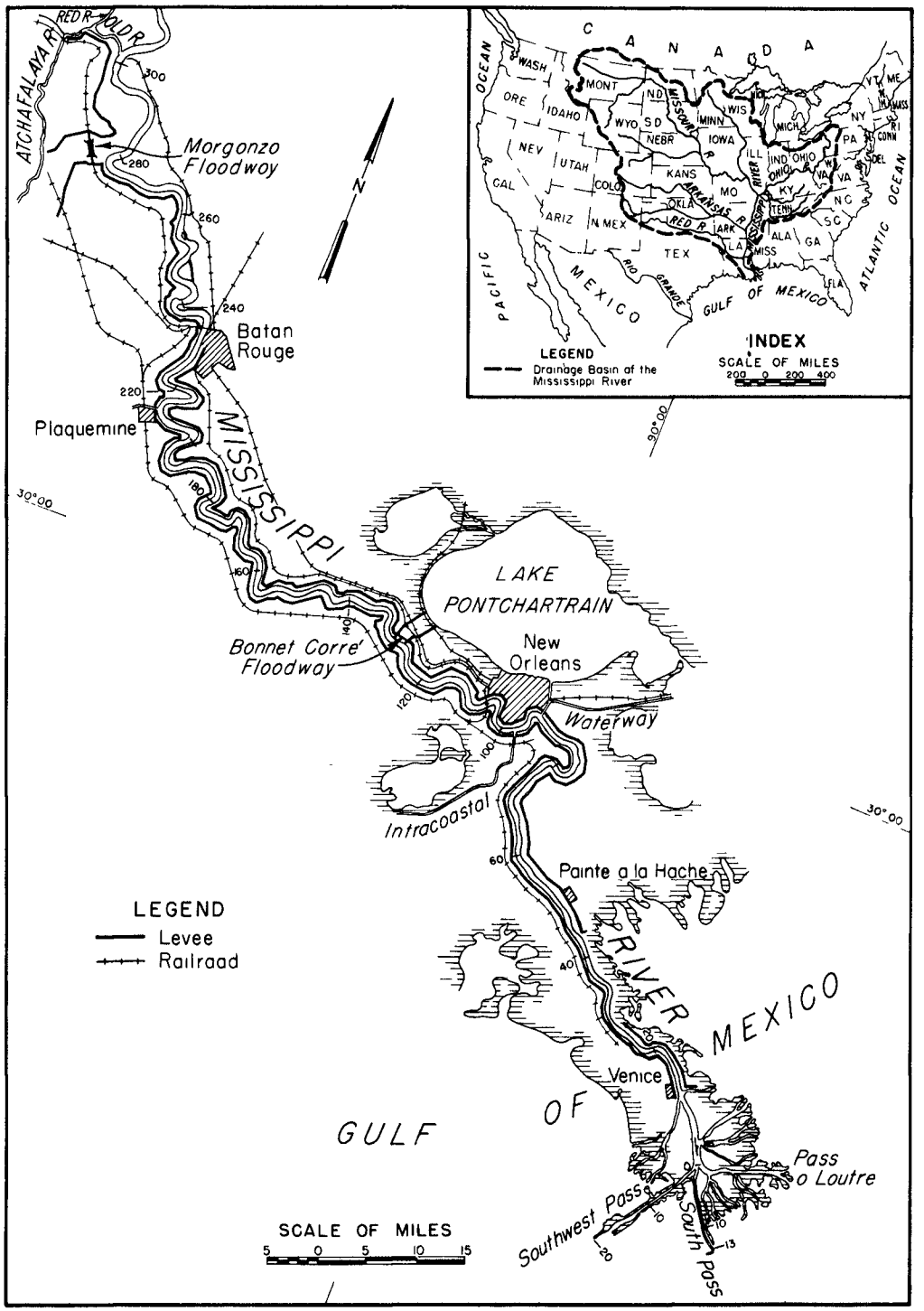

Fig. 1
General map, Mississippi River from Old River, La. to the Gulf of Mexico; and, drainage basin of the Mississippi River.

streams or lakes.

Approximately 322 miles from the Gulf of Mexico, the Mississippi River is connected on its west bank through Old River to Red River, a tributary, and to the Atchafalaya River, a distributary, connecting with the Gulf approximately 135 miles west of the Mississippi River Passes. The direction of flow in Old River may be in either direction, depending on stage differential between the Red and Mississippi Rivers, however, its flow at the present time is generally westward from the Mississippi to the Atchafalaya practically all of the time.

Above Baton Rouge a 9-foot channel is maintained. In this reach is located the Morganza Floodway, a part of the Mississippi River Flood Control Project. This floodway, having a design capacity of 600,000 c.f.s., is located on the west bank of the Mississippi River, approximately 25 miles northwest of Baton Rouge, Louisiana. It is an overbank floodway confined by guide levees with a control structure at the upper end along the Mississippi. The floodway is designed to pass flood waters from the river into the Atchafalaya Basin in order to limit flow in the Mississippi River below Morganza, La., to the safe capacity of the leveed river channel, 1,500,000 c.f.s. This floodway, now under construction, has never been operated.

Between Baton Rouge and the Port of New Orleans, a distance of approximately 132 miles, except for two or three local areas where shoaling occasionally occurs during times of flood, the channel is never less than 40 feet in depth; the minimum channel width normally is about 500 feet, while the average width exceeds 1,000 feet. The second controllable floodway, the Bonnet Carre Spillway, is situated on the east bank of the Mississippi, about 30 river miles above the City of New Orleans. It consists of guide levees with a control structure at the upper end along the Mississippi. This floodway is designed to divert 250,000 c.f.s. of river water to the Gulf of Mexico via Lake Pontchartrain in order to limit flow in the Mississippi past New Orleans to about 1,250,000 c.f.s. and was operated for that purpose in 1937, 1945 and 1950.

Below New Orleans, the river flows in a generally southeasterly direction a distance of approximately 95 miles to the Head of Passes. The gap in the east bank levee system between miles 44 and 33 above the Head of Passes is known as the Pointe-a-la-Hache Relief Outlet or the Bohemia Spillway. This uncontrolled State of Louisiana project is rapidly deteriorating as a highwater relief outlet as a result of sedimentation and lack of required maintenance. The purpose of this project was to lower Mississippi River flood stages at and below New Orleans. At low water, the river cross section varies between one-half a mile and a mile in surface width and between 50 and 200 feet in depth.

For approximately eight months of the year the lower Mississippi River is influenced to a greater or lesser extent by flood waters. Under average conditions, the river starts to rise in December, reaches a crest in April and recedes to low water stages by the end of August.

The delta at the mouth of the Mississippi River is typical of all alluvial silt-bearing streams. At the present time, the three principal

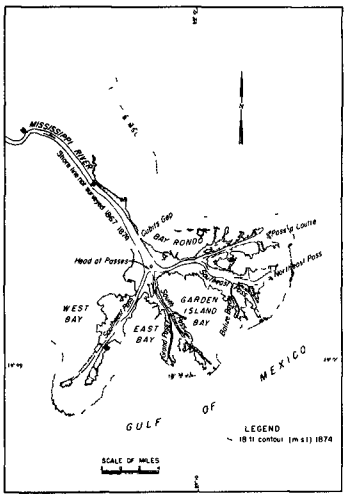

Fig. 2. Mississippi River Passes, 1874 conditions as developed by the U.S. Coast and Geodetic Survey.

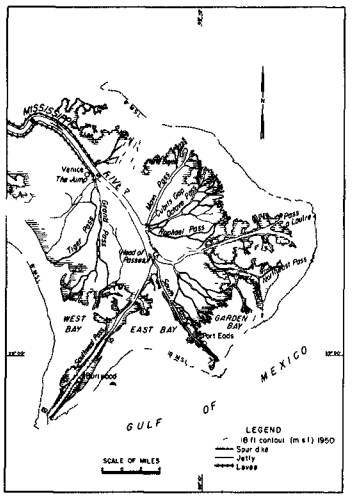

Fig. 3. Mississippi River Passes, 1950 conditions as developed by the U.S. Coast and Geodetic Survey, and as revised by the Corps of Engineers.

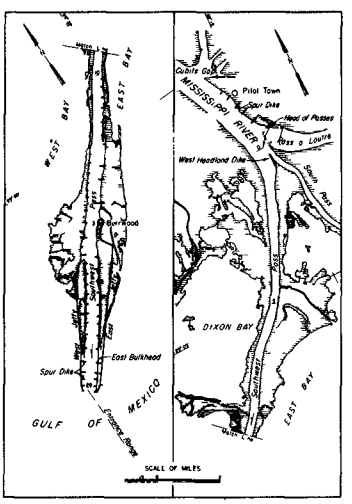

Fig. 4. Improvements of the Southwest Pass, Mississippi River.

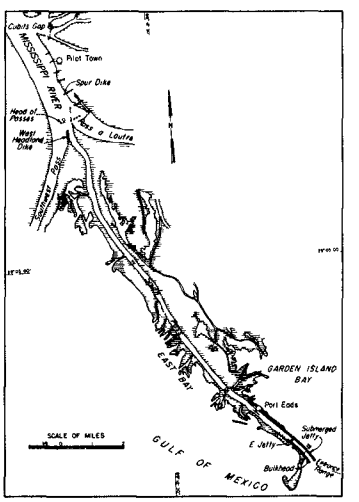

Fig. 5. Improvements of the South Pass, Mississippi River.

outlets of the river below New Orleans and in the order of their discharge capacity are Pass a Loutre, Southwest Pass and South Pass, which are joined at the Head of Passes. All of these passes have been used for commerce at various times, but only South and Southwest Passes have been artificially improved to permit their use by ocean-going ships. The remainder of the flow is discharged from the river upstream from the Head of Passes through Baptiste Collette Bayou, The Jump and Cubits Gap.

Pass a Loutre, the largest of the principal passes has a length of about 15 miles, flows slightly north of east, and discharges through several outlets to the Gulf. Southwest Pass, the most westerly of the three main outlets, has a length of 31.2 miles and flows southwesterly to the Gulf. South Pass, the smallest of these passes, has a length of 14.2 miles and flows in a southeasterly direction to the Gulf. The maximum discharges in c.f.s. recorded for these passes during the 1950 flood cycle were 410,000, 354,000, and 166,000, respectively.

Other outlets of lesser importance include Baptiste Collette Bayou, a small opening in the east bank about 83 miles below New Orleans; The Jump, an outlet through the west bank about 84 miles below New Orleans; and Cubits Gap, in the east bank of the Mississippi about 91 miles below New Orleans. During the 1950 high water the maximum discharges in c.f.s. through these openings were 28,700, 35,100, and 151,800, respectively.

GEOGRAPHY OF THE PASSES.

The land adjacent to the Mississippi River in the vicinity of the passes has undergone extensive changes during its period of record. The natural tendency of the Mississippi as a silt-bearing and delta-forming stream is to throw off branches from the main stem, which, in turn, subdivide into smaller branches. The process of subdivision continues until the Gulf is reached, with the individual outlets of small capacity when compared to the main river.

The banks of these passes are subject to overflow from time to time during flood periods. Materials in suspension are deposited in quantities sufficient, generally, to maintain height of banks at a rate equal to the subsidence of the delta, a rate of about 0.1 foot per year. A comparison of Figures 2 and 3 shows that considerable new delta has been formed in the area of the passes during the period 1874 to 1950. Bay Ronde has completely disappeared and in its place are deltaic deposits traversed by numerous minor outlets. On the other hand, excessive subsidence and loss of land area have taken place in East Bay, as a result of closure of many outlets along Southwest and South Passes that formerly discharged into the bay. Small regulated outlets are provided at critical places to maintain the banklines by supplying the adjacent bay areas with silt-laden water during times of flood.

IMPROVEMENTS OF THE PASSES

In view of the importance of a deep entrance channel to the development of the City of New Orleans, early efforts were made to deepen the natural 9-foot depth over the bars at the mouths of the Mississippi River, commencing as early as 1726 by the French government, and continuing

intermittently for over 100 years. None of these efforts met with much success.

After considerable controversy as to the best method to be followed in securing a satisfactory entrance channel from the Gulf to the Mississippi River, Congress, in 1875, accepted the "no cure, no pay" proposition of Captain James B. Eads wherein he was to secure, by construction of jetties at the mouth of South Pass, a 30-foot channel through the pass and maintain it for a period of 20 years. The results obtained far exceeded expectations. The jetties were completed in 1879 and a 30-foot channel was secured and maintained by dredging with brief interruptions during seasons of high floods, until 1901, when the work of maintenance was taken over by the Corps of Engineers.

As a result of the successful improvement of South Pass, the commerce of the Port of New Orleans rapidly increased and another deeper channel was required to meet the growing demands of navigation. Jetty construction in Southwest Pass was started in 1904 and completed in 1908. The east and west jetties extended to 10 or 12 feet of water and were 21,000 and 15,000 feet in length. Depths were increased from 9 to 20 feet. Over the years since the initial construction, additional improvements of various types have been undertaken to maintain the required project depth. These works included jetty extensions of some 3,000 feet, deflection of the axis of the bar channel some 35 degrees east of the axis of the jetty channel; contraction works to narrow the channel and a considerable amount of dredging.

EXISTING NAVIGATION PROJECT ON THE LOWER MISSISSIPPI

The navigation project on the lower Mississippi, as authorized by the River and Harbor Act of 3 March 1945 and prior Acts, provides for channel dimensions below mean low Gulf level of: Baton Rouge to New Orleans, 35 feet deep by 500 feet wide, 128.6 miles long; within limits of the Port of New Orleans, 35 feet deep by 1500 feet wide, 17.2 miles long; lower limits of the Port of New Orleans to the Head of Passes, 40 feet deep by 1000 feet wide, 86.7 miles long; Southwest Pass, 40 feet deep by 800 feet wide, 21.2 miles long; Southwest Pass Bar Channel, 40 feet deep by 600 feet wide; South Pass, 30 feet deep by 450 feet wide, 14.2 miles long; and South Pass Bar Channel, 30 feet deep by 600 feet wide.

The project is complete except for construction of contracting dikes, screening of existing dikes, and deepening of the pass and bar channel from 35 to 40 feet in Southwest Pass. Figures 4 and 5 show relative locations of improvements.

HISTORY AND DESCRIPTION OF SEDIMENT INVESTIGATIONS

The history of sediment observations on the lower Mississippi River dates from 1838. These observations, the first of record in the United States, were made in connection with a survey of the mouths of the Mississippi under the direction of Captain A. Talcott. Results indicated 580 parts of sediment per million parts of water in South Pass. In Southwest Pass, 18 samples from the surface and 9 samples from below the surface gave a combined sediment concentration of 796 p.p.m.

During the period from 1843 to 1846, Professor J. L. Riddell obtained samples from the river at New Orleans. The average sediment concentration was found to vary from 804 p.p.m. to 864 p.p.m. Other measurements were made in 1851-1852 by Professor C. G. Forshey at New Orleans.

In connection with improvements to South Pass, the Corps of Engineers sampled in this location continuously from 1877 to 1898. At the middle of the pass, samples were taken at the surface, 8, 16 and 24 feet below the surface, and near the bottom. About 150 feet from each shore, samples were taken at the surface, mid-depth, and near the bottom. The results of sediment observations in South Pass for each of the years from 1879 to 1893 are published in the annual report of the Chief of Engineers for 1894. The maximum sediment concentration was 1,100 p.p.m. in 1888, the minimum was 456 p.p.m. in 1879, and the mean was 688 p.p.m. The maximum concentration of sand was 473 p.p.m. in 1880, the minimum was 115 p.p.m. in 1879, and the mean was 313 p.p.m.

During the period 1879 to 1880, extensive sediment investigations were conducted under the direction of the Mississippi River Commission. Sediment observations were conducted at the Carrollton range, New Orleans, Louisiana, for a period of 264 days from December 19, 1879 to October 8, 1880. The work comprised 696 specimens collected in 29 sets of observations. Samples were taken at the surface, at mid-depth, and near the bottom at each of eight points located at about equal intervals across the sediment gaging range. These samples were combined vertically and horizontally in separate bottles. The vertical combination for any station contained two ounces at each depth placed in one bottle, so that eight bottles, each containing six ounces were required for one day's samples. In the horizontal combinations, two ounces from each of the surface samples were placed in one bottle, two ounces from each of the mid-depth samples were placed in a second, so that three bottles each containing 16 ounces were required for the day's samples. The points at which samples were taken were fixed by intersecting range lines.

During the period January 8 to August 5, 1927, two surveys and sets of observations were made by direction of the Mississippi River Commission at the Pointe-a-la-Hache Relief Outlet to determine the effect of the operation of the spillway upon each element of the Mississippi River regimen; i.e., high water slope, scour and fill in the river bed, volume of water discharged, and quantity of sediment carried in suspension. During this period, a total of 1,584 samples were collected in 33 sets of observations spaced at intervals of about four to five days. In each set of observations, samples were taken at the surface, mid-depth and near the bottom at eight points located at about equal intervals across two sediment gaging sections, one of which was located about 4.1 miles above the upper end of the spillway and about 1.0 mile below the lower end.

In 1929, under the direction of the Mississippi River Commission, sediment observations were made throughout the year at specified locations that included the taking of sediment samples at Red River Landing, Louisiana, and at the Carrollton range, New Orleans, Louisiana, with a procedure similar to that employed in 1927.

The Corps of Engineers collected numerous samples from the lower Mississippi in 1930-1931. Samples were generally taken about three times each

week at the surface, mid-depth, and near the bottom in each of eight verticals. From the average of thousands of discharge measurements taken previously in the Mississippi River, it was found that the upper quarter, the middle half and the lower quarter of a given cross section carried 27.2, 51.2, and 21.5 percent, respectively, of the total water discharge. Hence, weights of 1, 2, and 1 were applied to values of suspended sediment concentration observed at the surface, mid-depth and bottom layers, respectively.

In 1938 the Corps of Engineers collected samples and obtained velocity measurements simultaneously in the passes near the mouth of the river with six to eight verticals of eight to twelve points each.

Currently, suspended sediment sampling is being conducted on the lower Mississippi River at the Baton Rouge, Louisiana, discharge range. Forty point samples are secured at each observation at about a rate of twice monthly during the low water season and twice weekly during the high water season. The sampling points are spaced transversely and vertically so as to represent sections of equal discharge. Eight verticals are spaced across the width of the stream with five points at depths along each vertical. The location of these points are made according to a relatively simple graphical method devised by E. W. Lane of the Bureau of Reclamation. Based on the water discharge distribution over the desired range in stage, this method can be applied to any gaging station where sediment and water discharge measurements are taken regularly. The results of the observations at Baton Rouge initiated in 1949, provide an excellent basis for determination of suspended sediments carried by the Mississippi.

FACTORS AFFECTING SEDIMENTARY ACTION IN THE PASSES

Factors affecting sedimentary action in the passes may be divided into two classes, natural and artificial. The natural class includes such factors as river discharge, littoral currents, salt water intrusion, tides and wind direction. Artificial factors include the man-made works of diversion structures, contraction structures and dredging. The interrelation of these factors is a complex process with one influence modifying the influence of others in varying degrees of intensity from time to time.

Sedimentary action that causes shoaling involves three basic processes: pickup of material in one area, its transportation to another area, and its deposit in that other area to form a shoal. Thus, all of the above-mentioned factors may at times contribute to the shoaling of an area and at other times serve to move it, either to another part of the area under consideration or entirely out of the area. At or near the mouths of the passes the tidal influences are very important considerations in studies of shoaling action with, of course, the fluvial characteristics of the river tending to predominate over the tidal characteristics upstream from the mouth.

NATURAL FACTORS

Mississippi River flow at New Orleans is the forecast point for hydraulic characteristics in the passes. General criteria concerning the

natural factors affecting sedimentary action in the passes are as follows:

River Discharge - At mean low water, about 3 feet above mean sea level on the Carrollton Avenue gage, the discharge at New Orleans, 103 miles above the Head of Passes, is about 300,000 c.f.s. At normal stages, about 9 feet above MSL on the Carrollton gage, the discharge is about 600,000 c.f.s. At flood stage, about 17 feet above MSL on the Carrollton gage, the discharge is about 1,000,000 c.f.s. The minimum recorded discharge at New Orleans is 79,000 c.f.s. and it is estimated that, with the Morganza and Bonnet Carre floodways above New Orleans in operation, the maximum discharge will be limited to 1,250,000 c.f.s. This total discharge is normally distributed through the passes in the percentages of: Southwest Pass, 30; South Pass, 15; Pass a Loutre, 40; and Cubits Gap and other outlets, 15. The normal range in stage at New Orleans is about 16 feet, from about 2 to 18 feet above MSL on the Carrollton gage. The maximum allowable stage is 20 feet.

Velocities through the three principal passes range up to about 6 feet per second. Mean velocities at the heads of these passes usually range from about 2 to 5 feet per second.

Littoral currents - Relatively strong littoral currents, about 1 foot per second, flow generally in an east to west direction just Gulfward of the passes.

Salt water intrusion - Observation and study of salinity conditions in the lower Mississippi reveal that below certain fresh water discharges from the upper river there is intrusion of dense salt water from the Gulf of Mexico through the deep passes, South and Southwest Passes. The intrusion is in the form of a wedge having a fairly well defined interface which moves upstream through the passes below the outward fresh water flow. At stages of 10 to 12 feet above MSL on the Carrollton gage, or about 800,000 c.f.s., the salt water wedge is held just outside of the outer end of the jetty channel by the strong river current. At mean low water, about 3 feet above MSL on the Carrollton gage, or 300,000 c.f.s., the salt water interface is normally located at the Head of Passes. At extremely low stages, below 3 feet, the salt water proceeds upstream, the extent depending on the amount of low water river discharge. In October 1936, the upper end of the salt water wedge was located about 22 miles above New Orleans or about 145 miles from the Gulf, at a depth of approximately 120 feet below the water surface of the river.

In locating the wedge, it is constantly observed that the salinity content changes from fairly fresh water, several hundred p.p.m. of chlorine, to dense Gulf water, 10,000 to 15,000 p.p.m. of chlorine, within a depth of a few feet. The line of demarcation between fresh and salt water, referred to as the "interface," is arbitrarily taken as the point at which a chlorine content of 5,000 p.p.m. is observed.

Observations taken during several periods of extreme low water show conclusively that the entrance of salt water into the river is confined to the deep man-made navigable passes, South and Southwest Passes, and that under normal wind and tide conditions no intrusion of dense salt water occurs through any of the other relatively shallow outlets or passes.

Tides - The average daily tidal range at the end of the passes or in the Gulf of Mexico is about 14 to 16 inches, and is about 12 inches at the Head of Passes. During low water a slight tidal effect can be observed in the Mississippi River 35 miles above Baton Rouge.

Wind - Prevailing winds are from the southeast.

ARTIFICIAL FACTORS

Artificial factors affecting sedimentary action in the passes are those improvements or training works which have been performed or constructed in South and Southwest Passes. Regardless of the primary purpose of a project any work which affects the complex regimen of the passes definitely affects the sedimentary action in the delta area.

Jetties have been constructed for the purpose of increasing velocities and inducing greater depths in the bar channel by scour. Spur dikes were installed in the passes and jetty channels to secure lesser channel widths and thereby obtain a more efficient channel hydraulically. Submerged sills were placed across the head of Pass a Loutre and other openings to divert greater river flow through the navigable passes. Outlets in the banks of South and Southwest Passes were opened as required to maintain the integrity of the banks or closed for the purpose of increasing velocities in the jetty channels.

Maintenance dredging is performed annually to provide project depths through the navigable outlets, South and Southwest Passes. Critical areas requiring this corrective action are: Bars which form at and in the vicinity of the Head of Passes and bars which lie just Gulfward of the mouths of the passes that are commonly called "outer bars." As a result of improvement works accomplished to date, South Pass is practically self-maintained, whereas, Southwest Pass requires some dredging in order to maintain navigation depths.

MATERIALS IN TRANSPORT

Investigation of materials-in-transport in the Mississippi River, until recent years, were inadequate in scope to develop reliable scientific procedures. Consequently, the study of the laws governing the transport of sediment by flowing water has been intensified because of the increased rate of construction of river-control works. Transport of bed and soil materials in the Mississippi River and its outlets and the resulting changes in the configuration of the beds are important problems to the designer of projects for the improvement, regulation, and economic development of the river system. The average layman regards the river as merely a natural channel carrying a stream of water, whereas, the engineer has learned that the river is not only a stream of water, but to a greater or lesser degree is also a stream of sediment.

Recognizing the desirability of perfecting methods for measuring the quantity and for determining the character of sediment loads in streams, several agencies of the United States Government organized an Interdepartmental Committee in 1939 to sponsor an exhaustive study of all problems encountered in collecting sediment data and to eventually standardize

accepted methods and equipment. The agencies of the Federal Government which have actively participated in this endeavor include: Corps of Engineers, Department of the Army; Soil Conservation Service of the Department of Agriculture; Geological Survey and Bureau of Reclamation, Interior Department; and the Tennessee Valley Authority. The scope of the general subject "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams" consisting of several reports, has been completed except for continuing refinements and the procedures established are currently used in connection with sediment studies of the lower Mississippi.

In addition to the general standardization of sediment methods and equipment, the Chief of Engineers recognized the need for intensified research on sediment problems as exists at the mouths of the Mississippi River and at other such coastal areas. Accordingly, the Chief of Engineers on 20 October 1948, established the "Committee on Tidal Hydraulics" with the objectives of: Evaluating the present state of knowledge of tidal phenomena of interest to the Corps of Engineers; recommending programs of study, investigation, and research designed to provide the knowledge necessary to arrive at adequate solutions for the engineering problems associated with such tidal phenomena; and exercising technical supervision of the prosecution of the recommended programs.

This Committee, in fulfillment of the first objective, published Report No. 1 entitled "Evaluation of Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Phenomena" under date of February 1950 in which the problems of the lower Mississippi River were discussed specifically or by inference.

QUANTITY OF MATERIALS TRANSPORTED THROUGH THE PASSES

In discussing materials transported by the Mississippi the following terms are used as defined:

> "Materials in Transport" are all solid materials transported by the river with the exception of dissolved and colloidal solids. Sediment is synonomous in meaning with "materials in transport."
>
> "Materials in suspension" or "suspended load" is that portion of the materials-in-transport which is not in frequent contact with the river bed."
>
> "Bed load" is that portion of the materials-in-transport which is in frequent or direct contact with the river bed."

One of the earliest estimates of the amount of materials transported by the Mississippi through the passes was made by Humphreys and Abbott on the basis of observations taken during the period 1851 to 1853. Their estimate showed the mean amount of sediment discharged annually as equivalent to a prism having a base of one square mile, and a height of 268 feet, or an amount having a weight of approximately 391 million tons.

Captain M. R. Brown, Corps of Engineers, U. S. Army, computed the aggregate amount of suspended sediment discharged through South Pass during the year ending March 25, 1878 to be 23,446,365 cubic yards. The

discharge of South Pass was considered at that time to be approximately 10% of the entire river indicating a total of 234,464,000 cubic yards of suspended material discharged through all passes during the year. Captain Brown added 50,536,000 cubic yards for bed load movement along the bottom of the channel, making the total amount of river sediment carried to the Gulf about 285,000,000 cubic yards. This amount of material would cover a one square mile area to a depth of 276 feet, which agrees closely with the Humphreys and Abbot estimate. Using a specific gravity of 1.89 for the sediment average the total amount of material is about 453 million tons.

Results of sediment observations for the period 1879 to 1898 are printed in the annual reports of the Chief of Engineers, U. S. Army for 1886 and 1898. The maximum discharge of sediment per annum was 33,416,795 cubic yards in 1888, the minimum was 11,633,280 cubic yards in 1879, and the mean per annum for the 15-year period was 19,719,928 cubic yards. In the annual report of the Chief of Engineers for the year 1894, the amount of discharge through South Pass is given as approximately 10 percent for the years 1877 to 1881, but as 8 percent only in 1894. Assuming that during the period 1881 to 1894, there was a constant rate of decrease in the percentage of discharge carried by South Pass, the sediment discharge through the three passes aggregated 371,297,700 cubic yards in 1888, and the average annual discharge through the three passes for the 15 years, 1879 to 1893, was about 214,347,000 cubic yards, which was approximately 587,250 cubic yards per day. Using 1.89 as the specific gravity of the transported material, the annual total would be 592 million tons for the year 1888, and an average annual total of 341 million tons for the 15-year period.

There were no further investigations of materials in transport in the passes until early in the year 1938 when an investigation was initiated by the District Engineer, First New Orleans District. From the set of observations obtained in this investigation, the annual discharge of suspended sediment through Southwest Pass, South Pass, and Pass a Loutre was computed to be 514 million tons. At that time approximately 15 percent of the river discharge was going through Cubits Gap and other outlets so that this figure does not represent the total suspended material carried to the Gulf.

Annual discharges of suspended sediment computed from measurements of the Carrollton range at New Orleans during the years 1851, 1852, 1879 to 1880, and 1929 gave amounts of 391 million, 572 million, 363 million, and 845 million tons per year, respectively. The average of these measurements would indicate suspended sediment discharge of approximately 543 million tons annually.

The suspended sediment discharge of the Mississippi River at Baton Rouge, Louisiana, computed from observations for the water year commencing October 1949 was 544 million tons, which compares favorably with sediment discharges computed for the Mississippi River at New Orleans and at the passes.

An examination of the results of sediment observations from Baton Rouge to the Gulf indicates a fairly uniform suspended sediment concentration at stations in this reach. There has been no indication that the bed of the lower Mississippi above the Head of Passes is rising and it

follows that if the bed of the river is not being built up in its lower reaches by deposition, the sedimentary load, however carried, must be deposited over its banks or transported to its mouth. In this case the overflow is prevented by levees and the sedimentary load must be carried to its delta. No sediment of consequence is delivered to the Mississippi River from other streams below the latitude of Old River, 322 miles above its mouth. Therefore, the sediment content of any given volume of water during this 322 mile travel must be fairly constant whether carried as a suspended or bed load. There has been no connected series of sediment observations to confirm such a theory but for practical purposes the sediment discharge measured at Baton Rouge can be considered indicative of the amount carried to the passes.

The "bed load," or unmeasured part of the materials in transport, is estimated to be 25 percent of the measured suspended load. This percentage is higher than is generally estimated for Mississippi River bed load, in that it includes the heavier concentrations of the coarser suspended sediments which pass below the lowest sampling level. On the basis of this estimate and an annual suspended sediment discharge of 544 million tons, the bed load would amount to 136 million tons. The total of 680 million tons is for annual flows comparable to the water year of 1950.

The water year of 1950 was characterized by an unusually long high water period. The annual volume of flow for the 15 water year period from 1936 to 1950, inclusive, averaged about 72 percent of the 1950 discharge volume. Allowing that the sediment discharge would be reduced proportionately, the average amount of sediment transported annually, based on the 1950 measurement, would be approximately 500 million tons.

The sediment discharge through any particular pass can be considered as a function based on the percent of water discharge through that pass to that of the main river. The present discharge through Southwest Pass is about 29 percent; through South Pass about 15 percent; through Pass a Loutre about 37 percent, and through Cubits Gap and other outlets about 19 percent. Assuming an annual 500 million ton sediment load for the river, this would give annual sediment loads of 145 million tons for Southwest Pass; 75 million tons for South Pass; 185 million tons for Pass a Loutre; and 95 million tons for Cubits Gap and the other outlets. The manner in which this material contributes to the sedimentation in the passes and vicinity will be discussed later.

CHARACTERISTICS OF MATERIALS

At the mouth of the river the suspended material usually consists of very fine sand, silt and clay. The finest grades and the lowest degree of concentration are found near the water surface. The coarseness and the silt content increases toward the bottom with the heaviest grades near the bottom. Very coarse sand and gravel are rolled along the bottom.

In the 1938 study of suspended materials transported through the Passes, no samples were found to contain material exceeding the very fine sand particle size. Moreover, only a small percentage of the material fell within the very fine sand range. On the basis of the Udden or modified Wentworth-Udden classification of sediments according to particle size, a typical suspended sediment sample from the 1938 observations would consist of 2 percent

very fine sand, 0.125 m.m. to 0.0625 m.m. in size; 48 percent silt, 0.0625 m.m. to 0.0039 m.m. in size; and about 50 percent clay, 0.0039 m.m. to 0.0001 m.m. in size. The 1938 mechanical analyses of materials taken from the river bed and from the passes showed that the largest particles were retained on a sieve having a mesh opening of 3.327 m.m. and that all were under 4.669 m.m. The largest size particle contained in most of the samples was between 1.168 m.m. and 1.651 m.m. All bed samples contained material graded down to the clay size.

SEDIMENTATION IN THE LOWER MISSISSIPPI RIVER

The Mississippi Delta is a complex mass of sediment deposited by a series of ever-changing distributaries which carry an enormous amount of water and sediment to the Gulf of Mexico. The majority of the sediment consists of silt and clay and is deposited in the Gulf close to the river mouths. The coarser material, silt, is deposited on the outer bars of the outlets, chiefly on the west side. Most of the finer, clay-sized particles remain in suspension and are carried beyond the outer bars where they gradually settle to the Gulf bottom.

For purpose of comparison, the lower Delta is divided into the Pass a Loutre area which is essentially unaffected by the works of man, and the South Pass and Southwest Pass areas which have been so modified by jetties and dredging as to require separate analysis.

Sedimentation in the Pass a Loutre area follows the general laws of nature and is affected primarily by the type and amount of sediment, gradient of the stream, action of the Gulf at the location of discharge, and the effects of the littoral currents. The littoral currents in the vicinity of the Delta have not been studied in sufficient detail to establish their effectiveness as transportation agents. It is known, however, that the prevailing winds in this area cause surface circulation which is similar in effect to a littoral current. The eastern channels face almost into the prevailing wind, with the result that sediments are spread fanwise across the entire eastern front of the region. Northeast Pass and Southeast Pass are almost tied together by a long spit which completely blocks these two channels to navigation, even by shallow-draft boats.

In comparison, the construction of jetties and dredging operations have caused a drastic change in the manner and rate of sedimentation in South and Southwest Passes. These confined channels are much deeper, and, as compared with the other passes, are essentially static. Captain Eads, by the construction of the South Pass jetties, contracted the mouth of the river, with the resultant deepening of the channel across the outer bar. His results were eminently successful except that he did not at first recognize the importance of prevailing currents in causing an excess of deposition on the central and western side of the channel bar.

Due recognition is now given to the existence of the littoral currents Gulfward of the passes without which the economic maintenance of the bar channels at South and Southwest Passes would be impossible. There is, however, some difference of opinion among authorities as to what causes the shoaling of the bar channels and the source or sources of the deposited material.

During flood stages of the river, the bottom layers of fresh water

discharged by passes carry an excessive load of sand as compared to the surface layers. At South Pass this portion of the flow did not follow the line selected for the channel through the bar. At Southwest Pass, attempts to maintain a channel through the bar were confined to a zone traversed by the most heavily laden part of the fresh water stream, that is, a bar channel on the prolongation of the jetty channel. Efforts to secure such a channel through the bar by dredging at South Pass, extending over a period of 20 years, and similar efforts at Southwest Pass extending over a period of 13 years, were never successful. Deposits during high river stages always exceeded the amount removed by dredging. Bar channels of project dimensions at both passes were not secured until this channel, with respect to the jetty channel, was inclined about 36 degrees to the east. It can be said with respect to both passes that the adoption of lateral channels through the bars marked the turning point from failure to success in maintaining channels of project dimensions.

By far the larger portion of the material reaching the outer slopes of the bars, whether it reached there from suspension, or as a result of being pushed along the bottom, is carried to the west by the littoral current. Even if a small portion of the sediment discharged by the passes during flood stages were to be deposited, and remained in the immediate area in front of the jetties, South and Southwest Passes would soon be closed to navigation.

As previously described, a salt water wedge enters the navigable passes during low river stages. As the fresh water erodes along the plane of the salt water wedge, the deposition of some of the suspended load is hastened by coagulation, or flocculation. Since it is known, from observations during flood stages of the river, that a portion of the suspended load is deposited at least 20 miles from the passes, it follows that precipitation of this load is gradual and cannot be so rapid as to cause appreciable shoaling in the jetty and bar channels. The coagulated mass of mud is so soft it is usually difficult to detect with a lead line and is usually moved out into the Gulf during early flood stages of the river. It seems certain, therefore, that most of the troublesome shoaling is caused by the bed load of sediment carried down the passes.

Observations at the mouth of Southwest Pass show that at about 800,000 c.f.s. in the Mississippi at New Orleans, the fresh water currents have sufficient force to hold the salt water wedge just outside the jettied channel. Naturally, the wedge would be expected to work in and out of this channel with the flood and ebb of the tide in the Gulf, but the average position is about the ends of the jetties. At the latter point the flood stage shoaling commences with a Mississippi River flow of 800,000 c.f.s. at New Orleans. As the river discharge increases the salt water wedge is forced down the bar channels and is followed by shoaling.

Although the salt water wedge is above the ends of the jetties at flows below 800,000 c.f.s. at New Orleans, no shoaling of consequence occurs although suspended sediment concentrations at this range of flow often exceed that found at higher river discharges. Shoaling follows the salt water down the bar channel and is coincident with the salt water wedge at that point and about 800,000 c.f.s. discharge at Carrollton.

Comparing low water conditions in the bar at South Pass with Southwest Pass, it is found that while the latter bar channel is gradually shoaling, the former is scouring deeper. There are logical reasons for this inverse action in the South Pass bar channel. Some of the features which probably contribute to the favorable result are worthy of consideration. The axis of the South Pass bar channel is in a more favorable direction with reference to the littoral current and prevailing winds. The bearing of the South Pass bar is about S. 65° E.; the corresponding bearing at Southwest Pass is due south, a difference of 65°. Taking the direction of the prevailing winds as due Southeast, or S. 45° E. for a season average, the unfavorable wind angle at South Pass is 20° as compared with 45° at Southwest Pass. The littoral current in its approach to the mouth of South Pass does not traverse the lower reaches of Garden Island Bay as it does the reaches of East Bay in its approach to the mouth of Southwest Pass.

There is a small shoal area to the east and north of the South Pass bar channel similar in shape, extent and position to the like area at the mouth of Southwest Pass over which, in both cases, the littoral currents must pass in their approach to the bar channels. But the relative conditions are more favorable to South Pass to the extent of much flatter slopes, between shoal area and bar channel, for the transportation of sand and the reduced effect of wave action in greater water depths.

It would be unreasonable to contend that no material is carried into the South Pass bar channel, during the low river season, from the two adjacent shoal areas, or bars, but it can safely be said that scouring forces in the jettied and bar channels are sufficient to move not only any such material but considerable quantities of additional material deposited in the two areas by the falling river from the previous flood stage. Here again there must be a constant fight between scouring and depositing forces with the ascendency of the former, over the latter, well maintained throughout the low river season. That the scouring forces are greatest must be attributed to greater channel velocities than exist at Southwest Pass.

At South Pass in 1897, about the time the bar channel was inclined to the east, the 30-foot contour was approximately 2500 feet Gulfward of the jetties. Since 1897, the 30-foot contour has advanced about 4,400 feet and is presently approximately 6,900 feet Gulfward of the end of the jetties. The rate of advance of the 30-foot contour since 1897 has been approximately 85 feet a year. Figure 6 shows the progressive advancement of the 30-foot contour from 1897 to 1950.

Since 1922, the year after the Southwest Pass bar channel was inclined to the east, the 35-foot contour has advanced from a position 5000 feet seaward of the end of the present jetties, on a prolongation of the West Jetty axis to a position 8800 feet seaward, or 3400 feet in 28 years for an average of about 122 feet a year. Before 1922, the rate of advance was approximately 385 feet per year. Figure 7 shows the progressive advancement of the 35-foot contour since 1898.

The crest of both bars will continue to advance into the Gulf, the west side faster than the east side as a result of the east to west littoral current. The time will come when the velocity of the river water

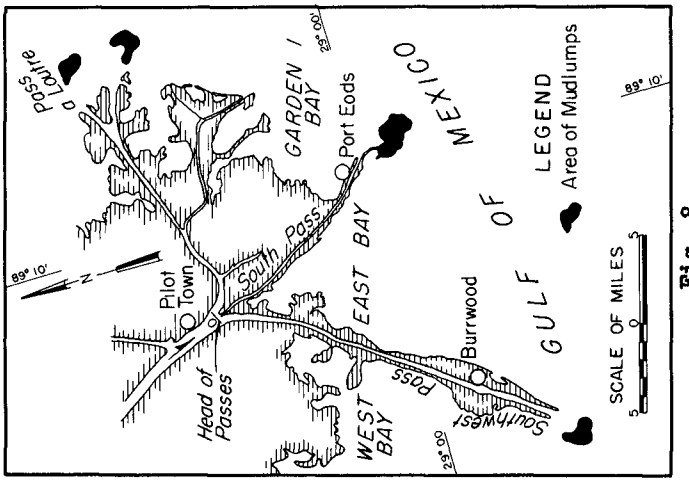

Fig. 8
Location of mudlumps in the Mississippi River Delta.

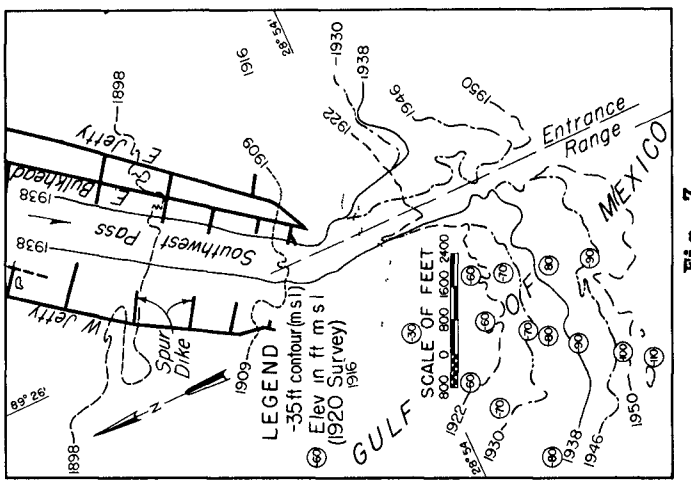

Fig. 7
Advance of the 35 foot below mean sea level contours, Southwest Pass of the Mississippi River, 1898 to 1950.

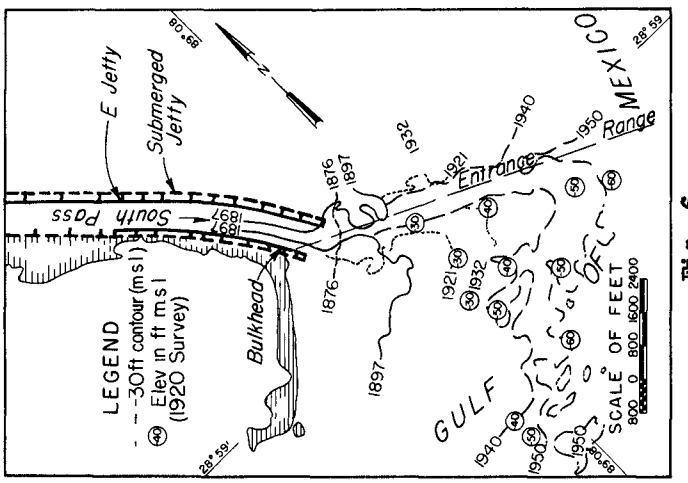

Fig. 6
Advance of the 30 foot below mean sea level contours, South Pass of the Mississippi River, 1897 to 1950.

into the Gulf will no longer be sufficient to overcome the resistance across the increased length of the bar. At that time the river will then flow more to the east, this being the path of least resistance. When this occurs, the salt water in the bar channel will be displaced by the silt-laden river water and shoaling will probably follow at a rapid rate. It will then be necessary to extend the jetties. Sedimentation studies of the passes should indicate necessary corrective action before the problem becomes acute.

MUDLUMPS

There is a close relationship between the sedimentary characteristics of the mouths of the Mississippi River passes and the origin and growth of mudlumps in those areas. However, since this phenomena is the subject for another paper to be presented at the Second Conference on Coastal Engineering, discussion of mudlumps will be limited to localities and general observations.

Mudlumps is the term commonly used for the upswelling of clay which forms islands near the mouths of the Mississippi River passes. These features usually are associated with the bars at the outlets of the various passes. At present, the mudlumps are found within a few thousand feet of the mouths of North Pass, Pass a Loutre, Northeast Pass, Southeast Pass, Old Balize Bayou, South Pass, and Southwest Pass. Relative locations of mudlump areas are shown on Figure 8.

Mudlumps appear to be a Mississippi River Delta phenomenon in that they are unknown elsewhere in the world. These islands of mud, because of their striking appearance, constantly changing locations, and proximity to the outlets of the Mississippi River, have caused comment by marine personnel since the earliest days of navigation. In a region having elevation differences of two or three feet the vertical mudlump cliffs of from five to ten feet in height are the most prominent features in existence.

REFERENCES

Committee on Tidal Hydraulics (1950). Evaluation of Present state of knowledge of Factors affecting tidal hydraulics and related phenomena: Report No. 1, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss.

Corps of Engineers (1950). Report upon the Improvement of Rivers and Harbors in the New Orleans, La. District. Extract from the Annual Report of the Chief of Engineers, 1949: Department of the Army, Office of the Chief of Engineers, Washington, D. C.

Elliott, D. O. (1932). The improvement of the Lower Mississippi River for Flood Control and Navigation: Vol. 1, Mississippi River Commission, Corps of Engineers, Vicksburg, Miss.

Federal Inter-Agency River Basin Committee, Sub-Committee on Sedimentation (1948). Measurement of the Sediment Discharge of Streams: Report No. 8, St. Paul District Sub-Office, Corps of Engineers, Hydrologic Laboratory, University of Iowa, Iowa City, Iowa.

First New Orleans District (1939). The Passes, Mississippi River: Brochure, Corps of Engineers, New Orleans, La.

First New Orleans District and U. S. Waterways Experiment Station (1939). Study of Materials in Transport, Passes of the Mississippi River: Tech. Memorandum No. 158-1, Corps of Engineers, Vicksburg, Miss.

Hutchings, Henry, Jr. (1933). Report on Hydraulic Study for Eliminating Dredging in Southwest Pass: First New Orleans District, Corps of Engineers, New Orleans, La.

Lane, E. W. and Borland, W. M. (1950). Estimating Bed Load: Paper presented at the Annual Meeting of the Amer. Geophys Union in 1950. Bureau of Reclamation, U. S. Department of the Interior, Denver, Col.

Morgan, J. P. (1951). The Occurrence and Origin of the Mudlumps at the Mouths of the Mississippi River: Part 1 of unpublished report, New Orleans District, Corps of Engineers, New Orleans, La.

New Orleans District (1941). Report of Improvements of the Passes of the Mississippi River: Corps of Engineers, New Orleans, La.

New Orleans District (1942). Salinity, Mississippi River at and below New Orleans, La.: Review of Reports, Corps of Engineers, New Orleans, La.

Tiffany, J. B., Jr. (1944). Memorandum Report on Proposed Model of Southwest Pass: U. S. Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss. Unpublished report.

U. S. Waterways Experiment Station (1930). Sediment Investigations on the Mississippi River and its Tributaries prior to 1930: Paper H, Corps of Engineers, Vicksburg, Miss.