PORT ARTHUR AND VICINITY, TEXAS

LETTER

FROM

THE SECRETARY OF THE ARMY

TRANSMITTING

A LETTER FROM THE CHIEF OF ENGINEERS, DEPARTMENT OF THE ARMY, DATED JUNE 7, 1962, SUBMITTING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, ON AN INTERIM HURRICANE SURVEY OF PORT ARTHUR AND VICINITY, TEXAS, AUTHORIZED BY PUBLIC LAW 71, 84TH CONGRESS, APPROVED JUNE 15, 1955

AUGUST 8, 1962.—Referred to the Committee on Public Works and ordered to be printed with two illustrations

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON : 1962

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CONTENTS

Page

Letter of transmittal — v
Comments of the Bureau of the Budget — vi
Comments of the Governor of Texas — vii
Comments of the Department of the Interior — x
Comments of the Department of Agriculture — xi
Comments of the Department of Commerce — xii
Report of the Chief of Engineers, Department of the Army — 1
Report of the Board of Engineers for Rivers and Harbors — 3
Report of the District Engineer:
- Syllabus — 8
- Authority — 9
- Purpose and scope:
  - Purpose of studies — 10
  - Scope of field investigations — 10
  - Other investigations — 10
- Prior reports:
  - Hurricane protection reports — 10
  - Navigation reports — 10
- Area characteristics:
  - Location and extent — 11
  - Physical description — 11
  - Streams and lakes — 11
  - Spoilbanks — 11
  - Topography — 12
  - Geology and soils — 13
  - Maps and charts — 13
- Economic development:
  - Basic economy — 14
  - Population — 14
  - Industrial development — 14
  - Residential areas — 15
  - Transportation — 15
  - Utilities — 15
  - Water commerce — 15
  - Recreational facilities — 16
  - Growth trends — 16
- Climatology:
  - Area weather characteristics — 16
  - Hurricanes—general — 17
  - Hurricanes of record — 18
  - Tidal range — 19
  - Hurricane tides — 19
  - Hurricane winds — 19
  - Hurricane waves — 20
  - Development of synthetic hurricanes — 20
  - Standard project and design hurricane — 21
  - Rainfall of record — 22
  - Design rainfall for interior drainage — 22
- Extent and character of flooded area:
  - Extent — 23
  - Character — 23
  - Property values — 23
- Hurricane flood damages:
  - General — 24
  - Damages from occurrence of design hurricane flood — 25
  - Average annual damages — 25

Report of the district engineer—Continued

	Page
Existing Federal Corps of Engineers' project:	
Hurricane protection projects	26
Navigation improvements	26
Improvements by other Federal and non-Federal agencies:	
Projects by other Federal agencies	26
Non-Federal hurricane protection	26
Existing interior drainage	27
Improvements desired:	
Public hearing	28
Requested improvements	28
Responsible local agencies	29
Hurricane flood problems and solutions:	
Hurricane protection problems	31
Protective measures considered:	
Hurricane warning and evacuation	31
Zoning regulations	32
Protective structures	32
Plans considered	32
Plans of improvement:	
General	34
Interior drainage	36
Reservation of ponding areas	36
Escape routes	38
Water resource development	38
Shoreline changes	38
Estimate of first cost	39
Estimates of annual charges	39
Estimates of benefits:	
Benefits	41
Prevention of damages	41
Increased utilization or enhancement benefits	42
Summary	42
Project formulation and economic justification:	
Project development	43
Comparison of benefits and costs	43
Proposed local cooperation	45
Apportionment of costs among interests	46
Coordination with other agencies	47
Discussion	49
Conclusions	52
Recommendations	53
Recommendation of the Division Engineer	54

APPENDIXES ACCOMPANYING THE REPORT OF THE DISTRICT ENGINEER

	Page
Appendix I.—Hydrology and hydraulics	55
Appendix II.—Economics	97
Appendix III.—Engineering data	119
Appendix IV.—Estimates of first costs and annual charges	141
Appendix V.—Comments and views of other agencies	161

Additional information called for by Senate Resolution 148, 85th Congress, adopted January 28, 1958	167

ILLUSTRATIONS ACCOMPANYING THE REPORT OF THE DISTRICT ENGINEER

(Only Plates 1 and 2 printed)

Plate 1.—Index map.
Plate 2.—Plan of improvement (Plan B).
Plate 3.—Investigated plan (Plan A).

LETTER OF TRANSMITTAL

DEPARTMENT OF THE ARMY
WASHINGTON 25, D.C.

IN REPLY REFER TO:

August 6, 1962

Honorable John W. McCormack

Speaker of the House of Representatives

Dear Mr. Speaker:

I am transmitting herewith a favorable report dated 7 June 1962, from the Chief of Engineers, Department of the Army, together with accompanying papers and illustrations, on an interim hurricane survey of Port Arthur and vicinity, Texas, authorized by Public Law 71, 84th Congress, approved 15 June 1955.

In accordance with Section 1 of Public Law 534, 78th Congress, and Public Law 85-624, the views of the Governor of Texas and the Department of the Interior are set forth in the inclosed communications. The views of the Departments of Agriculture and Commerce are inclosed also.

The Bureau of the Budget advises that there is no objection to the submission of the proposed report to the Congress; however, it states that no commitment can be made at this time as to when any estimate of appropriation would be submitted for construction of the project, if authorized by the Congress, since this would be governed by the President's budgetary objectives as determined by the then prevailing fiscal situation. A copy of the letter from the Bureau of the Budget is inclosed.

Sincerely yours,

Cyrus Vance

Secretary of the Army

1 Incl
Rept w/accompg
papers & illus

COMMENTS OF THE BUREAU OF THE BUDGET

EXECUTIVE OFFICE OF THE PRESIDENT
BUREAU OF THE BUDGET
WASHINGTON 25, D. C.

24 July 1962

Honorable Cyrus R. Vance
Secretary of the Army
Washington 25, D. C.

Dear Mr. Secretary:

Assistant Secretary Schaub's letter of June 12, 1962, transmits the favorable report of the Chief of Engineers on an interim hurricane survey of Port Arthur and vicinity, Texas, authorized by Public Law 71, 84th Congress, approved June 15, 1955.

The Chief of Engineers recommends protection of Port Arthur and vicinity from hurricane tidal damage by rehabilitating, raising, and extending existing levees and floodwalls and constructing pumping stations for removal of interior drainage. The protective works would comprise a single continuous levee and floodwall structure protecting the area north of Taylors Bayou including the City of Port Arthur, and separate levee systems for protection of two Gulf Oil Corporation industrial properties south of Taylors Bayou. The cost of construction is estimated to be $33,400,000. In addition to other stated conditions of cooperation, local interests would be required to bear 30 percent of the first cost of the improvements, an amount now estimated at $10,020,000, consisting of $690,000 for lands and relocations and $9,330,000 as a cash contribution. The benefit-cost ratio is stated to be 5.7.

I am authorized by the Director of the Bureau of the Budget to advise you that there would be no objection to the submission of the proposed report to the Congress. No commitment, however, can be made at this time as to when any estimate of appropriation would be submitted for construction of the project, if authorized by the Congress, since this would be governed by the President's budgetary objectives as determined by the then prevailing fiscal situation.

Sincerely yours,

Carl H. Schwartz, Jr., Chief
Resources and Civil Works
Division

COMMENTS OF THE GOVERNOR OF TEXAS

EXECUTIVE DEPARTMENT
AUSTIN 11, TEXAS

PRICE DANIEL
GOVERNOR

May 7, 1962

Lt. General W. K. Wilson, Jr.
Chief of Engineers
Department of the Army
Washington 25, D. C.

Dear General Wilson:

This has further reference to your letter of April 6, 1962, transmitting copy of the proposed report on an interim hurricane survey of Port Arthur and vicinity, Texas.

At my request, the Texas Water Commission reviewed this report and approved its feasibility, as evidenced by the attached copy of a Commission Order. I concur in the findings and conclusions of the Commission.

Sincerely yours,

Price Daniel

PD:gs

Enclosure

cc: Hon. Joe D. Carter, Chairman
Texas Water Commission
Capitol Station, Box 2311
Austin 11, Texas

TEXAS WATER COMMISSION

AN ORDER approving the feasibility of the proposed Federal project to provide hurricane flood protection to Port Arthur and vicinity, Texas, as proposed in the "Interim Report on Hurricane Survey of Port Arthur and Vicinity, Texas" by the Corps of Engineers, United States Army, on said project.

BE IT ORDERED BY THE TEXAS WATER COMMISSION:

Section 1. Statement of Authority. Article 7472e, Vernon's Annotated Civil Statutes, provides that upon receipt of any engineering report submitted by a Federal Agency seeking the Governor's approval of a Federal Project, the Texas Water Commission shall study and make recommendations to the Governor as to the feasibility of the Federal Project. The Commission shall cause a public hearing to be held to receive the views of persons or groups who might be affected should the Federal Project be initiated and completed.

Section 2. Statement of Jurisdiction. (a) By letter dated April 10, 1962, the Honorable Price Daniel, Governor of Texas, requested the Texas Water Commission to study and make recommendations concerning reports of the Corps of Engineers, United States Army, entitled "Interim Report on Hurricane Survey of Port Arthur and Vicinity, Texas", said report being initially dated November 29, 1961, and to enter its order finding said project to be feasible or not feasible. (b) In accordance with Article 7472e, the Commission caused a public hearing after due notice by publication and mail, to be held on May 4, 1962, at 9:00 o'clock, A.M., in the offices of the Texas Water Commission, 201 East Fourteenth Street, Austin, Texas, on said Review and Project, and at which time all those interested or who may be affected should the Project recommended in said Review be initiated and completed were requested to come forward and give testimony.

Section 3. After fully considering all the evidence and exhibits presented by persons and groups who may be affected should the Project be initiated and completed, including the matters set forth in Section 4 of Article 7472e, the Commission finds that said project is feasible and that the public interest will be served thereby.

Section 4. It is further ordered that a certified copy of this Order be transmitted to the Governor.

Section 5. This Order shall take effect on the 4th day of May, 1962, the date of its passage, and it is so ordered.

SIGNED IN THE PRESENCE OF THE
TEXAS WATER COMMISSION

Joe D. Carter, Chairman

ATTEST:

Ben F. Looney, Jr., Secretary

I certify that the foregoing order was adopted by the Texas Water Commission at a meeting held on the 4th day of May, 1962, upon motion of Commissioner Dent, seconded by Commissioner Beckwith, Commissioner Dent voting "aye", Commissioner Beckwith voting "aye", and Chairman Carter voting "aye".

Ben F. Looney, Jr., Secretary

STATE OF TEXAS §

COUNTY OF TRAVIS §

I, Ben F. Looney, Jr., Secretary of the Texas Water Commission do hereby certify that the foregoing is a true and correct copy of an order of said Commission, the original of which is filed in the permanent records of said Commission.

Given under my hand and the seal of the Texas Water Commission, this the 4th day of May, A.D., 1962.

Ben F. Looney, Jr., Secretary

COMMENTS OF THE DEPARTMENT OF THE INTERIOR

UNITED STATES
DEPARTMENT OF THE INTERIOR
OFFICE OF THE SECRETARY
WASHINGTON 25, D. C.

May 22, 1962

Lt. General Walter K. Wilson, Jr.
Chief of Engineers
Department of the Army
Washington 25, D. C.

Dear General Wilson:

This is in reply to your letter of April 6 transmitting for our comments reports on a hurricane survey of Port Arthur and vicinity, Texas. The recommended improvements consist principally of rehabilitating, raising, and extending the existing seawall, floodwalls and earthen levees, and constructing pumping stations for removal of interior runoff.

The Fish and Wildlife Service states that the project will have insignificant effects on fish and wildlife and will offer no opportunities for improvement of these resources. Other interests of the Department would not be adversely affected.

The opportunity of presenting our views is appreciated.

Sincerely yours,

Keith Holum

Assistant Secretary of the Interior

COMMENTS OF THE DEPARTMENT OF AGRICULTURE

DEPARTMENT OF AGRICULTURE
WASHINGTON 25, D. C.

31 May 1962

Honorable Elvis J. Stahr, Jr.
Secretary of the Army

Dear Mr. Secretary:

This is in reply to the Chief of Engineers' letter of April 6, 1962, transmitting for our review and comment his proposed survey report on Port Arthur and Vicinity, Texas.

The report recommends rehabilitating, raising, and extending existing flood walls and appurtenant works to provide protection against tidal flooding for urban and industrial areas at Port Arthur, Texas. The proposed improvements will not adversely affect projects or programs of this Department.

We appreciate the opportunity afforded us to review this report.

Sincerely yours,

Frank J. Welch
Assistant Secretary

COMMENTS OF THE DEPARTMENT OF COMMERCE

THE UNDER SECRETARY OF COMMERCE
FOR TRANSPORTATION
WASHINGTON 25

May 22, 1962

Lieutenant General W. K. Wilson, Jr., USA
Chief of Engineers
Department of the Army
Washington 25, D. C.

Dear General Wilson:

As requested in your letter of April 6, 1962, I am transmitting herein the comments of the interested Department of Commerce agencies on your proposed report on an interim hurricane survey of Port Arthur and vicinity, Texas.

The Coast and Geodetic Survey advises that the construction of this project will necessitate the revision of the nautical charts covering that portion of the shoreline. The cost of the photography necessary to make these revisions and the revision of the charts is estimated to be $1,500. The Coast and Geodetic Survey is of the opinion that the existing horizontal and vertical geodetic control are adequate and that the completion of the project will not endanger existing control monuments.

The Bureau of Public Roads notes that the construction of the levees and floodwalls will require the ramping of several State and local highways where they intersect the levees and floodwalls. The Bureau of Public Roads also notes that the cost of this work has been made a part of the project cost. It is assumed that the detailed design of the highway alterations will be coordinated with the highway authorities during the design phase.

Your courtesy in providing a copy of this report for our review is appreciated.

Sincerely yours,

Frank L. Barton

Frank L. Barton
Deputy Under Secretary
for Transportation

PORT ARTHUR AND VICINITY, TEXAS

REPORT OF THE CHIEF OF ENGINEERS, DEPARTMENT OF THE ARMY

HEADQUARTERS
DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON 25, D.C.

IN REPLY REFER TO

ENGCW-PD

7 June 1962

SUBJECT: Port Arthur, Texas

TO: THE SECRETARY OF THE ARMY

1. I submit for transmission to Congress my report on a survey of Port Arthur and vicinity, Texas, in partial response to Public Law 71, Eighty-fourth Congress, first session, with a view to providing improvement for preventing loss of human lives and damages to property from flooding caused by hurricanes. My report includes the reports of the District and Division Engineers and the Board of Engineers for Rivers and Harbors.

2. The reporting officers find that the most suitable plan for protection of Port Arthur and vicinity would consist of rehabilitating, raising, and extending the existing levees and floodwalls, and the construction of necessary pumping stations for the removal of interior runoff. They recommend the construction of the work at an estimated cost of $33,400,000. The annual charges are estimated at $1,150,000 including $100,000 for operation and maintenance by local interests. The estimated average annual benefits are $6,510,000 consisting of $6,388,000 for prevention of flood damages and $122,000 for increased land utilization. The benefit-cost ratio is 5.7.

3. The President of the Beach Erosion Board agrees with the reporting officers that the work would have no effect on the configuration of the adjacent shorelines.

4. The Board of Engineers for Rivers and Harbors recommends the proposed work substantially in accordance with the plan of the District Engineer subject to local cooperation including the requirement that local interests bear 30 percent of the first cost, a sum presently estimated at $10,020,000 consisting of $690,000 for lands, easements, rights-of-way, and relocations, and $9,330,000 as a cash contribution. The net cost to the United States for construction is estimated at $23,380,000.

ENGCW-PD
SUBJECT: Port Arthur, Texas

5. I concur in the recommendations of the Board of Engineers for Rivers and Harbors.

W. K. WILSON, JR.
Lieutenant General, USA
Chief of Engineers

ENGBR(29 Nov 61) 2nd Ind
SUBJECT: Port Arthur, Texas

Board of Engineers for Rivers and Harbors, Washington 25, D. C.
26 January 1962

TO: Chief of Engineers, Department of the Army

1. Port Arthur is on the west shore of Sabine Lake in the extreme southeast part of Texas, about 14 miles from the Gulf of Mexico. The area under consideration in this report comprises about 38,500 acres, and includes the cities of Port Arthur and Groves; the towns of Griffing Park, Pear Ridge, and Lakeview, and adjacent industrial areas. The population of the area is about 95,000 and the major industries are the processing and shipping of petroleum and petroleum products. Petro-chemical, iron and steel fabricating, shipbuilding, machine repair, and seafood processing industries also contribute to the economy. This complex of industrial, commercial, residential, and transportation facilities valued at $1,288,000,000 has been developed in the coastal marsh region on lands generally below elevation 5 feet mean sea level.

2. There are no existing Federal projects for hurricane protection in the Port Arthur area. The existing Federal projects for the Sabine-Neches Waterway, Texas, and Gulf Intracoastal Waterway traverse the area. The parts of the waterways pertinent to the hurricane problem are the 36-foot Port Arthur Canal and turning basins, and the 36-foot Sabine-Neches Canal. The spoil banks from these improvements reduce the damaging effects of hurricane waves. The seawall constructed by local interests to protect local levees and properties along the Port Arthur waterfront of the Sabine-Neches Canal from wave wash and erosion is an integral part of the existing tidal flood-protection works. Local interests have also constructed a system of earth levees generally to 9 feet above mean sea level for storm tide protection for the older parts of the developed area, including portions of Port Arthur, Groves, Lakeview, Griffing Park, Pear Ridge, and certain industrial plants. Lesser protection by earth levees to about elevation 7 feet mean sea level has been provided by local interests in the Port Acres section of Port Arthur.

3. Although no severe hurricanes have been experienced in the immediate vicinity of Port Arthur since it has developed into a major industrial center, several hurricanes have caused damaging tidal floods in the area. The hurricane of August 1915, which

crossed the coast near Freeport, Texas, 83 miles to the southwest, produced tidal flooding to elevation 7.3 feet above mean sea level in Port Arthur, and caused the loss of six lives and damages estimated at several million dollars. The existing protective levees had not been constructed at that time. Hurricane "Carla", 11 September 1961, which entered the mainland near Port O'Connor, Texas, 190 miles to the southwest, caused a tide of 7.2 feet above mean sea level at Port Arthur. The areas protected by the main levees were not flooded. However, about 700 homes in the Port Acres section of Port Arthur and in the unprotected parts of Groves were flooded, causing about $5,000,000 in damages. Studies made under Public Law 71 by the United States Weather Bureau of the hurricane problem along the Gulf Coast indicate that much higher hurricane tides than have been experienced may be reasonably expected in the Port Arthur vicinity. These studies provided the basis for determination of the standard project hurricane for the Port Arthur vicinity, which is defined as the most severe hurricane having a reasonable probability of occurrence in the locality. This hurricane, selected as the design hurricane for consideration of protective works, would produce tides of about 14 feet above mean sea level at Sabine Pass on the coast south of Port Arthur and has an estimated frequency of occurrence of once in about 160 years. This tide would be modified to about 12 feet at Port Arthur and under the present state of development and protection would cause damages estimated at about $228,000,000.

4. Local interests desire protection against tidal flooding and protection against erosion of existing works along the Sabine-Neches Waterway. They request the repair and strengthening of the seawall along the Sabine-Neches Canal, the raising of the existing levees and walls, the extension of the protective works to presently unprotected areas, and consideration of protection for the county highway, extending southward along the spoil bank to Sabine Pass.

5. The District Engineer has considered all of the improvements requested by local interests. He also considered hurricane warnings and evacuation, and zoning regulations as damage prevention measures. He finds that structural protection against hurricane tides up to 12 feet above mean sea level by means of levees and walls is economically justified and would meet the desires of local interests. The protection of the county highway along the spoil bank was found to be not justified. Two basic plans were developed in detail by the District Engineer. One, designated Plan A, would provide protection for the presently developed

portions of Port Arthur by enclosing two separate industrial areas south of Taylors Bayou and four separate areas north of Taylors Bayou. The most suitable plan for hurricane improvements, designated as Plan B, would provide for enlarging, strengthening, and extending the existing levees and floodwalls to protect by a single enclosure about 37,000 acres of Port Arthur, Groves, Lakeview, Pear Ridge, and Griffing Park, and adjacent and intervening industrial areas; protecting by ring levees two separate industrial areas south of Taylors Bayou; and constructing necessary pumping stations for the removal of interior drainage. Based on September 1961 prices, the District Engineer estimates the total cost of the work at $33,496,000, consisting of $32,710,000 for construction, $690,000 for lands, easements, rights-of-way, and relocations, and $96,000 for preauthorization studies. The annual charges are estimated at $1,150,000 including $100,000 for maintenance and operation by local interests. He estimates the average annual benefits at $6,510,000 consisting of $6,388,000 for prevention of flood damages and $122,000 for increased land utilization. The benefit-cost ratio is 5.7, based on a 100-year period of analysis. The District Engineer apportions the costs between Federal and non-Federal interests in accordance with the actions of Congress on similar projects authorized by the Flood Control Act of 1958. The resulting apportionment for the Port Arthur project would require that local interests furnish lands, easements, rights-of-way, and relocations at an estimated value of $690,000 and contribute in cash $9,330,000, for a total of $10,020,000. The various local cities, towns, and drainage districts have indicated willingness to furnish the required local cooperation. No single agency now has the legal authority to provide the assurances. However, local officials are seeking the necessary changes in law to give a consolidated drainage district full legal and financial powers to furnish the local cooperation for the entire project. The District Engineer is of the opinion that the local cooperation requirements will be furnished. He recommends the authorization of his Plan B. The Division Engineer concurs.

6. The Division Engineer issued a public notice stating the recommendations of the reporting officers and affording interested parties an opportunity to present additional information to the Board. No communications have been received.

7. Views.--The Board of Engineers for Rivers and Harbors concurs in general in the views and recommendations of the reporting officers. The Board notes that the design levels of the works recommended are adequate to provide protection against tidal flooding from the most severe hurricane considered reasonably characteristic of the area. The requirements of local cooperation are generally appropriate; local interests have indicated their willingness to comply and are taking steps to obtain the necessary legal and financial powers.

8. Recommendations.--Accordingly, the Board recommends improvements for hurricane tidal flood protection at Port Arthur and vicinity, Texas, to provide for:

Reconstructing and raising 4.9 miles of existing concrete and steel sheet-pile seawall along the Sabine-Neches Canal in front of the city of Port Arthur and the town of Lakeview;

Reconstructing and raising 1.7 miles of existing concrete and steel sheet-pile floodwalls and constructing 0.3 mile of new concrete and steel sheet-pile floodwalls principally along Taylors Bayou south of the Gulf Oil Corporation refinery;

Enlarging and raising 10.3 miles of existing earth levees, including 3.0 miles extending from the seawall southward to Taylors Bayou, and 7.3 miles around two separate industrial areas south of Taylors Bayou;

Constructing 18.7 miles of new earth levees, consisting of 5.6 miles extending from Lakeview northeastward along Sabine-Neches Canal and northwestward to the north side of Groves, 0.5 mile along Taylors Bayou south of the Gulf Oil Corporation, 11.3 miles extending from the Gulf Oil Corporation westward along Taylors Bayou and northward around Port Acres to high ground near Rhodair Gully, and 1.3 miles around the Sabine Road tank farm to complete the protection for the industrial areas south of Taylors Bayou; and

Constructing appurtenant structures including pumping stations as required;

all generally in accordance with Plan B of the District Engineer and with such modifications thereof as in the discretion of the Chief of Engineers may be advisable; at an estimated first cost of $33,400,000, consisting of $32,710,000 for construction and $690,000 for lands, easements, rights-of-way, and relocations: Provided that, prior to construction, local interests give assurances satisfactory to the Secretary of the Army that they will:

a. Provide without cost to the United States all lands, easements, and rights-of-way, including all borrow areas, and the relocation of buildings, pipelines, and utilities necessary for the construction of the project, at costs presently estimated at $690,000;

b. Bear 30 percent of the first cost, to consist of items listed in a above and a cash contribution presently estimated at $9,330,000, to be paid either in a lump sum prior to initiation of construction or in installments prior to start of pertinent work items, in accordance with construction schedules as required by the Chief of Engineers, the final apportionment of costs to be made after actual costs and values have been determined;

c. Hold and save the United States free from damages due to the construction works;

d. Maintain and operate all works after completion in accordance with regulations prescribed by the Secretary of the Army; and

e. Prevent any encroachment on the ponding areas that would reduce the capacity of a ponding area, unless such is offset promptly by additional pumping capacity provided at no cost to the United States.

9. Of the Federal construction cost of $32,710,000, the net cost to the United States is estimated at $23,380,000.

FOR THE BOARD:

KEITH R. BARNEY
Major General, USA
Chairman

REPORT OF THE DISTRICT ENGINEER

INTERIM REPORT
ON
HURRICANE SURVEY
OF
PORT ARTHUR AND VICINITY, TEXAS

SYLLABUS

Pursuant to authority of Public Law 71 (84th Congress, 1st session), a survey was made to determine the need and economic feasibility of providing hurricane flood protection to Port Arthur and vicinity, Texas. It was found that a serious problem of hurricane tidal flooding exists in the populated and heavily industrialized Port Arthur area. Portions of the area are protected to some degree by existing levee and floodwall systems, but would be subject to inundation from wave overtopping and breaching of the levees during major hurricanes. Other large developed and undeveloped areas are without protection. The total damages that would result from the occurrence of the design hurricane are estimated at about $228,000,000 under existing conditions.

The most feasible plan for hurricane protection improvements, designated as plan B in this report, would provide for enlarging, strengthening and extending the existing levees and floodwalls to protect within a single enclosure about 37,000 acres north of Taylors Bayou, including the cities and towns of Port Arthur, including the recently annexed communities of Port Acres, Rosemont and El Vista; Groves; Lakeview; Pear Ridge and Griffing Park and the intervening industrial areas. Two small industrial areas south of Taylors Bayou would be protected by separated ring levees. Additional pumping stations would be provided for adequate interior drainage of the inclosed areas during high tide periods.

The improvements proposed under plan B would afford large benefits by preventing most of the damages that would occur from the flooding of existing properties and future growth and development either by hurricane tides or rainfall runoff. The estimated annual benefits would exceed the annual charges and would have a favorable ratio of 5.7.

Accordingly, it is recommended that a plan for hurricane flood protection improvements in the Port Arthur, Texas, area be authorized, essentially as described in plan B of this report. The total first cost of construction is presently estimated at $33,400,000, excluding $96,000 which has been expended for preauthorization study costs. The net cost to the United States is presently estimated at $23,380,000. The total cost to local interests is estimated at $10,020,000, including the fair value of lands, easements, rights-of-way and relocations, presently estimated at $690,000. The recommendation is subject to certain other specified conditions of local cooperation.

U. S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

November 29, 1961

SUBJECT: Interim Report on Hurricane Survey of Port Arthur and Vicinity, Texas

TO: Chief of Engineers, Department of the Army,
Washington, D. C., through
Division Engineer, U. S. Army Engineer Division, Southwestern
Dallas, Texas

AUTHORITY

1. This interim report on hurricane survey of Port Arthur and vicinity, Texas, is submitted under Public Law 71 (84th Congress, 1st session) adopted June 15, 1955, which authorizes and directs an examination and survey of the eastern and southern seaboard of the United States with respect to hurricanes, with particular reference to areas where severe damages have occurred. Pertinent portions of the authorizing act read as follows:

> "Sec. 1 - That in view of the severe damage to the coastal and tidal areas of the eastern and southern United States from the occurrence of hurricanes, ... the Secretary of the Army, in cooperation with the Secretary of Commerce and other Federal agencies con-concerned with hurricanes, is hereby authorized and directed to cause an examination and survey to be made of the eastern and southern seaboard of the United States with respect to hurricanes, with particular reference to areas where severe damages have occurred.
>
> "Sec. 2 - Such survey, to be made under the direction of the Chief of Engineers, shall include the securing of data on the behavior and frequency of hurricanes, and the determination of methods of forecasting their paths and improving warning services, and of possible means of preventing loss of human lives and damages to property, with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams, and other structures, warning services, or other measures which might be required."

2. By letter ENGWD dated December 5, 1956, subject, "Hurricane Appraisal Report", the Chief of Engineers approved preparation of an interim report on the Port Arthur area.

PURPOSE AND SCOPE

3. Purpose of studies.- This interim report of survey scope comprises the results of a study to determine the extent of potential tidal flooding from hurricanes in the Port Arthur, Texas, area and the feasibility of improvements to prevent loss of lives and damages to property in the area from hurricane floods. The report studies include a determination of the advisability of improving interior drainage facilities.

4. Scope of field investigations.- Field investigations made in connection with this report included topographic and hydrographic surveys as necessary to supplement available topographic maps and aerial photographs. Earth borings were taken at selected locations. Economic surveys were made to determine the extent of development and potential damages from tidal flooding in the Port Arthur area. All elevations stated in this report are referred to mean sea level datum.

5. Other investigations.- Office studies included analysis of existing hydrographic data; analysis of the historical and potential effects of storms, including storm surge tides and wave heights; design of protective structures and estimates of construction costs; and estimates of benefits to be derived from such improvements.

6. The views of local interests regarding hurricane protection in the Port Arthur area were obtained at a public hearing in Port Arthur, Texas, on March 21, 1958 and at a number of conferences held subsequent to the hearing. The improvements desired by local interests are discussed in paragraphs 62 through 64.

PRIOR REPORTS

7. Hurricane protection reports.- There are no previous reports by the Corps of Engineers on the subject of hurricanes and hurricane protection in the Port Arthur area.

8. Navigation reports.- Numerous reports have been prepared and submitted on the Sabine-Neches Waterway navigation project, which serves the Port Arthur area. In general, however, those reports considered the navigation aspects of various requested improvements and are not pertinent to this investigation.

AREA CHARACTERISTICS

9. Location and extent.- Port Arthur is located in the extreme southeastern part of Texas on the west side of Sabine Lake, about 14 miles from the Gulf of Mexico. The Port Arthur area considered for protection in this report comprises about 38,500 acres and includes the cities of Port Arthur and Groves; the towns of Griffing Park, Pear Ridge and Lakeview; a number of outlying portions of Port Arthur, known as Port Acres, Rosemont and El Vista; and adjacent major industrial areas including large plants of the Gulf Oil Corp., Texaco Inc., the Atlantic Refining Co. and the Koppers Co. Plate 1 shows the location and extent of the area considered herein.

10. Physical description.- The Port Arthur area is located in a low coastal marsh region traversed by streams, canals and waterways. This coastal region is one of the three short reaches of the Texas coast, wherein the mainland extends to the Gulf of Mexico without separation by offshore barrier islands or peninsulas. The Sabine-Neches Canal, an artificial deep-draft navigation channel, along the west shore of Sabine Lake, is the east boundary of the area. The major drainage stream in the area is Taylors Bayou which enters the Sabine-Neches Waterway at the southern edge of Port Arthur. Tributary drainage is by Alligator Bayou and Rhodair Gully flowing southward into Taylors Bayou, and Crane Bayou flowing eastward into the navigation channel.

11. The city of Port Arthur and the town of Lakeview front on the Sabine-Neches Canal, a portion of the Sabine-Neches Waterway, which affords deepwater navigation to the ports of Port Arthur, Beaumont and Orange, Texas.

12. Streams and lakes.- Sabine Lake covers an area of about 64,000 acres. The lake is generally oval with a length of about 17 miles in a northeast to southwest direction and a maximum width of about 7.5 miles. Natural depths are about 5 to 7 feet over most of the lake and the maximum depth, except at the outlet to Sabine Pass, is about 8 feet. The bottom is generally soft mud, with occasional spots of hard bottom and shell reefs. Sabine Lake connects with the Gulf of Mexico through the natural outlet, Sabine Pass, which has been improved for deepwater navigation as a part of the Sabine-Neches Waterway. Two major rivers, the Neches and the Sabine, empty into the north end of Sabine Lake and several small streams enter the east side of the lake. Taylors Bayou formerly emptied into the west side of the lake below Port Arthur but now flows into the Sabine-Neches Waterway. Floods on the Sabine and Neches Rivers have only slight effect on the water levels in Sabine Lake.

13. Spoilbanks.- A spoilbank, varying in width from 800 to 3,500 feet, lies between the Sabine-Neches Waterway and Sabine Lake and extends about 18 miles from the mouth of the Neches River to Sabine Pass. The spoilbank has been formed by deposition of over 65,000,000 cubic yards of excavated materials from waterway construction and additional large quantities from maintenance dredging. The total area above mean sea level

is about 3,900 acres. The principal topographic feature is a series of mounds along the canal side, ranging in height from 10 to 30 feet above sea level, which were formed at the end of hydraulic dredge discharge lines by deposition of the heavier dredged materials. On the lake side, except in the bulkhead reach opposite the city of Port Arthur, the finer dredged spoils have formed a wide, flat, marshy foreshore which is generally low and subject to tidal flooding. Salt grasses and other vegetation retard erosion to some extent. However, the deposition of spoil from maintenance dredging on the spoilbank has been discontinued and some reaches of the spoilbank presently are eroding, both on the canal side and along the Sabine Lake side. However, the erosion rate is relatively slow and the higher exposed clay mounds along the canal side are above the area of wave action, except during abnormally high tides. Local interests have developed a considerable portion of the spoilbank in front of the city for recreational purposes and have constructed a highway extending southwestward along the spoilbank to its lower end. If the erosion of the spoilbank threatens these developments it is believed that control measures will be undertaken by local interests. Accordingly, it is believed that the spoilbank will endure throughout the life of the project.

14. A concrete and timber sheet pile bulkhead extends along the lake side of the spoilbank in the reach opposite the city of Port Arthur at an average distance of about 2,500 feet from the Sabine-Neches Canal. A section of the bulkhead, comprising 7,249 feet of concrete wall and 2,000 feet of treated timber wall, was authorized by the River and Harbor Act of August 30, 1935, and constructed in 1938, as part of the Sabine-Neches Waterway project. The top of the bulkhead is at elevation 4 feet above mean sea level. An additional 602 feet of concrete wall forms the outer end of the Port Arthur Pleasure Pier, which was constructed by private interests in 1912. The total length of the bulkhead, including a 100-foot entrance opening to a small boat basin, is 9,951 feet. The area behind the bulkhead has been filled almost completely with spoil material dredged from the waterway.

15. A number of recreational facilities, including an amusement park, swimming pool, golf course, and park area, and several Federal Government facilities, including the Corps of Engineers Resident Office and reserve training installations of the U. S. Army, Navy, and Marine Corps have been constructed on the spoilbank opposite the city. A bascule type vehicular bridge, owned by the city of Port Arthur, crosses the Sabine-Neches Canal to the Pleasure Pier area. An extension to the bridge, made necessary by widening of the canal, was constructed by the Federal Government in 1950. In 1958, Jefferson County and the State of Texas constructed a highway on the spoilbank, extending southwest from the Pleasure Pier area to Sabine Pass, thence east across a toll bridge into the state of Louisiana.

16. Topography.- The Port Arthur area considered in this investigation lies between the Neches River on the north and Taylors Bayou on the south and extends westward from Sabine Lake to Rhodair Gully, a tributary of Taylors Bayou. The land slopes southward from the higher ground of

15 to 20 feet elevation on the north to a large salt marsh area of 1 to 2 feet elevation in the south and east parts of the area. Two small industrial areas, totaling about 1,400 acres, which are located south of Taylors Bayou, are included in the investigated area. The area subject to flooding from storm tides lies below 11 feet above mean sea level and totals about 38,500 acres. Of this area subject to storm tide flooding, about 72 percent lies below 5 feet elevation and 52 percent is below 3 feet elevation. The entire industrial area and all of the populated sections of the area have been developed on ground with less than 5 feet elevation, except along a narrow, finger-like ridge, with elevations as high as 10 feet, which extends southward into the northeast portion of the area through the towns of Groves, Griffing Park and Pear Ridge.

17. The shortest approach from Port Arthur to the Gulf of Mexico is across the wide expanse of marsh land directly to the south, a distance of about 12 miles. Elevations throughout this reach generally are less than 2 feet above mean sea level, except for the natural beach ridge, of from 4 to 12 feet elevation, directly along the coast and dredging spoil mounds of 6 to 10 feet elevation along the Gulf Intracoastal Waterway south of Port Arthur.

18. Geology and soils.- Geological history of the region in which Port Arthur is located has been one of extensive marine and continental deposition on a fluctuating margin or shelf of the Gulf of Mexico. The upland portions of the area generally are outcrops of the Beaumont clay formations, the youngest of the Pleistocene sedimentary deposits. These deposits are from 25 to 400 feet thick. The surface soils in the lowlands surrounding Port Arthur are the recent clays that have been laid down over the Beaumont clays to depths of 5 to 25 feet. These clays generally are black, bluish or gray in color. The more extensive of these soils are designated as Lomalto clay, Lake Charles clay and marsh. In their natural undrained conditions, these soils are classed as wetlands and support heavy growths of water-loving grasses, reeds, and rushes usually found in brackish or fresh water marshes. Engineering aspects of the soils relative to the improvements considered in this report are discussed in appendix III.

19. Maps and charts.- Topography of the area is shown on U. S. Army Quadrangle Sheets, AMS Series V882, designated as Port Arthur North, Port Arthur South, Port Acres, Sabine Pass, and Texas Point. Hydrography of the area is shown on U. S. Coast and Geodetic Survey Coast Charts numbers 517, 533, 884, 1116 and 1279. Plates 1, 2 and 3 accompanying this report show the location and extent of the area considered herein.

20. Basic economy.- Port Arthur was founded in 1895 as the southern terminus of the Kansas City Southern Railroad. To connect the railroad with deepwater transportation, private interests dug a ship canal from Sabine Pass to Port Arthur, which was completed in 1899. The discovery of the first major oil field in Texas in 1901 near Beaumont led to establishment of a number of refineries and oil shipping terminals at Port Arthur. Since that time the basic economy of the area has developed around the processing and shipping of petroleum and petroleum products. The petroleum refineries in the Port Arthur area are among the largest in the nation and the three refineries located within the area considered in this report have total processing capacity of over 620,000 barrels of crude oil daily. In recent years, the manufacture of chemicals and chemical products has developed major importance. The shipping of petroleum, chemicals and other products through the port, the related shipbuilding industry, commercial seafood processing, and farming and ranching in the surrounding areas are also important segments of the economy.

21. Population.- Since World War II, the population of Port Arthur and adjacent communities has grown steadily as shown in the following table of population in the area since 1940.

TABLE 1

POPULATION

City or community	Population		
	1940	1950	1960
Port Arthur	46,140	57,530	66,676
Groves	900	1,300	17,304
Lakeview	852	3,091	3,849
Pear Ridge	1,198	2,029	3,470
Griffing Park	1,344	2,096	2,267
Totals	50,434	66,046	93,566

22. Industrial development.- The large petroleum refining, petrochemical, iron and steel fabricating, shipbuilding and marine repair and other related industries comprise the foundation for the growth and development of the Port Arthur area. Important industries within the area considered for protection in this report include major plants of the Gulf Oil Corp., Texaco, Inc., Koppers Co. and the Atlantic Refining Co., as well as numerous smaller industries and business concerns. The major oil refineries in the area alone employ about 13,000 people and have annual payrolls of over $85,000,000.

23. Residential areas.- There are five incorporated cities and towns in the immediate Port Arthur vicinity; Port Arthur, Groves, Lakeview, Pear Ridge and Griffing Park. In 1960 the total population of these cities and towns was 93,566 persons, occupying about 22,400 homes. The Port Acres, El Vista and Rosemont communities, with populations totaling about 6,500, located just west of Port Arthur were recently incorporated into the city limits of Port Arthur; however, for the purpose of this report will be considered as separate communities. Most residents of the Port Arthur area are employed either in the local industries or in one of the several petroleum refineries, petrochemical, synthetic rubber, asphalt and other plants located along the Neches River between Port Neches and Beaumont. Per-capita income in the area is relatively high and a large percent of the residences are single-unit dwellings occupied by the owners. Most of the residences are single story structures of frame construction. Many of the newer units are founded on concrete floor slabs raised only a few inches above ground level. The residential areas generally have paved streets and attractive, well-kept, buildings and lawns.

24. Transportation.- Port Arthur is served by the Kansas City Southern and Southern Pacific Railroads and by several excellent State and Federal Highways. Two bus lines and several common-carrier motor freight lines serve the area. Excellent water transportation is one of the chief economic advantages of the city. All of the major industries have shipping terminals located on the Sabine-Neches Waterway, which accommodates ocean-going vessels. The shallow-draft Gulf Intracoastal Waterway provides barge transportation facilities along the entire Gulf coast and connects with the Mississippi River inland waterway system at New Orleans, Louisiana. Three airlines, Eastern, Trans-Texas, and Delta, serve the area. A large network of common-carrier and private pipelines carry petroleum and natural gas to the refineries and industries in the area and petroleum products from the refineries to inland markets.

25. Utilities.- The Gulf States Utilities Co., through an extensive transmission line system, serves the area adequately with electric power. Ample supplies of industrial and municipal fresh water are taken from the Neches River above Beaumont and distributed throughout the Port Arthur area by a system of canals owned by the Lower Neches Valley Authority. An abundant supply of natural gas is distributed by the Southern Union Gas Co.

26. Water commerce.- The total commerce on the Sabine-Neches Waterway in 1960 was reported at 68,693,000 tons, of which 28,207,000 tons were credited to the port of Port Arthur. The total for Port Arthur comprised 24,485,000 tons of seagoing commerce and 3,722,000 tons moving over the Gulf Intracoastal Waterway in barges. Petroleum and petroleum products accounted for about 91 percent of the total commerce for Port Arthur. Other commodities that were moved in substantial quantities included grains, iron and steel products, seashells and chemicals.

27. Recreational facilities.- Most of the immediate area is occupied by industrial and residential developments and suitable space for development of recreational facilities is somewhat limited. Pleasure Island, the local designation for the spoilbank paralleling the Sabine-Neches Canal, has been developed for recreation to some extent. During the winter months there is excellent duck hunting in the marshes near the city. One of the more important recreational interests is fishing and boating. A number of small streams in the area are extensively fished. Sabine Lake provides a large and convenient water area for boating and fishing.

28. Growth trends.- Growth and development of the Port Arthur area has been steady and rapid over the last 60 years. The older portion of the city was developed in the south part of the area, adjacent to the main business district and the refineries of the Gulf Oil Corp. and Texaco, Inc. Over the years the direction of growth has extended generally north and northeast, within the limits of the existing storm levees. Development to the west and beyond the existing storm levees to the northeast has been shut off by low-lying marsh lands which are without protection from storm tides. The mid-county area to the north, including the cities of Nederland, Port Neches and Groves, has developed around industrial plants located along the Neches River. In recent years growth of the entire area has been accelerated by location of additional large industries in the mid-county area and rapid expansion of those near Port Arthur. The newer residential and business areas now occupy practically all available space within the existing storm levees and along the ridge of slightly higher natural ground which extends south from Groves into Griffing Park, Pear Ridge and the north edge of Port Arthur. The entire area embracing these cities and towns and the town of Lakeview is almost solidly developed, so that boundary lines between the cities are distinguishable only through marking signs along the streets. Recent expansion in the eastern and southwestern parts of Groves has pushed into low-lying lands having little or no protection from storm tides. Some of the more recent developments near Port Acres have been built on ground of less than 5 feet elevation. The developers have provided levees, which offer a low degree of protection from tidal flooding, and pumps to remove rainfall runoff from within the leveed areas. It is apparent that continued growth of the area at the current rate soon would result in development of all of the remaining ground to the northeast and force a more rapid expansion into the low-lying lands to the west and northwest of the city.

CLIMATOLOGY

29. Area weather characteristics.- Port Arthur is located in a relatively mild, humid region characterized by warm summers and moderate winters. The records of the United States Weather Bureau at Port Arthur indicate that the mean annual temperature is about 69 degrees. Prevailing winds are from the south and southeast except during the winter

months when northerly winds prevail. Plate 1 of this report shows a wind diagram based upon winds recorded at Port Arthur for the 27-year period 1917 to 1943, inclusive. The normal annual rainfall at Port Arthur is 55.2 inches. The maximum recorded 24-hour precipitation was 17.76 inches in July 1943. Additional data relative to weather characteristics of the Port Arthur area are given in appendix I.

30. Hurricanes - general.- The term "hurricane" is applied to tropical cyclones originating in the Atlantic Ocean, Gulf of Mexico or Caribbean Sea and producing wind speeds of 75 miles per hour or greater. Although records show that hurricanes may occur during any month of the year, the usual period of development is during the months of June to October, with the greatest number occurring during August, September and October.

31. Practically all hurricanes that affect the Texas coast originate either in the Atlantic east of the Lesser Antilles, the western Caribbean Sea or the Gulf of Mexico. The Atlantic and Caribbean storms usually move first in a westerly direction with a tendency to curve to the northwest and north after entering the Gulf of Mexico. The forward movement of the storm mass over water usually averages from 10 to 14 miles per hour, although the speed may increase rapidly as the storm approaches land. Storms that originate in the Gulf usually are less intense although faster moving than the Atlantic and Caribbean storms and their direction of movement tends to be more erratic. Practically all of the storms, upon reaching and crossing the coastline, curve to the north and east before dissipating over land.

32. Examination of various records indicate that at least 80 tropical cyclones struck the Texas coast during the 143 year period, 1818 to 1961. Although records of wind velocities and other meteorological data are not complete, it is believed that most of these storms were of hurricane intensity. Thousands of lives were lost, entire communities obliterated, and millions of dollars worth of property were destroyed during this period. The Texas shores and beaches were damaged extensively by the high tides and waves produced by these hurricanes. As shown by the computations in appendix I, the records indicate that the Texas coast has been affected by tropical cyclones or hurricanes at average frequency intervals of about once in 1.8 years and that hurricane winds and attendant high tides may be expected to occur at any point on the Texas coast with frequencies averaging about once in 9.3 years.

33. The paths of hurricanes that have crossed the Texas coast since 1900 are shown on exhibit 13 of appendix I. A tabulation of hurricanes crossing the Texas coast since 1900 and producing a tide of 9 feet or more at some point along the coast is given in the following table 2.

TABLE 2

SEVERE HURRICANE TIDES ALONG TEXAS COAST
(1900 THROUGH OCT 1961)

Date	Crossed Texas coastline at or near	Maximum tide ft. above M.S.L.	CPI (1) inches of Hg.
Sep 8, 1900	Galveston	14.5	27.64
Jul 21, 1909	Freeport	9.0	28.31
Aug 16, 1915	Freeport	13.5	28.01
Sep 14, 1919	Sarita	15.0	28.00
Sep 5, 1933	Port Isabel	11.0	28.02
Jul 25, 1934	Rockport	10.2	29.00≁
Sep 23, 1941	Freeport	9.5	28.98
Aug 30, 1942	Port O'Connor	13.8	28.07
Aug 27, 1945	Palacios	14.5	28.57
Oct 4, 1949	Freeport	11.5	28.88
Jun 27, 1957	Sabine Pass	9.2	27.95
Sep 11, 1961	Port O'Connor	12.3	27.50 (2)

(1) "Central pressure index" or the lowest barometric pressure at center of storm while traversing Gulf of Mexico.
(2) Preliminary report.

34. Hurricanes of record.- Port Arthur has been fortunate in that no severe storms have struck the area since its development as a city of major importance. Some of the early residents refer to severe storms causing high tides at Sabine Pass and in the Port Arthur area in 1872, 1886 and 1897. However, prior to 1900 the area was sparsely settled and records of tide heights or damages caused by these reported storms are not available. The area was affected by the 1900 hurricane which devastated Galveston, about 70 miles to the southwest. Tides of 8.0 feet at Sabine Pass and 4.5 feet at Port Arthur were reported but damages were small because of the sparse development. The 1915 hurricane, which crossed the coast near Freeport, about 83 miles to the southwest, caused extensive flooding and damages in Port Arthur. Tides of 11.2 feet at Sabine Pass and 7.3 feet at Port Arthur were reported. Practically all of Port Arthur was inundated, with water being several feet deep in houses and buildings. Six lives were lost and property damages were estimated at several million dollars. Photographs of the flooding at several locations within the city are included as exhibit 11 of appendix II.

35. On August 7, 1940, a small, fast-moving hurricane struck Port Arthur, causing extensive wind damages throughout the city. However, because of the small size of the storm, tides were raised only slightly and little or no water damage resulted. On June 26-27, 1957, hurricane "Audrey", moving northward across the Gulf of Mexico, crossed the coast

about 15 miles east of Port Arthur. The tide reached elevations of 9.2 feet at Sabine Pass and 4.8 feet at Port Arthur. Extensive wind damages and some minor flooding of low areas occurred at Port Arthur. This storm devastated Cameron, Louisiana, about 35 miles east of Port Arthur, with a loss of over 500 lives. Tides of 13 to 14 feet occurred along the coast east of Cameron for a distance of 15 to 20 miles. On September 11, 1961, the very large, slow-moving hurricane "Carla" crossed the coast at Port O'Connor, about 190 miles southwest of Port Arthur. The tide reached elevations of 8.8 feet at Sabine Pass and 7.2 feet at Port Arthur. Extensive flooding occurred in the lower parts of Groves, which are unprotected, and in Port Acres, which has a low degree of protection from small earth levees. About 700 homes were flooded, total damages from all sources being estimated at about $5,000,000.

36. Tidal range.- Sabine Lake is tidal throughout and the Sabine and Neches Rivers are tidal to points some distance above Orange and Beaumont, Texas. The ordinary tides are diurnal with mean ranges of about 2.2 feet at the Gulf entrance, 1.0 foot at Port Arthur, and 0.5 foot at Beaumont and Orange. Prolonged southerly winds raise the water surface in Sabine Lake and the waterway channels by several feet and prolonged north winds depress the water surface during the winter months. Water levels in Sabine Lake and the Sabine-Neches Canal at Port Arthur also are affected slightly by flood discharges from the Sabine and Neches Rivers, which may last over a period of 10 days to 2 weeks; however, the effect is small and would be of no particular significance in the Port Arthur area relative to hurricane tidal flooding.

37. Hurricane tides.- The tides caused by tropical cyclones along the Gulf coast are extremely variable, depending upon the size, intensity, and forward speed of the storm and the combination of topographic and hydrographic features of the reach of coast affected. As a storm approaches the coast it pushes and piles the water up against the shore causing abnormally high tides. The highest tides are created on the right of the storm path. Great storms moving slowly in a direction nearly normal to the coastline develop very high tides and storm waves. Storms of small diameter generally have a faster forward movement than large storms and usually produce lesser tides along the coast. Some of the most severe storms of record have caused tides of about 14.5 to 15 feet above mean sea level at various points along the Texas coast from Corpus Christi to Galveston.

38. Hurricane winds.- The effects of the forward movement of the storm mass and the counter-clockwise direction of rotation produces the greatest wind velocities at points to the right of the storm center, generally at distances of 10 to 20 miles from the eye. Away from the storm center, the winds decrease gradually to gales, then to squalls and at the outer limits to fresh and moderate breezes. The fastest mile wind velocities during storms affecting the Texas coastline has been estimated within the range of 90 to 110 miles per hour. Estimates of peak wind gust velocities for hurricanes crossing the Texas coast,

including the large storms of 1900, 1915, 1945 and 1949, have ranged from 120 to 135 miles per hour. Preliminary reports of peak gust velocities of the recent hurricane "Carla" range from an actual measurement of 112 miles per hour at Galveston to estimates as high as 150 miles per hour at several locations on or near Matagorda Bay.

39. Hurricane waves.- Extremely high hurricane waves are not developed along the Texas coast because of the flat slope of the Gulf bed from the shore to the outer limits of the wide, offshore continental shelf. No records of storm wave heights for the Sabine Pass area are available. For the Port Arthur area, the effects of hurricane waves would require consideration only for the waves developed in Sabine Lake, the Sabine-Neches Waterway in front of the city and across the low marsh areas south of Port Acres. Using criteria and wave forecasting relationships given in the Beach Erosion Board's Technical Report No. 4 and Technical Memorandum No. 84, it was determined that maximum waves of 12 feet and significant waves of 10 feet could be developed in Sabine Lake at the height of a design hurricane; however, these waves would be tripped and blocked by the spoilbank between Sabine Lake and the Sabine-Neches Waterway. The Port Arthur levees fronting the waterway would be subjected only to the waves propagated in the waterway, which were estimated to reach heights of about 2 feet. Since the spoilbank is the first line of defense against wave attack from Sabine Lake, its probable integrity for the life of the project was investigated. It was concluded that the spoilbank could be expected to remain effective as a wave barrier throughout the life of the project. In the marsh area south of Port Arthur and Port Acres, it was estimated that maximum waves about 7 feet high and significant waves of about 4.5 feet could be developed for a short period of time. Maximum wave crest elevations would range from 15 to 15.5 feet elevation.

40. Development of synthetic hurricanes.- Available data from hurricanes of record are not sufficient for proper evaluation of storm tide potentials pertinent to the design of hurricane protective works in a given locality. Because of the effects of varying land and underwater topography on the development of hurricane tides, it is obvious that a given hurricane, if transposed to another location, would not produce the same storm tide elevation. For example, the 1900 storm, which produced a 14.5 foot tide at Galveston, would have produced a higher tide at the shoreline near Sabine Pass, if transposed to a location and path critical to that area. This is caused principally by the effect of the shallow water depths over the continental shelf, which is wider in the Sabine Pass area than in the vicinity of Galveston. Response of the water level on the sloping shelf is related to the length of movement over the reach of shallow water. A longer movement over shallow water results in higher storm tides at the coastline.

41. To facilitate the hurricane investigations being made pursuant to Public Law 71, the United States Weather Bureau analyzed various characteristics of hurricanes which have affected the eastern and southern

coasts of the United States. The Gulf of Mexico coast was divided into three zones, each zone being about 400 miles long and extending from the generalized coastline to a parallel line 150 miles offshore. The Texas Gulf Coast area was designated as Zone C. The hurricanes passing through each zone during the period of record were analyzed for central pressure index (CPI), radius of maximum wind speed, and other pertinent characteristics which identify the magnitude of a storm. These characteristics are referred to as hurricane parameters. The results of the studies are presented in Weather Bureau memoranda HUR 2-4 and HUR 7-45. By using parameters included in these memoranda and techniques presented in Beach Erosion Board Technical Memorandum No. 83, hurricanes of various magnitudes and frequency were evaluated and the following synthetic hurricanes were analyzed for effects in the Port Arthur area.

42. Standard project and design hurricane.- To permit analyses of the effects of severe hurricanes having a reasonable probability of affecting localities along the Texas Gulf coast at specified average time intervals, the United States Weather Bureau developed various parameters of severe hurricanes which might be expected to occur in that portion of the Gulf of Mexico bordering the eastern Texas coast (Zone C). A selection of parameters, including that of a central (barometric) pressure index (CPI) has been combined to define a standard project hurricane for the Port Arthur locality. This hurricane would be the most severe hurricane that would have a reasonable probability of occurrence in the locality. The central pressure for such a hurricane would be 27.54 inches, the maximum sustained winds (over a 5-minute period) 14 miles from the eye of the hurricane were estimated at 100 miles an hour. This storm moved to its most critical position and path for Port Arthur is designated as the design hurricane and would be of lesser expected frequency. It is estimated that the design storm would produce a tide of about 14 feet above mean sea level at the coast in the Sabine Pass area, south of Port Arthur with an expected frequency of occurrence of once in about 160 years.

43. The magnitude of the standard project hurricane is greater than the maximum hurricane of record that has affected the Port Arthur area or, possibly, that has affected the Texas coast. Up to this time, parameters of the recent hurricane "Carla" have not been fully evaluated; however, preliminary indications are that this storm was of the general magnitude of the standard project hurricane and, in some respects, may have exceeded it slightly. A synthetic hurricane with more intensive parameters of central pressure, wind velocity, and radius could be developed that would result in computed tides higher than the standard project hurricane tide. However, the Weather Bureau has indicated that there is no known way to determine the probability of occurrence of such a hurricane, nor to determine the maximum possible hurricane. A combination of phenomena necessary to produce tides significantly greater than those of the standard project hurricane, while theoretically possible, is considered highly improbable. Further information relative to development of the design hurricane is given in appendix I.

44. Rainfall of record.- In order to correlate hurricane characteristics with excessive rainfall, the United States Weather Bureau analyzed the rainfall patterns and amounts produced by 78 storms which affected the Gulf of Mexico coastal region in the 55 year period extending through the 1955 hurricane season. The survey data were presented in a report entitled "Rainfall Associated with Hurricanes and Other Tropical Disturbances," Report No. 3, dated July 1956. According to this report, the greatest 24-hour rainfall in the United States from a tropical storm occurred in September 1921. That storm moved westward across the southwestern Gulf of Mexico and passed inland over Mexico, after which it turned northward and crossed the Rio Grande Valley into Texas. After passing inland, the storm rapidly dissipated and, by the time it reached Texas, could scarcely be identified as a cyclone except by torrential rains. Within 24 consecutive hours, 38.2 inches of rain fell at Thrall, Texas, located approximately 220 miles northwest of Port Arthur.

45. The maximum 24-hour rainfall recorded at Port Arthur was 17.76 inches which occurred during the hurricane of July 27-29, 1943. This storm was a small intense hurricane, first noted over the southeastern Gulf of Mexico on July 25, which moved west-northwestward and crossed the Texas coast a few miles east of Galveston about noon on July 27. The maximum recorded rainfall at Port Arthur over a 72-hour period was 19.58 inches which occurred in connection with the same hurricane.

46. Design rainfall for interior drainage.- The heaviest rainfalls of a hurricane often occur at a considerable distance from the eye of the storm and at localities some distance inland from the coast. Even along the coast, the maximum rainfalls do not occur, necessarily, at the locality of maximum tides. Hydrographs of typical storm surges from hurricanes show that the duration of peak tide elevations, is relatively short. However, tides remain sufficiently high to block gravity drainage for many hours during the passage of a storm. Accordingly, where adequate interior drainage of enclosed areas is dependent, either wholly or in part, upon gravity outflow, the problem must be considered under the assumption that all gravity drainage outlets would be blocked for a period of at least 24 hours. Analyses of tide records along the Texas coast show that tides will be sufficiently high to block gravity drainage from low-lying lands several times each year, although many of these tides are not accompanied by coincident rainfall. Studies indicate that a reasonable degree of protection from interior rainfall flooding can be provided with pumping capacity sufficient to remove runoff from the maximum rainfall that reasonably could be expected to occur coincident with an exterior tide sufficiently high to block gravity outflow with a frequency of once in 30 years. Analyses of rainfall and tide records for the Port Arthur area determined that this rainfall would be about 9.7 inches in a 24-hour period. A rainfall of this amount is estimated to have an expected frequency of once in 10 years under all conditions. During periods of normal or low tides, the pumps and the gravity outflow structures operating together would be adequate to handle runoff from a 24-hour rainfall of 16 inches, which has an expected frequency of once in 100 years, under all conditions.

EXTENT AND CHARACTER OF FLOODED AREA

47. Extent.- Port Arthur is located in the low coastal marsh region which borders the Gulf of Mexico along the Louisiana and upper Texas coasts. Generally a fringe of low sand ridges, ranging from 4 to 7 feet above sea level, parallels the coast just back of the beach line. These ridges are not uniform or continuous, however, and many washovers occur during storms. Behind the beach ridges, generally low marshy ground of less than 5 feet elevation extends inland up to 25 or 30 miles. Except for a few small natural mounds or domes and the minor barriers created by construction of highways, levees along water supply canals, and spoil deposits along excavated canals and waterways, there are few obstructions to flooding of the entire marsh region from a storm of major proportions. In the Port Arthur area, it is estimated that the storm surge generated by the standard project hurricane in its most critical path of approach would extend inland from the Gulf for distances of from 10 to 15 miles and would flood all areas below 11 feet mean sea level which are not protected. Flooding would extend into the low areas along the Sabine and Neches Rivers and would raise water levels upstream as far as Beaumont and Orange, Texas.

48. Character.- The area subject to flooding from hurricane tides, which is being considered for protection in this report, includes urban, industrial, and agricultural lands, as well as some low marsh land, which is without beneficial use at this time. The total of about 60 square miles within the area comprises about 32 percent developed urban land, 18 percent developed industrial land and about 50 percent agricultural and unused marsh land. Practically all of the industrial land and large portions of the other lands have elevations of less than 3 feet. The industrial and urban developments are very dense within the occupied areas. Existing protective structures, the spoil bank along the Sabine-Neches Waterway, and some small areas of filled land afford a degree of protection from storm flooding in the Port Arthur vicinity. The height of flood tides from a major storm probably would vary as much as 2 to 3 feet in different parts of the area, depending upon the position and direction of the storm path. However, a slight shift of the storm could produce the maximum flood levels in any part of the area. Since the tides generated by a standard project hurricane would overtop all existing protective structures, all of the area below 11 feet elevation considered for protection in this report is subject to inundation. The extent of the flooded area is shown on plate 2 of this report.

49. Property values.- The total value of all real property in the area considered for protection in this report was estimated at about 1 billion, 288 million dollars in November 1959. Detailed estimates of the property values in the area being considered for protection from flooding, are given by areas and by principal classes of property in tables 2 and 3 of appendix II and are summarized in the following table 3.

TABLE 3

VALUE OF PROPERTY IN THE PORT ARTHUR AREA
SUBJECT TO STORM TIDE FLOODING

Type of property	Total value all areas
Industrial	$708,830,000
Commercial	88,757,000
Utilities	16,270,000
Residential	379,651,000
Schools	24,290,000
Churches	15,942,000
Hospitals	3,371,000
Local Government	30,011,000
Federal Government	3,674,000
Unimproved land	17,593,000
Total	1,288,389,000

HURRICANE FLOOD DAMAGES

50. General.- The only major hurricanes that have caused severe flooding in the Port Arthur area since its development as a city of major importance were the 1915 hurricane and the 1961 hurricane "Carla." The 1915 storm crossed the coast about 83 miles southwest of Port Arthur and the city was flooded to a depth of several feet by a tide of 7.3 feet above mean sea level. Six lives were lost and property damages were estimated at several million dollars. However, since 1915, the existing storm levees were constructed around the older sections of Port Arthur. The 1961 storm crossed the coast about 190 miles southwest of Port Arthur and produced a tide of 7.2 feet in the Port Arthur area. No tidal flooding occurred within the area protected by the main protection levees. Extensive flooding occurred in the lower areas of Groves, which has no protection and in the Port Acres area which has a low degree of protection from small local levees. Photographs of flooded areas in 1915 and 1961 are shown on exhibits 11, 12, and 13 of appendix II. As discussed in appendix II, the area has grown greatly in size and wealth since the 1915 flooding and similar flooding in the same areas today would cause much greater damages. Severe flooding of the storage facilities of the adjacent refineries and chemical plants could release large quantities of gasoline and other highly flammable liquids, which, spread on the flood waters, would present a threat of holocaust if the materials were ignited.

51. Inundation of the Port Arthur area by tide waters during a hurricane would result in large scale property damages and, probably, a heavy loss of human lives. Further losses would be experienced through loss of business, production and wages, disrupted traffic and communications, costs of emergency operations, relief and rehabilitation measures, and costs of cleanup and reconstruction of the area following the storm. Complete recovery of the area probably would require a period of several years.

52. <u>Damages from occurrence of design hurricane flood</u>.- Available records of actual storm tides that have occurred in Port Arthur and vicinity are of little value in estimating damages that would result from storms that would overtax the existing protective levees. The maximum storm flooding of record within the inclosed area occurred prior to construction of the existing levee system. As shown in paragraph 49, the present value of property subject to flooding in the area is about 1 billion, 288 million dollars and growth in the area is continuing. Accordingly, the estimate of probable damages from the design hurricane was based on a survey of damages that would result from inundation under present conditions. The methods used are discussed in appendix II.

53. The tide accompanying a design hurricane would inundate the entire study area lying below the 11-foot contour. The damages that would be caused by such an occurrence under the present state of protection and development are estimated at about $226,000,000 for the areas which would be included in improvement plan A and about $228,000,000 for the areas included in plan B. The estimates include damages that would be caused by high water, wave action and scour, but do not include damages that would be caused directly by the force of the hurricane wind and rain. The estimate is based on values established by field appraisals, tax records, and statements of representatives of various business and industries in Port Arthur and vicinity. Prices of September 1961 were used in the estimates of damages. Details of the estimate are given in appendix II.

54. <u>Average annual damages</u>.- Under present conditions, damages begin in the low-lying unprotected areas from a tide of about 3 feet and increase rapidly as the tide height increases. Tides of about 5 feet would begin to flood some houses in the lowest unprotected areas of Groves and tides of about 4 feet would begin to overtop the existing low levees at Port Acres. A tide of about 7 feet would begin to overtop the existing protective levees in the older section of Port Arthur and start flooding in the interior. Storm tides of 10 to 12 feet would cause failure of the weakest existing levees. Once this had occurred, the entire protected area would be inundated. Estimates were made of the damages that would result from inundation by tides of various heights between a minimum of 2 feet and a maximum of 13 feet, under existing conditions of development. The estimates were based on the type, value, elevation and location of the structures subject to damage in each subarea. From these data and exhibits 10a thru 10g, from appendix I showing the relation of exterior tide stages to interior stages, tidal stage-damage curves were developed. Separate composite exterior tidal stage-damage curves were developed for all areas under each of the two plans of development discussed later in this report. A tidal stage-frequency curve was developed from records and studies of hurricane tides as shown in appendix I. Data from the composite stage-damage curves were combined with the stage-frequency curve to develop composite damage-frequency curves

for each plan shown on exhibits 4 and 6 of appendix II, and the average annual damages were computed therefrom. The two stage-damage curves and the stage-frequency curve are also shown in appendix II as exhibits 3, 5 and 7. The estimated damages are primary damages which would occur under the present state of development with the existing storm protective works. The total average annual damages for the various subareas investigated in the vicinity of Port Arthur are estimated at $4,700,000 for the areas included under improvement plan A and at $4,825,000 for those included under improvement plan B.

EXISTING FEDERAL CORPS OF ENGINEERS' PROJECT

55. Hurricane protection projects.- There are no existing Federal projects for hurricane protection in the Port Arthur area.

56. Navigation improvements.- The existing Federal project for the Sabine-Neches Waterway, Texas, provides for deepwater navigation channels from the Gulf of Mexico to Port Arthur, Beaumont and Orange, Texas. The waterway extends from the natural 38-foot depth in the Gulf through a jettied entrance at Sabine Pass, thence 36 feet deep through Sabine Pass and the Port Arthur Canal to the turning basins south of Port Arthur, thence 36 feet deep through the Sabine-Neches Canal and the Neches River to Beaumont and 30 feet deep in the upper Sabine-Neches Canal and the Sabine River to Orange. Minimum channel widths are 400 feet to Port Arthur, 350 feet to Beaumont and 200 feet to Orange.

57. As described more fully in paragraphs 11 through 14, the city of Port Arthur and the town of Lakeview front on the Sabine-Neches Waterway, which is separated from Sabine Lake by a long, narrow spoilbank. The spoilbank was created by deposition of materials dredged from the waterway. The shallow-draft Gulf Intracoastal Waterway, which provides a channel, 12 feet deep and 125 feet wide, extending along the Gulf coast from Apalachee Bay, Florida to Brownsville, Texas, is coincident with the Sabine-Neches Waterway from a point near Orange, Texas, to a point just south of Port Arthur.

IMPROVEMENTS BY OTHER FEDERAL AND NON-FEDERAL AGENCIES

58. Projects by other Federal agencies.- There are no existing improvements constructed by other Federal agencies for protection against hurricane tides and waves in the Port Arthur area.

59. Non-Federal hurricane protection.- The local interests have constructed a system of earthen levees which afford a considerable degree of storm protection to the older parts of the developed area, including portions of the cities of Port Arthur and Groves, the towns of Lakeview, Griffing Park and Pear Ridge and the industrial plants of the Gulf Oil

Corp. and Texaco, Inc. The existing local levees generally have a crest elevation of about 9 feet and a total outer periphery length of about 29 miles. In addition there are about 3 miles of interior levees along common boundaries of the city of Port Arthur and the Gulf and Texaco refineries. The city of Port Arthur constructed 4.9 miles of concrete and steel sheet pile seawall along the Sabine-Neches Canal to protect the earthen levees and waterfront property from wave wash and erosion along the canal. Erosion along the channel side of the wall and deterioration of tie rods have contributed to numerous failures of sections of the wall during recent years. The entire wall appears to be approaching the end of its useful life. A description and typical sections of the levees and seawall are given in appendix III. In the Port Acres area, two small levees were constructed in 1947-48 to about 7 feet elevation. One of these levees, about 2½ miles long, is located along Taylors Bayou. The other, about 2 miles long, extends along Rhodair Gully.

60. The city of Port Arthur reports the cost of its existing storm protective system at about $1,000,000 at the time of construction in 1932-33. Approximately $500,000 additional has been spent in repairs to the seawall along the Sabine-Neches Canal. The costs of the storm protective systems of the Gulf Oil Corp. and Texaco, Inc. and the Port Acres levees are not known.

61. Existing interior drainage.- Within the existing main storm protection inclosure, a number of small, localized areas fronting the Sabine-Neches Canal are drained by gravity flow into pipe conduits extending through the seawall. Drainage through these pipes is blocked by tides only slightly above normal. Interior drainage from the remainder of the main inclosed area is removed by pumping through a series of pump stations located at various points along the exterior levees. The city of Port Arthur operates nine of the existing pump stations, with a total capacity of 1,526,000 g.p.m. and Jefferson County Drainage District No. 7 operates one station with 590,000 g.p.m. capacity. Eight of the city operated stations discharge into the Sabine-Neches Canal. The remaining station operated by the city and the one operated by the drainage district discharge into the Alligator Bayou watershed west of the city. All of the underground drainage system within the main leveed area is designed for gravity flow into deep sumps at the various pumping stations. The Gulf Oil Corp. and Texaco, Inc. refineries have seven principal pumping stations for interior drainage of their plants. Two of the stations discharge into the Sabine-Neches Canal and the remainder into Taylors and Alligator Bayous. In the Port Acres vicinity, the areas inclosed by the small local levees are drained by 4 small pumping stations, operated by the city of Port Arthur. Two of these stations discharge into Taylors Bayou, one into a drainage canal leading to Alligator Bayou and one into Rhodair Gully. Total pumping capacity of the 4 stations is 280,000 gallons per minute.

62. Public hearing.- A public hearing was held in Port Arthur, Texas, on March 21, 1958, to determine the character and extent of improvements desired by local interests for protection of the area from storm tides and to afford all interested parties an opportunity to express their views concerning the desired improvements. There were 77 persons present; including Federal, State, County and local officials; representatives of industries, businesses, and civic organizations; property owners; individuals; and other interested parties.

63. A brief requesting repair and strengthening of the existing concrete seawall and publicly owned earthen levees and extension of a suitable earth levee to protect the unprotected areas east of Port Arthur and Groves was submitted jointly at the hearing by the cities of Port Arthur and Groves, Texas. Letters endorsing the requests and offering to cooperate in the studies were submitted by the mayors of the towns of Lakeview and Pear Ridge. The requests also were supported in briefs and oral testimony by the Seawall Committee of the Port Arthur Chamber of Commerce; Beaumont Chamber of Commerce; Beaumont Navigation District; various county and local government officials; representatives of business organizations; and individuals. The Commissioner of Jefferson County Precinct No. 3 orally requested consideration of protection for a county highway, which extends from Port Arthur southward along the spoilbank to Sabine Pass. No opposition to hurricane protection improvements was expressed at the hearing. Subsequent to the public hearing numerous conferences were held with representatives of the city and officials of the adjacent industries concerning various aspects of the hurricane protection problem. As a result of the conferences, later requests were made to expand the study to consider adequacy of the existing protective systems around the oil refineries of the Gulf Oil Corp. and Texaco, Inc. Request was also made to include the city of Groves water treating plant within the area to be protected and to extend protection to the Koppers Co. petrochemical plant and the communities of Port Acres, El Vista and Rosemont, all located on low ground west of Port Arthur. This area subsequently has been incorporated into the city limits of Port Arthur.

64. Requested improvements.- The local interests now desire the Federal Government to provide hurricane protection improvements that would furnish adequate protection against flooding, erosion, and damage caused by hurricanes to the city of Port Arthur, including the communities of Port Acres, Rosemont, and El Vista; the city of Groves; the towns of Lakeview, Pear Ridge and Griffing Park; and the industrial plants of the Gulf Oil Corp., Texaco, Inc., Atlantic Refining Co., and Koppers Co. The specific improvements desired include the following:

a. Repair and strengthen as necessary the existing seawall along the Sabine-Neches Canal and the earthen levees which now enclose the protected parts of the area; and

b. Extend protection by suitable earthen levees to the unprotected parts of the area.

65. In support of the requested improvements, local sponsors state:

a. Port Arthur is located on low, flat terrain and the waters of the Gulf of Mexico pose an ever present threat of hurricane flooding, erosion and damage to the area;

b. A portion of the developed area and the main plants of the Gulf Oil Corp. and Texaco, Inc., are protected to some extent by existing earthen levees and concrete walls. The remainder of the developed area and large industrial plants of the Atlantic Refining Co. and Koppers Co. are without protection.

c. In addition to the threat of overtopping and breaching of the existing levees by major hurricane tides and waves, the city is particularly vulnerable because of the deteriorated seawall along the Sabine-Neches Canal. In many sections, the soil foundation for the wall has eroded so that the concrete pilings are unsupported. Without the protection of the concrete wall, the adjacent earthen levee soon would wash away.

d. The existing publicly owned earthen levee and concrete seawall were built by the city of Port Arthur in 1932-1933 at a cost of approximately $1,000,000. In recent years, about $500,000 have been spent on emergency repairs to failed sections of the concrete wall, with virtually no effect toward maintaining its overall structural integrity.

e. Seawall undermining has been caused by deepening of the Sabine-Neches Canal and by the increased size and speed of ships using the canal. When the wall was constructed, it was adequate for the purpose intended; however, since then the adjacent canal has been deepened from 30 feet to 34 feet in 1946 and to 36 feet in 1951.

f. The protected part of the area has been developed, mainly by the construction of residences, right up to the existing public earthen levee. Moving the levee further inland would not be practicable since the right-of-way costs would be prohibitive.

g. Since construction of the existing protective system in 1932-33, no major hurricane had affected the area to any great extent until the recent hurricane "Carla". However, with the evident inadequacy of existing protection, it is certain that severe hurricane flooding would result in a major disaster to the area with property damage of many millions of dollars and a probable large loss of human lives.

66. Responsible local agencies.- The initial request for hurricane protection improvements was made jointly at the public hearing by the cities of Port Arthur and Groves. Officials of these cities and of the town of Lakeview furnished statements indicating a willingness to furnish required local cooperation for the project. Subsequently, at the request of various local interests, the study was expanded to include industrial areas and a large additional area west of Port Arthur. At this time

there is no single local agency which has legal and financial responsibility throughout the entire area covered by the study. The following local government agencies have some degree of responsibility and legal capability in all or certain parts of the area: city of Port Arthur, city of Groves, town of Lakeview, town of Griffing Park, town of Pear Ridge, Jefferson County Commissioners Court, Jefferson County Drainage District No. 4, Jefferson County Drainage District No. 7, Beaumont Navigation District, and Jefferson County Water Control and Improvement District No. 5. Based on recent local political developments relative to incorporation and extension of city limits, there is some possibility that the city of Nederland also may be concerned.

67. The problem of furnishing local cooperation has been discussed at numerous conferences between representatives of the various local agencies. The consensus is that, at this time, there is no existing local agency with legal and financial capability to provide local cooperation for the overall project. Further, that the most feasible solution would be either to form a new district within the area concerned which would have the necessary authority and capability or to change the legal authority of one of the existing special purpose districts by broadening its powers sufficiently to serve the purpose. The existing districts are constituted under laws of the State of Texas and derive their authority from such laws. Either the creation of a new district or changing the authority of an existing district would require legislative action of the state.

68. The local interests recognize that certain problems would be involved in providing a single agency empowered to furnish local cooperation. They believe, however, that the problem can be worked out. In a recent election, the voters of Jefferson County Drainage Districts No.'s. 4 and 7 approved consolidation of the two drainage districts with a view toward providing local cooperation for the proposed hurricane protection proje[illegible] Local officials state that, in a special session of the State Legislature to be held in January 1962, the necessary changes in law will be sought to give the consolidated drainage district full legal and financial powers to furnish the local cooperation for the entire project. In the opinion of the district engineer, the required items of local cooperation would be furnished if a Federal hurricane protection project were authorized.

69. Hurricane protection problems.- Damages from hurricanes in the Port Arthur area would result chiefly from inundation from the high storm tides and the destructive forces of storm generated waves, flooding from accompanying torrential rains, and the destructive effects of high velocity storm winds.

70. Protection against hurricane winds is not feasible except through design and construction of buildings with sufficient strength to withstand the wind forces. The general application of this solution could be achieved by adequate building code standards. This measure would be a matter of concern to the local authorities. Protection against flooding by storm tides and waves and by rainfall can be provided. This report is concerned with solution of the problem of providing protection against storm tide and wave damages, and damages from interior rainfall flooding.

71. Protective measures considered.- Protective measures possible in the Port Arthur area would fall into three categories discussed below:

a. Hurricane warning and evacuation.- Hurricane warnings can be protective in that they permit early evacuation of areas threatened with flooding. This was well demonstrated by the mass evacuation of at least 250,000 people from the coastal region of Texas during the occurrence of the recent major hurricane "Carla." Less than 40 lives were lost in Texas from this storm. With the extensive flooding that occurred, there is no doubt that many times this number would have been lost except for the mass evacuation. Advance warning permits some reduction in damages by other emergency measures, such as removal of some types of property and shutting down industrial plants. Such warnings probably are the only feasible measures in sparsely populated areas. The warnings, to be effective, must be issued well in advance of the storm and must be reasonably accurate with respect to the localities affected, time of occurrence and probable magnitude of the storm tide inundation. The hurricane warning service of the U. S. Weather Bureau has the responsibility of issuing advance warning of hurricanes to the general public. The advisories generally are accurate and the Weather Bureau is constantly improving the service. During the occurrence of "Carla," the advisory and warning services functioned in an excellent manner. Evacuation measures were effective along the entire coast because the warnings were issued well in advance of the danger period and with sufficient emphasis to alert the general population to a situation of acute danger. Storm warnings are essential to minimizing loss of lives in any area, but warnings alone would be of little benefit in effecting an appreciable reduction in property damages in the Port Arthur area.

b. Zoning regulations.- A possible measure for prevention of storm damage would be the removal of all improvements from the area subject to storm tide inundation and prevention of any future development in the area. State and local governments, in some instances, have proposed adoption of zoning restrictions to prevent new construction in badly exposed areas. Such measures, however, where proposed for existing concentrations of homes, commercial establishments, and industries, tend to develop strong opposition because of high investment in property and prospective loss to property owners and municipalities. The responsibility for enacting legislation on zoning and building regulations lies with the state and local government agencies. Zoning restriction measures along undeveloped, low coastal areas appear to offer a feasible means of preventing damage from tidal flooding, but such measures alone would not solve the problem in a highly developed area such as Port Arthur and adjoining communities. Local authorities might well consider this type of protection for application to new construction and development of new areas.

c. Protective structures.- Although hurricane warnings, emergency protective measures, and more stringent zoning regulations and building codes might reduce the flood damage in the Port Arthur area, such measures alone would not eliminate the danger from disastrous tidal flooding. The most feasible means of protection would consist of structures which would physically reduce or prevent the inundation of properties by tidal flood waters entering the Port Arthur area at the time of a hurricane. From economic and engineering considerations, the most feasible protective structures for the Port Arthur area were found to be earth levees with suitably protected side slopes and floodwalls of sufficient elevation to prevent the entry of hurricane tides. The protective inclosures would be supplemented by pumping facilities as required to provide adequate interior drainage and prevent damages from flooding by runoff of rainfall within the protective levee system.

72. The problem of providing adequate protective structures in the Port Arthur area would involve, principally, raising and strengthening existing levees to afford a high degree of protection and constructing new levees to extend such protection to areas which are presently unprotected. Along the Sabine-Neches Canal, levees fronting the waterway require a protective seawall to prevent erosion from waves, currents, and vessel wash in the canal. Consideration must be given to adequate interior drainage of all areas inclosed by protective levees.

73. Plans considered.- The improvements requested by local interests, discussed in paragraph 64, would require generally (1) rehabilitating or replacing the existing seawall along the Sabine-Neches Canal, (2) raising and strengthening portions of the existing levees, (3) constructing new levees to encircle the areas northeast and west of Port Arthur, which are now without protection and (4) providing new drainage facilities or supplementing existing drainage facilities as necessary to insure adequate interior drainage of the protected areas.

74. The request made at the public hearing to provide protection to the county highway extending southward along the spoilbank from Port Arthur to Sabine Pass was carefully considered. The highway construction is of a type generally associated with secondary highways, consisting of a bitumen and gravel surface overlying a compacted earth and shell base. The overall length of the highway is about 9.5 miles. The highway follows generally the higher portions of the spoilbank, with elevations of the northerly four miles ranging from 12 to 20 feet and the southerly 5.5 miles ranging from 7 to 15 feet. Adequate protection of the highway would require extensive riprapping along both sides of the spoilbank as well as extensive grade raising of the lower 5.5 mile reach of the highway. There is little doubt that the costs of protection would exceed by many times the relatively cheap construction cost of the highway. The highway is not an important artery for vehicular access to the city. Accordingly, protection of the highway from hurricane damage is considered to be unjustified from an economic standpoint and is not considered further in this report.

75. General.- Two alternate plans, designated as plans A and B, were developed for consideration of hurricane protection improvements for Port Arthur and vicinity in accordance with the desires of local interests. The improvements proposed under either plan would protect the areas included from flooding effects of the design hurricane, which would be capable of producing a storm tide of 12 feet in the Port Arthur vicinity. The plans also provide for interior drainage facilities adequate to prevent damaging flooding from the drainage design rainfall. The design rainfall for pumping, in subareas where gravity drainage is feasible and adequate, is 9.7 inches in 24 hours when drainage outlets are blocked by high exterior tides. For areas requiring pumping during normal or ordinary tides, a design rainfall of 14.0 inches in 24 hours was selected for drainage analysis and design purposes. The improvements proposed under either plan would protect virtually all of the area that is developed at the present time. The principal difference in the two plans would be the protection of a large and practically undeveloped area of low-lying land in the Alligator Bayou vicinity, west of Port Arthur, under plan B, which would not be protected under plan A. Plan A would provide for four separate inclosures by levees in the area north of Taylors Bayou and two separate inclosures south of Taylors Bayou. The largest of the six inclosures would be the Port Arthur-Groves vicinity and the main plant facilities of the major industries. The five smaller inclosures, including two south of Taylors Bayou, would be for separated industrial facilities and the Port Acres-Rosemont-El Vista residential communities. The improvements proposed under plan A would not cross the principal drainage outlet for the entire area, which is through the Alligator Bayou watershed into Taylors Bayou. Plan B would provide for a large single inclosure by levees of the entire area north of Taylors Bayou and separate inclosures for the two small industrial facilities south of Taylors Bayou, as in plan A. The protective structures proposed under plan B would cross the Alligator Bayou drainage outlet.

76. The estimated costs of construction for each of the two plans were found to be approximately equal. Plan A has obvious disadvantages which are largely overcome in plan B. The compartmented inclosures of plan A would tend to isolate units of the general area and restrict future development to the inclosed segments, which are developed virtually to capacity at the present time. Plan B would protect the entire area north of Taylors Bayou by one integrated system and would permit development of a large amount of undeveloped land which is not suitable for development in the absence of storm protection. Local interests strongly favor plan B over plan A. Accordingly, because of its obvious advantages, plan B is presented in this report as the plan of improvement, with plan A being considered an alternate plan. The improvements proposed under plan A are described in appendix III and shown on plate 3.

77. The improvements proposed under plan B would provide for:

a. Reconstructing and raising 4.9 miles of existing concrete and steel sheetpile seawall along the Sabine-Neches Canal in front of the city of Port Arthur and the town of Lakeview.

b. Reconstructing and raising 1.7 miles of existing concrete and steel sheetpile floodwalls and constructing 0.3 mile of new concrete and steel sheetpile floodwalls, principally along Taylors Bayou south of the Gulf Oil Corp. refinery.

c. Enlarging and raising 10.3 miles of existing earth levees, including 3 miles extending from the seawall southward to Taylors Bayou, and 7.3 miles around portions of the two separated areas south of Taylors Bayou.

d. Constructing 18.7 miles of new earth levees, including 5.6 miles extending from Lakeview northeastward along the Sabine-Neches Canal and northwestward to the north side of Groves, 0.5 mile along Taylors Bayou south of the Gulf Oil Corp., 11.3 miles extending from the Gulf Oil Corp. westward along Taylors Bayou and northward around Port Acres to high ground near Rhodair Gully, and 1.3 miles around a portion of the Sabine Road tank farm area south of Taylors Bayou.

e. Constructing miscellaneous appurtenant structures, including 5 highway ramps, 37 road and street ramps, 20 gated closure structures at railroad and road crossings, structural modifications to 8 existing drainage pumping stations, 4 additional drainage pumping stations, and various gated gravity drainage outlet structures as required. The improvements proposed under plan B are described in detail in appendix III and are shown on plate 2.

78. The combined length of the protective walls and levees under plan B would be about 35.9 miles, including 29.0 miles of earth levees, 4.9 miles of concrete seawall and 2 miles of concrete and steel sheetpile floodwalls. These lengths do not include a reach of about 1.5 miles along the Sabine-Neches Canal in the Crane Bayou vicinity, where spoil deposits from waterway dredging have raised the ground elevations higher than 16 feet and a reach of concrete floodwall 490 feet long, along Taylors Bayou south of the Gulf Oil Corp., which does not require alteration. All of the concrete walls would have top elevations of 14 feet. Concrete mats would be placed along the Sabine-Neches Canal bottom adjacent to the seawall for erosion protection. Earth levees would have crown elevations of 16 feet along the southerly and eastward sides of the inclosed areas, while those along the northerly and westward sides would have crown elevations of 14 to 12 feet. Levee slopes along the southerly side would be riprapped for protection from wave action. The remainder of the levee slopes would have a sod covering. The tops of the levees would be paved with oyster shell and given a single bituminous surface treatment. A total of 396 acres of land would be required for rights-of-way and borrow areas for construction of the improvements proposed under plan B.

79. Interior drainage.- Control of interior drainage under plan B would be provided by construction of gated gravity drainage structures and pumping stations at four locations where existing gravity drainage outlets would be crossed by the proposed levees. At two of the locations near Port Acres the pumps would be added to supplement small existing pumping stations. The gravity drainage structures would serve during periods of normal and low tides and the pumping stations would serve, primarily, for removal of interior drainage from the protected area during periods of high tides. Gated gravity drainage structures and pumping stations would be provided at locations and with pumping capacities as follows:

Crane Bayou, northeast of Port Arthur, 680,000 g.p.m.;

Alligator Bayou, west of Gulf Oil Corp., 1,170,000 g.p.m.;

Snake Bayou, south of Port Acres, 290,000 g.p.m. additional; and

Rhodair Gully, west of Port Acres, 290,000 g.p.m. additional

80. In addition to runoff from the areas north and west of Port Arthur, the Alligator Bayou drainage system is the outlet for water removed from a considerable portion of the existing inclosed areas of Port Arthur, Pear Ridge, Griffing Park and southwest Groves. An extensive underground drainage system carries runoff from these urban areas to two existing pumping stations, which have total pumping capacity of 1,290,000 g.p.m. and are located adjacent to the levees along the west side of the area. The underground drainage system empties by gravity flow into deep sumps at the pumping stations. It would not be practicable to relocate or abandon the pumping stations because of complete disruption of the existing drainage system in the cities.

81. Along the Sabine-Neches Canal seawall, numerous culverts and drainage pipes extend through the seawall for gravity drainage of small localized areas adjacent to the seawall. Some of these outlets are gated. Under improvement plan B, these outlets would be combined or eliminated, insofar as practicable, to reduce the number of openings through the new seawall. All openings through the seawall necessary for this purpose would be provided with both flap gates and manually operated slide gates.

82. Reservation of ponding areas.- Within the existing main leveed area, inclosing the older part of Port Arthur and Lakeview, drainage is handled primarily by pumping. Existing pumping capacities generally are adequate, although during periods of intense rainfall, runoff rates sometimes exceed pumping rates and temporary ponding of excess runoff occurs in the streets and yards of the lowest parts of the area. The ponding areas generally are flat and shallow flooding of streets and yards occurs over areas of considerable size; however, only minor damages result. The existing pumps have sufficient capacity to remove runoff from the developed areas at a rate of approximately 0.6 inch per hour. While this is slightly deficient for the most intense period of the drainage

design rainfall, the ponding capacity available in the underground drainage system and streets would provide temporary storage for the excess so that no appreciable damages would result. No additional pumps are proposed for this area. Within the industrial areas, existing pumping capacities are adequate to limit flooding from interior drainage to non-damaging levels. Generally the industrial facilities are so constructed that temporary, shallow flooding causes little or no damage and no additional pumps are proposed for any of the industrial areas. The existing pumping capacities of the small pumping stations in the two small leveed areas at Port Acres are not adequate to remove runoff from the drainage design rainfall. Sufficient additional pumps would be added so that ponding would be limited to the streets and yards of the lowest parts of the areas.

83. The areas outside of the existing levees are drained by gravity flow through the main outlets of Crane Bayou and Alligator Bayou. Under existing conditions, rainfall runoff accumulates in the lowest part of each area when the outflow is blocked by high tides or when the runoff rates exceed the carrying capacities of the outlet channels. Generally, extensive development has not taken place in these areas below 6 feet elevation. However, in recent years, due to the increasing scarcity of undeveloped higher land, development has been extending into the lower elevation lands, particularly in the Crane Bayou vicinity. Additional land suitable for industrial and residential uses is essential to the continued growth and development of the Port Arthur vicinity.

84. An analysis of growth trends and development practices for the Port Arthur area indicated that the Crane Bayou area would be fully developed within about 42 years and that about one-half of the large Alligator Bayou area would be developed in 100 years. Development of these low areas would be made possible by construction of a series of inclosures with small levees offering a low degree of storm protection and small pumping units to handle interior drainage. This type of development is occurring in the area at this time and developers are providing this type of protection for the low lands. Based on the prospective full development of the Crane Bayou area, it was found that provision of pumps to limit ponding to the non-damaging levels described above would be justified and that no inviolate ponding area need be reserved for this area.

85. In the Alligator Bayou area, it was found that the need for additional land for growth and development would result in use of about one-half of the land between 6 feet elevation and 1.5 feet elevation within the next 100 years. As in the Crane Bayou area, this development would occur as local developers provided small levee inclosures and pumps offering a low degree of protection both from tidal and interior rainfall flooding. Under existing conditions of little or no development within the lower parts of this area, runoff from the drainage design rainfall would pond to about 3.6 feet elevation during periods in which gravity outflow is blocked by high tides. With future development and reduction

of the available storage area by the small leveed inclosures, the elevation of ponding in the remaining area would be increased and it is probable that some of the earlier developments then would be subject to frequent flooding. To afford adequate protection from rainfall runoff flooding to the future growth in this area, sufficient pumps would be provided to reduce the elevation of ponding from the drainage design rainfall during high tide periods to elevation 2.5 feet. No plans for development of this low area are known at this time; however, it is probable that industrial expansion into the area would occur at some future date if the area were available. This would present no problem since any industry moving into the area undoubtedly would incorporate adequate drainage plans and facilities into its construction. For this reason it is not considered desirable to restrict all development in the area permanently by the requirement of flowage easements on the ponding area. However, it is considered essential that encroachments in the ponding area be prevented unless pumping capacity equivalent to the reduction in ponding area storage capacity is installed. Responsibility for prevention of encroachment is included as an item of local cooperation in paragraph 99. The pumping capacities, shown in paragraph 79 above, were selected for the several drainage outlet areas.

86. Escape routes.- The Port Arthur area is served by a network of improved streets and highways. During any storm tide that would not overtop the existing levee system, vehicular traffic could move northward through Griffing Park, Pear Ridge and Groves to Port Neches and Nederland, although outside the leveed area many streets and roads would be impassable during the tides of 6 to 7 feet. State Highway 87 would be blocked toward the west by tides exceeding 4 feet and toward Orange by tides of 6 to 7 feet. All roads would be blocked by the design hurricane tide, although those leading north would be available as escape routes until inundated. However, orderly evacuation must be planned and executed well in advance of the storm, since the large population could not be removed safely over escape routes in a short period of time. During the warning period of the recent hurricane "Carla," practically the entire population of the area was evacuated within a period of about 12 hours with only minor mishaps.

87. Water resource development.- The proposed improvements for hurricane tide protection would have no effect on the use of water for hydroelectric development, industrial and domestic water supply, irrigation, abatement of stream pollution, fish and wildlife, recreation, or other related water resource uses.

88. Shoreline changes.- The proposed improvements would be located on land and would have no effect on the configuration of shorelines.

ESTIMATE OF FIRST COST

89. The total first costs of providing the hurricane flood protection improvements in the Port Arthur area, as described in this report, are estimated at $33,900,000 for plan A, and $33,400,000 for plan B. The unit prices of construction used in estimating the first costs of the proposed improvements are based on the experienced costs of similar work in this area during September 1961. The estimate of land costs required for construction is based on real estate appraisals made in July 1958 and October 1959, which were revaluated in September 1961. The estimated total first costs include the costs for construction, lands, rights-of-way and damages, contingencies, engineering, supervision, administration and overhead and the preauthorization study cost of $96,000, which has been expended for this investigation. The principal items of the estimated first costs are given in detail in tables 1 and 2 of appendix IV, and are summarized in the following table 4.

TABLE 4

ESTIMATED FIRST COSTS
HURRICANE FLOOD PROTECTION
AT
PORT ARTHUR AND VICINITY, TEXAS

Item	Total estimated first cost	
	Plan A	Plan B
Lands and damages	$ 900,000	$ 690,000
Levees and floodwalls	24,720,000	23,070,000
Pumping plants	3,240,000	4,680,000
Subtotals	28,860,000	28,440,000
Engineering and design	2,310,000	2,270,000
Supervision and administration	2,730,000	2,690,000
Subtotals, estimated construction cost to be apportioned	33,900,000	33,400,000
Preauthorization studies	96,000	96,000
Total estimated first cost	$33,996,000	$33,496,000

ESTIMATES OF ANNUAL CHARGES

90. The principal items of Federal and non-Federal investment and annual charges, including the interest and amortization costs and annual maintenance and operation costs, are given in detail in appendix IV. The estimated total annual charges for the improvements considered in this

report are summarized in table 5. The division of costs between Federal and non-Federal public interests is based on the apportionment of costs set forth in paragraphs 102 and 103.

TABLE 5

ESTIMATED ANNUAL CHARGES
HURRICANE FLOOD PROTECTION
AT
PORT ARTHUR AND VICINITY, TEXAS

Item	Estimated annual charges	
	Plan A	Plan B
Federal annual charges		
Corps of Engineers:		
Interest and amortization	$ 720,000	$ 710,000
Maintenance and operation	0	0
Total Corps of Engineers	720,000	710,000
Non-Federal public annual charges		
Interest and amortization	346,000	340,000
Maintenance and operation	74,000	100,000
Total non-Federal public	420,000	440,000
Total estimated annual charges	$1,140,000	$1,150,000

91. The estimated annual maintenance and operation costs include the cost of maintaining the seawall, floodwalls and earth levees, maintaining and operating the gated drainage outlet structures and pumping plants, and cleaning the drainage ditches adjacent to the levees. The normal maintenance costs would be below the average except in years of major hurricanes at which time the maintenance costs would be above the average. All maintenance and operation costs of the improvements would be the responsibility of the local interests and have been apportioned accordingly.

ESTIMATES OF BENEFITS

92. Benefits.- The benefits that would be derived from the proposed hurricane flood protection to Port Arthur and vicinity would consist of the storm tide and wave damages that would be prevented by the proposed improvements, enhancement of land values from a higher order of land use, and certain secondary benefits that have not been evaluated. These secondary benefits would include reduction of time and costs required for normal recovery from damages caused by hurricane tides; however, such costs are not readily separable from similar costs attributable to hurricane winds and have not been credited to improvements considered in this report. In addition to the evaluated benefits, certain intangible benefits would be realized in prevention of loss of lives, prevention of disease, reduction in fire hazards, and improvement in the general welfare of inhabitants.

93. Prevention of damages.- As discussed in paragraph 54, the total average annual damages from hurricane tides, under existing conditions of protection and development in the vicinity of Port Arthur are estimated at $4,700,000 for the areas included in improvement plan A and $4,825,000 for those included in improvement plan B. These estimates include the primary damages to property from tidal flood inundation, wave action and scour. The proposed protective works would prevent all of the damages in the protected areas that would result from storms as large as the design hurricane and would materially reduce damages that would result from very infrequent larger storms. Rainfalls greater than the drainage design storm would produce some damages within the areas inclosed by levees from impoundment of interior drainage during coincident periods of high exterior tides. The amounts of these damages would depend largely on the intensity of the rainstorm and the capacity of pumps provided for removing interior drainage. Such damages would occur at infrequent intervals and under existing conditions of development, would not be sufficiently large to warrant pumping capacities greater than required for the drainage design rainfall. Although there is a lack of suitable lands that would not be subject to storm tide inundation, growth and development in the Port Arthur vicinity will soon occupy all remaining vacant land within the existing protected area and the remaining small areas above 6 feet elevation outside of the protected area. A number of low areas have been developed recently in the Port Acres vicinity, with the developers providing small levees to inclose the area being developed and some pumps to remove accumulations of interior drainage. The degree of storm protection afforded by the local levees is low and a number of these areas were badly flooded during the recent hurricane "Carla." However, because of the shortage of suitable land, it is expected that this type of development will continue until large areas of the low, vacant lands are occupied. Estimates of this development have been made and of the damages that would be prevented to the future developments by the proposed improvements. These estimates were reduced to average annual equivalent benefits by compound interest methods and have been included in the estimated benefits.

As evaluated in appendix II, the total benefits from prevention of damages to existing properties and to future growth and development that would occur under existing conditions in the Port Arthur vicinity are estimated at $4,677,000 annually for the improvements proposed under plan A and $6,388,000 annually for the improvements proposed under plan B.

94. Increased utilization or enhancement benefits.- Extensive development has occurred throughout the Port Arthur vicinity in the portion inclosed by the existing storm protective system and, generally, on lands higher than 6 feet elevation outside of the protected area. Development is spreading into the areas below 6 feet elevation by provision of a low degree of storm protection as described above. However, estimates of probable future development under existing conditions show that a large area of low land in the Alligator Bayou vicinity west of Port Arthur would remain undeveloped within the economic period of analysis of the proposed storm tide protection project. The improvements proposed under plan B would make this land suitable for development and should effect an immediate increase in its value because of a permissive higher order of land use. As discussed in detail in appendix II, estimates have been made of the benefits to this area from higher order of land utilization or enhancement. These benefits, reduced to an annual basis, are estimated at $122,000 for plan B only.

95. Summary.- The total average annual benefits that would accrue from the hurricane protection improvements proposed in this report are estimated at $4,677,000 for plan A, all of which would be prevention of damages. The total average annual benefits from the improvements proposed in plan B are estimated at $6,510,000, of which $6,388,000 would be prevention of damages and $122,000 would be attributable to increased utilization of land. The benefits that would be credited to plans A and B are shown in the following table 6.

TABLE 6

ESTIMATED AVERAGE ANNUAL BENEFITS
FROM HURRICANE FLOOD PROTECTION IMPROVEMENTS
AT PORT ARTHUR AND VICINITY, TEXAS

Item	Estimated average annual benefits	
	Plan A	Plan B
Prevention of damages	$4,677,000	$6,388,000
Increased utilization of land	0	122,000
Totals	$4,677,000	$6,510,000

96. Project development.- In the studies of the problem of providing storm protection to the area in the vicinity of Port Arthur, consideration was given to other possible means of providing the desired degree of storm protection. In view of the extensive development throughout the area and the existing protective systems, including the main seawall and levee system of Port Arthur and the small local protective levees in the Port Acres vicinity, it is apparent that the most economical means of providing adequate protection would be to rebuild the existing seawall and raise, strengthen and extend the existing levees as necessary. Protection to a degree that would prevent extensive damage from tidal flooding during the occurrence of the design hurricane, with a tide 12 feet above mean sea level in the Port Arthur vicinity, and which would not be destroyed or breached by a hurricane of appreciably greater magnitude, is considered to be the economical limit to which storm protection should be provided. Extension of storm protection to the areas now without protection would require crossing two principal drainage outlets. Also, some water would accumulate in the inclosed areas from wave overtopping and washover during the infrequent storms approaching or exceeding the magnitude of the design hurricane. Removal of this water and the accompanying hurricane rainfall would require additional pumps in the Snake Bayou and Rhodair Gully areas of Port Acres and would require the installation of pumps in the Crane Bayou and Alligator Bayou drainage outlets, which are not crossed by levees at the present time. A determination was made, as described in appendix I, that a rainfall of 9.7 inches in 24 hours would occur coincident with tides sufficiently high to block gravity drainage with a frequency of once in about 30 years. Protection from damaging interior flooding resulting from the limited amounts of wave overtopping and washover and from a rainfall of this magnitude is considered to be a reasonable degree of protection. These conditions are met in the improvements proposed for storm protection at Port Arthur under both plans A and B.

97. Comparison of benefits and costs.- The estimated average annual benefits, the estimated average annual charges, and the ratio of benefits to charges for the improvements proposed in plans A and B are given in table 7.

TABLE 7

COMPARISON OF BENEFITS TO CHARGES
FOR HURRICANE FLOOD PROTECTION IMPROVEMENTS
AT PORT ARTHUR AND VICINITY, TEXAS

Item	Plan A	Plan B
Estimated annual benefits	$4,677,000	$6,510,000
Estimated annual charges	1,140,000	1,150,000
Excess benefits over charges	3,537,000	5,360,000
Ratio of benefits to charges	4.1	5.7

98. The areas that would be protected under plan A include six component parts or subareas, while plan B comprises only three component parts or subareas. Two of the separated components of both plans are industrial areas south of Taylors Bayou. The entire area north of Taylors Bayou would be within a single inclosure under plan B, while four separated inclosures would exist north of Taylors Bayou under plan A. The isolation of the various components under plan A would offer many problems of communications and providing emergency services during a severe hurricane. Each of the two plans has a very favorable ratio of benefits to charges; however, the larger excess of benefits over charges is found in plan B. Further, this plan would provide protection to large areas of low land which are badly needed for continued growth of the Port Arthur vicinity. Unless adequate storm protection is provided, it is expected that considerable areas of this land will be developed with a low degree of storm protection facilities being provided by individual developers and that extensive damages would occur during large storms. Accordingly, plan B is considered to be the more feasible plan and is selected as the plan to be recommended.

PROPOSED LOCAL COOPERATION

99. Proposed local cooperation.- The proposed items of local cooperation for a Federal project for hurricane flood protection at Port Arthur and vicinity, Texas, would be similar to those specified in the Flood Control Act of July 3, 1958, in authorizing three similar hurricane protection projects. The proposed items of local cooperation are that local interests will:

a. Provide without cost to the United States all lands, easements and rights-of-way, including borrow areas, and the relocation of buildings, pipelines and utilities necessary for construction of the project, when and as required, the fair value thereof to be credited to the required local share of the project first cost;

b. Hold and save the United States free from damages due to the construction works;

c. Maintain and operate the improvements after completion of the project in accordance with regulations prescribed by the Secretary of the Army;

d. Provide assurance that no encroachment that would reduce the storage capacity of a ponding area would be permitted unless pumping capacity equivalent to the reduction in storage capacity is provided promptly without cost to the United States; and

e. Contribute 30 percent of the total first cost of the project less the fair value of lands, easements, rights-of-way and relocations, as set forth in "a" above.

100. All lands, easements and rights-of-way, including necessary relocations of buildings, pipelines and utilities, will be provided by the local interests without cost to the United States and the fair value thereof will be credited toward the local contribution. As discussed in paragraphs 66 through 68, at this time there is no single local agency which has legal and financial capability to provide local cooperation requirements throughout the entire area encompassed by the proposed improvements. However, voters of Jefferson County Drainage Districts No's. 4 and 7 have recently approved consolidation of the two districts with a view toward providing local cooperation for the proposed hurricane protection project. The necessary changes in state laws to give the consolidated district full legal and financial powers to furnish the local cooperation will be sought in a special session of the Texas legislature to be held in January 1962. It is believed that the required items of local cooperation would be furnished if a Federal hurricane flood protection project were authorized.

APPORTIONMENT OF COSTS AMONG INTERESTS

101. The apportionment of first costs of the proposed improvements is based on policy established in Section 203 of the 1958 Flood Control Act, Public Law 85-500, 85th Congress S. 3910, approved July 3, 1958, which authorized three similar hurricane flood protection projects. In accordance with this policy the apportionment of costs between local interests and the Federal Government would be made as follows: (1) the total first cost of hurricane flood protection improvements, including lands, easements, and rights-of-way, but excluding the cost of preauthorization surveys, will be apportioned at 30 percent to non-Federal interests and 70 percent to the Federal Government. The Federal share of first cost of the proposed hurricane flood protection improvements would be allocated to the Corps of Engineers. Lands, easements and rights-of-way will be provided by non-Federal interests without cost to the United States, and the fair value thereof will be credited toward the local contribution; (2) maintenance, operation, and replacement costs will be the responsibility of non-Federal interests.

102. The total first cost for plan B does not include the costs for additional pumping capacities that would be required of local interests to prevent encroachment on proposed ponding areas. Therefore, the costs for additional pumping to prevent encroachment are not items to be apportioned.

103. The proposed apportionment of the estimated first costs and annual maintenance costs of the proposed plans of improvement for hurricane flood protection under plan B in the Port Arthur vicinity is shown in the following table 8. Preauthorization study costs are not included in the costs that are apportioned.

TABLE 8

APPORTIONMENT OF ESTIMATED FIRST COST
AND ANNUAL MAINTENANCE COST
FOR HURRICANE FLOOD PROTECTION AT
PORT ARTHUR AND VICINITY, TEXAS

PLAN B

Item	Federal	Non-Federal	Total
First Cost			
Construction	$23,380,000	$ 9,330,000	$32,710,000
Lands, damages and relocations	-	690,000	690,000
Total first cost	23,380,000	10,020,000	33,400,000(1)
Preauthorization survey costs	96,000	-	96,000
Total cost	23,476,000	10,020,000	33,496,000
Annual cost of maintenance and operation	None	100,000	100,000

(1) Apportioned 70 percent to Federal and 30 percent to non-Federal interests.

COORDINATION WITH OTHER AGENCIES

104. Copies of the notice of public hearing held in Port Arthur, Texas, on March 21, 1958, were sent to all known local, State, and Federal agencies that might be interested in the hurricane investigations in the Port Arthur area.

105. During the progress of field investigations and studies, close coordination was maintained with officials of the local interest agencies listed in paragraph 63. Pertinent data for various phases of the investigation were obtained from the U. S. Weather Bureau, the U. S. Geological Survey, the U. S. Coast and Geodetic Survey, the Federal Housing Administration and various state and local government agencies. Consultations were held with local government and industrial officials during the planning of the improvements and preparation of the report to assure their agreement as to the suitability of the features in the plans.

106. Representatives of the U. S. Weather Bureau and the U. S. Navy attended the public hearing at Port Arthur, but made no comments with respect to the requested improvements. No letters or other expressions of interest were received from Federal or State agencies at the public hearing or during the progress of the investigations. The Southwestern

Regional Director, Bureau of Sport Fisheries and Wildlife, in a letter report dated July 14, 1960, which was coordinated with the Texas Game and Fish Commission, stated that the plan of improvement, as proposed, would cause insignificant losses to wildlife resources and would offer no opportunities for improvement of the fish and wildlife resources. The complete report of the Fish and Wildlife Service is included as exhibit 1 of appendix V.

DISCUSSION

107. The Port Arthur area considered in this report is located on the west side of Sabine Lake about 14 miles from the Gulf of Mexico. The area covers about 62 square miles and includes the cities of Port Arthur and Groves, the towns of Lakeview, Pear Ridge, and Griffing Park and several separated communities, including Port Acres, El Vista and Rosemont, which were recently incorporated into the city of Port Artnur. The population of the area totals about 94,000 persons. The area is highly industrialized in the petroleum refining and petro-chemical fields and has many business establishments and extensive residential areas. The Port Arthur area is exposed to hurricane tide surges approaching from the Gulf of Mexico through Sabine Lake, the Sabine-Neches Waterway and across the large low-lying marsh areas to the south. About 29 miles of levees have been constructed by local interests to enclose the older parts of the urban area and the industrial plants of the Gulf Oil Corp. and Texaco, Inc., located north of Taylors Bayou. The top elevation of the existing levee system generally is about 9 feet above mean sea level. The existing levees afford considerable protection to the enclosed areas; however, large areas have been developed on low ground outside of the existing protective system. About 4.5 miles of small levees, with top elevation of about 7 feet, have been constructed in the Port Acres vicinity. The hurricane investigations made in connection with this report revealed that the design hurricane would produce a storm surge of 11 to 12 feet above mean sea level throughout the Port Arthur area and would overtop all existing protective structures. It was estimated that the design hurricane would cause about $228,000,000 in property damages in the areas considered in this report under existing conditions of development and protection. It is evident that additional protection is needed to safeguard the area from future attacks.

108. Some reduction in hurricane tide damages could be effected by improved forecasting and warning services, the establishment of programs for evacuation of danger areas, enactment of zoning ordinances, and adoption of more stringent building codes for exposed areas. Improved warning facilities and plans for evacuation, although effective in reducing loss of life and damage to items which are readily movable, would not prevent the actual flooding and would be of relatively little value in preventing damage to fixed property. The costs incurred by relocation or grade raising would be prohibitive in the densely developed areas of Port Arthur, Lakeview, Groves, Pear Ridge, Port Acres, and El Vista, which are subject to tidal flooding. A system of sound protective structures, which would eliminate the threat of future flooding in developed areas, is considered to be the most feasible means of providing protection in the Port Arthur vicinity.

109. Two basic plans for protection of the area by levees and protective structures were considered. In plan A, consideration was given primarily to providing protection to the existing developed areas north and south of Taylors Bayou. Under this plan, six developed areas would be enclosed separately and only small amounts of undeveloped land would be protected. In plan B, the entire area north of Taylors Bayou would be

enclosed by a single, continuous levee and floodwall structure and a large amount of low-lying mostly undeveloped land, west and northwest of Port Arthur, would be afforded protection. The improvements proposed under both plans would provide for raising and strengthening portions of existing levees and floodwalls, reconstructing the existing seawall along the Sabine-Neches Canal in front of Port Arthur and Lakeview, and constructing new earth levees, floodwalls, pumping stations and appurtenant structures as necessary to provide adequate protection from exterior flooding by the design hurricane and from interior flooding by the drainage design rainfall during coincident periods of high exterior tides. Most of the exising levees which are incorporated into the proposed plans would be raised from 4 to 7 feet, reshaped, and protected from erosion and wave wash in various locations. The proposed levee and floodwall systems would afford full protection in the Port Arthur area from hurricane tides of 12 feet above mean sea level that has an indicated frequency of occurrence of once in about 160 years, and would reduce damages appreciably from the more severe storms that might produce higher tide elevations at extremely long occurrence intervals. Under plan B, storm protection would be afforded to large areas of low lands which, at present, have only a low degree of hurricane flood protection or none at all. Most of this land would be developed in the future with a low degree of protection being provided by local developers. The proposed improvements would prevent large damages to the future growth and development occurring on these lands. A comparatively small amount of low undeveloped land, which otherwise would not be occupied by future development, would be made suitable for development and would be enhanced in value through a permissive higher order of land utilization.

110. The area within the existing levee system around the older sections of Port Arthur and Lakeview is almost completely developed. Most of the rainfall runoff is pumped out of the area through seven large pump stations and several pumping installations located at various points along the levees. The existing pumping capacity is slightly deficient for the most intense period of runoff from the drainage design rainfall, however, ponding would be limited to streets and minor, shallow flooding of yards in the lowest areas, with no appreciable damages resulting. No additional pumps are proposed for the area within the existing main levee system for Port Arthur and Lakeview. In the Snake Bayou and Rhodair Gully vicinity of Port Acres, the existing pumping installations do not have sufficient capacity to remove runoff from the drainage design rainfall without temporary ponding to damaging levels. Additional pumps are proposed for these areas. In the Crane Bayou area, northeast of Port Arthur, and the Alligator Bayou area, west of Port Arthur, existing gravity drainage outlets would be crossed by the proposed levees. Sufficient gravity drainage outlet structures would be provided to permit outflow during normal and low tide periods without ponding to damaging levels. Sufficient pumps would be installed at each of these locations to remove runoff from the drainage design rainfall without ponding to damaging levels during the periods that gravity outflow was blocked by high exterior tides.

111. The total cost of the improvements proposed under plan A, including preauthorization studies, is estimated at $33,996,000 and the average annual charges are estimated at $1,140,000. The annual benefits to be derived from the improvements proposed under plan A are estimated at $4,677,000 and the

benefit-cost ratio is estimated at 4.1. The total cost of the improvements proposed under plan B, including preauthorization studies, is estimated at $33,496,000 and the average annual charges are estimated at $1,150,000. The annual benefits to be derived from the improvements proposed under plan B are estimated at $6,510,000 and the benefit-cost ratio at 5.7. Accordingly, both plans are well justified. The annual excess of benefits over costs is $5,360,000 for plan B and $3,537,000 for plan A.

112. The proposed improvements would have no adverse effects on pollution abatement or on fish or wildlife resources. There would be no effect on navigation or on the shorelines in the area.

113. The improvements proposed under plan B offer a larger excess of benefits over costs than those proposed under plan A, and numerous other advantages to the area would be found in plan B. The entire area north of Taylors Bayou would be protected by a single, integrated protective system under plan B, thus permitting a logical and orderly pattern of future growth and development. Under the separated enclosures proposed in plan A, future development would be restricted largely to the vicinity of existing developed areas, which have only limited amounts of suitable remaining space. The considerable amount of undeveloped land which would be protected under plan B, is essential to continuation of the rapid growth which the area has experienced in the past. During periods of high hurricane tides, the separate areas of plan A, would be isolated with no means of moving emergency vehicles or equipment between the various areas. Local interests strongly favor the improvements proposed in plan B. In view of the many advantages of plan B, it has been selected as the plan to be recommended in this report.

114. The costs of the improvements under plan B would be apportioned in accordance with the Federal policies established by the Congress in Section 203 of the Flood Control Act of July 3, 1958, which authorized three similar hurricane flood protection projects. Under these policies local interests would be required to pay 30 percent of the project first cost, excluding the cost of preauthorization studies. Local interests would acquire lands, easements, and rights-of-way and effect all relocations of buildings, pipelines, and utilities, and would be credited with the fair value of these items on their share of the project cost. The Federal Government would pay 70 percent of the total first cost for constructing the hurricane flood protection improvements and all of the preauthorization study costs. The annual cost of operation and maintenance of the improvements would be assigned to the local interests. Accordingly, the estimated first costs for construction of the improvements proposed under plan B of $33,400,000 is apportioned in the amounts of $23,380,000 to the Federal Government and $10,020,000 to the local interests. The preauthorization study cost of $96,000, which has been expended, is assigned to the United States. The estimated annual cost of operation and maintenance of $100,000 is apportioned to the local interests. The local interests would acquire all lands, easements, damages and relocations of buildings, pipelines, and utilities, estimated at this time at $690,000, and contribute the balance of the local share, estimated at this time at $9,330,000, toward the cost of construction of the project.

115. Additional information on recommended and alternative projects as called for by Senate Resolution 148, 85th Congress, adopted January 28, 1958, is contained in an attachment to this report.

CONCLUSIONS

116. Based on the findings in this report, it is concluded that:

a. The Port Arthur vicinity, including the cities of Port Arthur and Groves; the towns of Lakeview, Pear Ridge and Griffing Park; the separated communities of Port Acres, El Vista, and Rosemont, which were recently incorporated into the city of Port Arthur; and the adjacent large petroleum refining and petro-chemical industrial installations, are susceptible to heavy damages from flooding caused by hurricane surges that would overtop, breach and flank the existing levee protection system; and that these communities and industries face the continuing threat of even greater damages in the future.

b. Protection against tidal flooding can be attained most suitably through construction of the improvements proposed under plan B, as described in this report, which provides for reconstructing, raising and strengthening portions of the existing seawall, floodwalls and levees and extending new levees and floodwalls to protect areas that are now without protection. The proposed improvements would provide full protection against a hurricane tide of 12 feet above mean sea level. The plan also provides for gravity outlet drainage structures adequate to maintain suitable interior drainage in the new enclosed areas and new pumping stations with sufficient capacity to limit ponding of interior drainage to non-damaging levels during periods of coincident heavy rainfall and high exterior tides.

c. The improvements proposed under plan B have a total estimated cost of $33,496,000, including a cost of $96,000 which has been expended for preauthorization surveys and studies. This plan, which affords a high degree of protection to the area, is amply justified, having a benefit-cost ratio of 5.7. Realization of the plan would meet the urgent need for protection in the area.

d. Federal participation in the cost of plan B should be based on the present policy for apportionment of costs of hurricane protection projects, which would assign to local interests 30 percent of the total first cost of the project, including fair value of lands, easements, damages and relocation of buildings, pipelines and utilities. The total cost to the local interests is presently estimated at $10,020,000, of which $690,000 would be the fair value of lands, easements, damages and relocations and $9,330,000 would be construction cost. Seventy percent of the total first cost, presently estimated at $23,380,000 and the entire preauthorization survey and study cost of $96,000 would be apportioned to the United States. The annual maintenance and operation cost presently estimated at $100,000, would be assigned to the local interests.

e. The proposed improvements presented in this report are based on studies and investigations of survey scope. If the project is authorized for construction, more detailed studies will be necessary to determine the exact location and scope of the project features.

RECOMMENDATIONS

117. Accordingly it is recommended that a Federal project for hurricane flood protection to Port Arthur and vicinity, Texas, consisting principally of rehabilitating, enlarging, and extending the existing seawall, floodwalls and earthen levees and constructing new pumping stations, generally in accordance with the provisions of plan B of this report and with such modifications thereof as in the discretion of the Chief of Engineers may be advisable to afford protection from the standard project hurricane, be authorized at a total estimated first cost for construction of $33,400,000. The net first cost to the United States would be 70 percent of the first cost for construction, presently estimated at $23,380,000.

118. The foregoing recommendation shall be subject to the conditions that local interests agree to:

a. Provide without cost to the United States all lands, easements and rights-of-way, including borrow areas, and the relocation of buildings, pipelines and utilities necessary for the construction of the project when and as required, the fair value thereof to be credited to the required local share of the project first cost;

b. Hold and save the United States free from damages due to the construction works;

c. Maintain and operate all of the works after completion of the project in accordance with regulations prescribed by the Secretary of the Army;

d. Provide assurance that no encroachment that would reduce the storage capacity of a ponding area would be permitted, unless pumping capacity equivalent to the reduction in storage capacity is provided promptly at no cost to the United States; and

e. Contribute 30 percent of all project first costs, excepting the cost of preauthorization studies; the total local contribution being presently estimated at $10,020,000, including the credit to be allowed for the fair value of lands, easements, rights-of-way and relocations, as set forth in "a" above, presently estimated at $690,000.

JAMES S. MAXWELL
Lt. Colonel, CE
District Engineer

3 Incls.
1. Plates 1 thru 3
2. Appendixes I thru V
3. Attachment

SWDGW-4
SUBJECT: Interim Report on Hurricane Survey of Port Arthur and Vicinity, Texas

United States Army Engineer Division, Southwestern, Dallas, Texas, December 4, 1961

TO: Chief of Engineers, Department of the Army, Washington, D.C.

I concur in the conclusions and recommendations of the District Engineer.

ROBERT J. FLEMING, JR.
Major General, USA
Division Engineer

INTERIM REPORT
ON
HURRICANE SURVEY
OF
PORT ARTHUR AND VICINITY, TEXAS

APPENDIX I

HYDROLOGY AND HYDRAULICS

1. Introduction.- This appendix presents data to supplement the sections of the main report relating to the subjects of hydrology and hydraulics. It includes a summary of temperature and precipitation data to amplify the section of the report on climatology, and data on hurricane wind velocities, rainfall intensities and frequencies, evaporation data, and barometric pressures to augment report material on the history and frequency of hurricanes. Estimates of hurricane storm surges and analyses of wave heights, runup, and overtopping of protective structures are also included in this appendix.

2. Climate.- The city of Port Arthur, Texas, and contiguous area is in a humid region with warm summers and mild winters. The proximity of the area to the Gulf of Mexico, the prevalence of southerly winds, and the absence of marked relief result in high relative humidity and uniformity of climate. Freezing temperatures are infrequent and of short duration. Based on data from the U. S. Weather Bureau station at Port Arthur, the normal mean annual temperature is 68.8 degrees Fahrenheit. January, the coldest month, has a normal mean temperature of 52.9 degrees and August, the warmest month, has a normal mean temperature of 81.8 degrees. The maximum and minimum temperatures of record were 102 degrees and 11 degrees, respectively. Normal annual rainfall at Port Arthur is 55.2 inches. A maximum rainfall of 17.76 inches in 24 hours has been experienced.

3. The prevailing winds are from the south or southeast during all but the winter months when this flow is interrupted at times by anticyclonic conditions and attendant "northers". Climatological data relating to precipitation and winds are given in tables 1 and 2.

TABLE 1

PRECIPITATION AT PORT ARTHUR, TEXAS
(PERIOD OF RECORD 38 YEARS 1920-1957)

Month	Normal (1) monthly rainfall	Maximum monthly		Minimum monthly		Maximum in 24 hours	
	Inches	Inches	Year	Inches	Year	Inches	Year
Jan.	5.12	9.08	1944	0.17	1928	3.87	1920
Feb.	4.19	13.15	1952	0.36	1954	4.80	1949
Mar.	4.00	10.66	1934	0.06	1955	7.08	1945
Apr.	3.94	12.59	1945	0.86	1937	6.69	1932
May	4.40	20.87	1946	0.36	1927	7.41	1946
June	4.78	15.04	1942	0.23	1930	7.69	1946
July	6.80	24.25	1943	0.35	1924	17.76	1943
Aug.	5.14	12.86	1955	0.05	1952	7.52	1945
Sept.	4.88	15.37	1941	0.50	1953	6.88	1946
Oct.	2.93	16.03	1949	0.00	1952	8.18	1949
Nov.	3.56	12.87	1929	1.08	1942	6.56	1949
Dec.	5.47	12.47	1956	1.32	1954	5.41	1927
YEAR	55.21						
MEAN	4.60						

(1) Based on period 1921-1957 inclusive.

TABLE 2

WIND VELOCITY AT PORT ARTHUR, TEXAS
(WIND MOVEMENT IN MILES PER HOUR)
(PERIOD OF RECORD 38 YEARS 1920-1957)

Month	Mean hourly speed	Prevailing direction (1)	Fastest recorded mile (2)		
			Speed	Direction (1)	Year
January	10.9	N	59	SW	1946
February	11.4	S	45	SW	1954
March	12.2	S	54	SE	1946
April	12.1	S	56	SE	1940
May	10.8	S	53	SE	1938
June	9.7	S	72	NW	1957
July	8.5	S	54	SE	1943
August	8.3	S	82	NE	1940
September	8.9	NE	57	SE	1941
October	9.0	E	70	SE	1949
November	10.4	N	56	SW	1957
December	10.1	S	69	S	1953
YEAR	10.2	S			

(1) Direction from which wind is blowing.

(2) Prior to 1945 maximum velocity recorded.

4. Precipitation.- The maximum annual precipitation recorded at Port Arthur was 82.80 inches, which occurred in 1946, and the minimum annual precipitation at this station was 30.52 inches in 1924. Normal annual precipitation at Port Arthur is 55.21 inches, according to U. S. Weather Bureau records. The mean of the normal monthly rainfall at Port Arthur is 4.60 inches and the normal monthly distribution varies from a maximum of 6.80 inches in July to a minimum of 2.93 inches in October. The mean monthly distribution of rainfall and the percentage relationship of the mean of each month to the mean of all the months of the year at Port Arthur are shown in table 3. The percentage relationship varies from a minimum of 64 percent of the mean in October to a maximum of 148 percent of the mean in July.

TABLE 3

NORMAL MONTHLY DISTRIBUTION OF PRECIPITATION
PORT ARTHUR, TEXAS

Month	Precipitation in inches	Percent of mean
January	5.12	111
February	4.19	91
March	4.00	87
April	3.94	86
May	4.40	95
June	4.78	104
July	6.80	148
August	5.14	112
September	4.88	106
October	2.93	64
November	3.56	77
December	5.47	119
Average monthly	4.60	100

NOTE: Normal values are based on the period 1921 - 1957 adjusted to represent observation at the present standard location.

5. Rainfall intensities for short periods.- Rainfall intensities for short periods are available from the records of the first order Weather Bureau station at Port Arthur. Table 4 shows the maximum recorded precipitation at this station for selected periods of 1 through 72 hours.

TABLE 4

MAXIMUM PRECIPITATION FOR SHORT PERIODS
PORT ARTHUR, TEXAS

Selected period in hours	Precipitation in inches
1	3.97
2	5.45
3	8.14
6	10.72
12	12.67
24	17.76
72	19.58

6. Rainfall intensity - duration-frequency.- U. S. Department of Commerce, Weather Bureau Technical Paper No. 25 presents a set of rainfall intensity-duration curves for durations of 5 minutes to 24 hours, and frequencies of occurrence of 2, 5, 10, 25, 50, and 100 years for each of 203 U. S. Weather Bureau stations. The Port Arthur curves are based upon the period 1917 through 1951. These curves represent the most reliable analysis of rainfall intensity-duration-frequency data at Port Arthur available. Table 5 is based upon these curves, adjusted to transform values from annual series to partial duration series as provided on page 1 of Technical Paper No. 25.

TABLE 5

RAINFALL INTENSITY - DURATION - FREQUENCY
PORT ARTHUR, TEXAS

Frequency of occurrence in years	Rainfall in inches					
	1 hr.	2 hr.	3 hr.	6 hr.	12 hr.	24 hr.
2	2.60	3.28	3.73	4.21	4.88	5.70
5	2.91	3.95	4.53	5.62	6.74	7.98
10	3.34	4.55	5.41	6.93	7.88	9.70
25	3.80	5.20	6.30	7.80	9.60	11.75
50	4.30	5.80	6.90	8.40	10.80	13.68
100	4.75	6.50	7.80	9.60	12.00	15.36

(Note: Table 6 deleted)

7. Tropical cyclones.- Tropical cyclones that affect the Texas Gulf Coast are cyclonic disturbances that originate during the months of June through October in the eastern part of the Atlantic Ocean near and south of the Cape Verde Islands; in the western Caribbean Sea; and in the Gulf of Mexico. These storms are known as hurricanes or West Indian hurricanes.

8. From their origin, these storms generally move in a broad sweeping parabolic curve extending westward and northwestward, then curving northward and northeastward. Those that reach the Texas coast generally follow a west northwest course into and across the Gulf of Mexico to the coast and curve to the right after crossing the coast. They generally move inland on a course normal to the coastline. The direction followed by these storms is greatly affected by anticyclonic movements on the continent and the pattern of atmospheric pressures over the Gulf coast states. Some hurricanes have followed erratic paths, even to the extent of moving southwestward parallel to the Texas and Mexican coastlines before turning to the west and entering Mexico. The paths of tropical cyclones affecting the Texas coast during the period 1900 through 1961 are delineated on exhibit 11.

9. A tropical hurricane has two distinct movements, a progressive movement of the entire storm mass and a rotary movement within the storm mass. The progressive movements of storms that strike the Texas coast averages about 13 miles per hour, but have varied from about 4.5 miles per hour to about 23 miles per hour as they approached the coast. The rotary winds of a hurricane blow around and incline toward the center of the storm with sustained velocities up to and well over 100 miles per hour. The direction of rotation is counter-clockwise and the progressive movement of the storm mass is in the direction of declining isobars.

10. A fully developed hurricane consists of a well-defined area, more or less circular, throughout which the atmospheric pressure diminishes rapidly on all sides toward the center or point of lowest atmospheric pressure. Within the storm area the winds blow with great force, the velocity increasing toward the center, however the direction is not toward the center but around the center in a counter-clockwise direction. At the center is an area, usually 10 to 20 miles in diameter, throughout which relatively calm conditions prevail.

11. Tropical cyclones vary greatly in size and intensity, from storms of small extent accompanied by fresh winds having velocities of 19 to 24 miles per hour to great hurricanes up to 600 miles in diameter and winds exceeding 100 miles per hour. Winds of hurricane velocity (75 miles per hour or more) may be felt over a width of over 100 miles in storms of large size and severe intensity. Occasionally tropical cyclones of small diameter and severe intensity do great damage over a small area.

12. The tropical cyclone communicates its whirling movement to the water. If its progressive movement is slow the rotary winds act for a longer time upon the same water area and more vigorous currents are set up around the storm center. As the storm approaches the coast the currents thus created pile the water up against the shore causing extremely high water levels. When the storm is some distance from the coast the first effect is a slow rise of the water in the section toward which the storm is moving. The greatest response to the storm usually occurs to the right of its path or track as this is the side in which the winds are directed onshore by the counter-clockwise rotation. The height of the storm surge depends upon the size and intensity of the storm, its forward speed, and the underwater topography. Great storms moving slowly in a direction nearly normal to the coastline develop very high storm surges and storm waves at the coastline. Lesser storms of hurricane intensity with smaller diameters and faster progressive movement produce lesser storm surges at the coastline. Severe hurricanes of large diameter have produced surges as great as 14 to 15 feet above mean sea level along the upper Texas coast. Average hurricanes and intense storms of small diameter usually result in storm surges of 8 feet or less above mean sea level. Usually the rise of the sea is gradual as the storm approaches the coast, but sometimes it comes swiftly. The great Galveston storm of September 8, 1900, according to some reports, was accompanied by a sudden additional rise in the water of about 4 feet at the height of the storm.

13. The winds of a hurricane, while damaging in themselves, are not nearly so destructive in the low coastal areas as the high water, storm waves and currents, that accompany it. There is no way of preventing damage from winds alone except by constructing structures that are able to withstand them. The destruction caused by high water, storm waves and storm currents, can largely be prevented by the construction of seawalls and similar structures that afford protection from these forces.

14. Frequency of tropical cyclones.- According to United States Weather Bureau Memorandum HUR 2-4 there have been 50 tropical cyclones with central pressure indexes (principal intensity criterion) less than 29.00 inches, in the period 1900-1956, which have affected the Gulf of Mexico coast of the United States. Ten of these storms were relatively severe and created tides of 9 feet or greater at some point along the Texas coast. These severe hurricanes and two storms which have occurred subsequent to issuance of Weather Bureau Memorandum HUR 2-4 are listed in table 2 of the text to this report.

15. Storm tides.- The tides or surges caused by hurricanes as they approach and then cross the coast are extremely variable, depending upon the size and intensity of the storm, the relative position of the point on the coast with respect to the storm path, the rate at which the storm mass approaches the coast, shoreline configuration, land and underwater topography in the storm path, and the barometric pressure profile between the storm's center and the periphery of the storm. The astronomical tide, which is not affected by the storm, has its effect on the total rise in the water surface. The great storms of 1900 and 1915 crossed the coast southwest of Galveston and caused tides of 14.5 and 12.7 feet, respectively. The latter storm center made its landfall about 83 miles southwest of Sabine Pass on the Gulf opposite Port Arthur and produced tides in the Gulf at Sabine Pass of about 11 feet above mean sea level and at Port Arthur of 7.3 feet above mean sea level. Hurricane Audrey, which caused tremendous loss of life and millions of dollars in property damage in Cameron Parish, Louisiana on June 27, 1957, passed inland with its center about 25 miles east of Sabine Pass, Texas, and 15 miles west of Cameron, Louisiana. The tide at Cameron was about 12 feet while at Sabine Pass it was about 9.2 feet above mean sea level. The maximum was 13.9 at a point several miles east of Cameron. Hurricane Carla, which took about 32 lives and caused millions of dollars in property damage in the Texas Gulf Coast during September 8-13, 1961, moved inland over the Port O'Connor-Port Lavaca area in the afternoon of September 11, 1961. The tide in Pass Cavallo was 12.3 feet above mean sea level and high water reached elevations between 14 and 18 feet on the westerly shores of Lavaca Bay, a tributary bay of Matagorda Bay. The center of hurricane Carla crossed the coast about 190 miles southwest of Sabine Pass and produced a tide in the Gulf at Sabine Pass of 8.8 feet above mean sea level and a tide at Port Arthur of 7.2 feet above mean sea level. There are few records of storm tide heights at Port Arthur and Sabine Pass; however, records of storm tides at Galveston are available over a period of about 110 years. Available data are inadequate to correlate storm tide potentials at Port Arthur or Sabine Pass from Galveston records.

16. Tide tables of the United States Coast and Geodetic Survey show that diurnal range of the predicted normal tide at Sabine Pass Light

is 2.2 feet and that the mean range of predicted normal tides is 1.4 feet. High tides are about one-half the range above mean sea level.

17. Records of storm tides at Galveston that have exceeded 4 feet above mean sea level are available for the period beginning with 1847. A list of these tides is shown in table 7, which gives the dates that the centers of these storms crossed the coastline and the maximum height of the tide at Galveston in feet above mean sea level. It is believed that all instances of storm tides in excess of 5 feet and above are included in the list but the records of storm tides less than 5 feet above mean sea level are not complete for the years prior to 1900 and there may be some omissions of storm tides between 4 and 5 feet during that period. A storm tide frequency tabulation based on available data is given in table 8. This does not necessarily represent conditions at Sabine Pass Light and of a certainty does not represent conditions at Port Arthur. However, it is indicative of what may be expected in the Gulf of Mexico opposite Port Arthur, Texas.

TABLE 7

STORM TIDES AT GALVESTON, TEXAS

Date	Max. elev. of tide at Galveston MSL
September 8, 1900	14.5
August 16, 1915	12.7
September 11, 1961	8.8
September 16, 1875	8.2
September 16, 1854	8.2
1847	7.7
August 20, 1886	7.7
September 14, 1919	7.6
August 30, 1942	6.3
June 27, 1957	6.1
July 25, 1934	6.0
September 23, 1941	5.7
October 4, 1949	5.7
October 3, 1867	5.3
October 12, 1886	5.2
July 21, 1909	5.2
September 4, 1933	4.6
August 13, 1932	4.5

TABLE 8
FREQUENCY OF STORM TIDE ELEVATIONS
AT GALVESTON, TEXAS

Frequency in years	Storm tide elev. ft. MSL
10	5.7
20	7.3
25	8.0
50	10.4
75	12.1
100	13.5
150	15.1

18. <u>Hurricane characteristics</u>.- The central pressure is the principal intensity index of a hurricane and the radius to the region of maximum wind speed is an index of its size. The size and central pressure represent the best available parameters of hurricane classification. Weather Bureau memorandum HUR 2-4 presents data on hurricane frequency and correlates characteristics of hurricanes that occur in the Gulf of Mexico. Weather Bureau memorandum HUR 7-45 presents standard project hurricane parameters and isovels of storm wind patterns applicable to the Port Arthur area. Using parameters and methods outlined in the above memoranda; CPs, Rs, and maximum wind velocities were determined for storms having return periods of 200, 100, 50, 20, 10, 5, and 3-1/3 years. By the use of methods and charts in Beach Erosion Board Technical Memorandum No. 83 the water level response to the winds of these storms were estimated for the Gulf of Mexico opposite Port Arthur, Texas. Allowances were made for the rise in water level caused by the difference in pressure between normal pressure and pressure at the radius of maximum wind speed as determined from the above mentioned Weather Bureau memoranda. Exhibit 1 shows the resulting frequency curve for storm tides in the Gulf of Mexico opposite Port Arthur. All storm centers were assumed to cross the coast line on a path normal thereto and at a location such that Port Arthur would be in the region of maximum wind speed on the right side of the storm. Frequency is based upon the frequency of central pressure indexes given in U. S. Weather Bureau Memorandum HUR 2-4. The resulting frequency curve is probably too high especially with respect to the more frequent storm events. Therefore an adjusted curve was developed in the following manner:

a. A frequency curve, similar to the above curve was developed in the same manner for Galveston, Texas.

b. A frequency curve based on records of storm tides at Galveston for the period 1847-1957 was developed.

c. The curves developed in a and b above were plotted on log-log paper. These two curves were approximately 2 feet apart at the 100 events per 100 year end of the scale, approached each other at the 1 event per hundred year point on the scale, and ran together at the 0.3 events per 100 years point on the scale.

d. An adopted storm tide frequency curve was drawn midway between the synthetic and the record frequency curve.

e. The synthetic or computed curve for the Gulf of Mexico in the vicinity of Port Arthur was then adjusted downward by the ratio Galveston adopted curve/Galveston synthetic curve. The adopted or adjusted frequency curve for Port Arthur Gulf tides is shown on exhibit 1. Some of the more severe storms that have struck the Texas coast have been indicated on the frequency curve at the estimated tide elevations they would have produced if transposed to result in maximum water levels in the Port Arthur area.

19. <u>Standard project hurricane tide</u>.- The following computation shows the derivation of the estimated water level response in the Gulf opposite Port Arthur that would result from a standard project hurricane crossing the coast on a path normal thereto with its center southwest of Port Arthur a distance equal to the radius to the region of maximum wind speed. Hurricane parameters and characteristics used below are explained in detail in Weather Bureau memorandum HUR 2-4.

CPI = 27.54 from W.B. Memo HUR 2-4

R = 14 naut. mi. W.B. Memo HUR 2-4

T = 11 knots W.B. Memo HUR 2-4

P_n = 29.92 W.B. Memo HUR 2-4 Fig 13

V_x = 100 MPH HUR 7-45 (30 Ft. above water wind speed)

W_m = 100 x 0.92 = 92 MPH Onshore component

N_m = $KW^2_m S$ BEB Tech Memo No. 83

= $1.78 \times 10^{-3} W_m^2 S$ (Port Arthur Formula)

= $1.78 \times 10^{-3} \times 92^2 \times S$

= 15.0 S

$V/\bar{c}$ = $11 \times 1.15/37.5$ = 0.34

F/L = $100 \times 1.15/132$ = 0.87

From BEB Tech Memo No. 83 S = 0.80

$\therefore N_m$ = 15.0×0.80 = 12.0 Wind Set Up - Max.

Where:

CPI = Estimated barometric pressure of center of storm.

R = Radius to region of maximum wind speed.

T = Forward speed of storm mass

V_x = Maximum wind speed 30 feet above water

W_m = Maximum wind speed 30 feet above water adjusted for direction; onshore component

N_m = Maximum wind set up.

$V/\bar{c}$ = Shoreward velocity of storm divided by mean free wave speed across the continental shelf

F/L = Fetch length (length of wind region) divided by width of continental shelf along the storm's path

S = A response factor depending on $V/\bar{c}$ and F/L

20. Exhibit 2 shows the shelf profile and its characteristics which were used in computing water level responses in the Gulf opposite Port Arthur. Exhibit 3 shows the wind pattern for the standard project hurricane and exhibit 4 shows the pressure profile for this storm computed from the formula $\frac{P - P_o}{P_n - P_o} = e^{\frac{-R}{r}}$, in which P is the pressure at radius r; P_o is the pressure at the center of the storm; P_n is the pressure at the periphery of the storm; R is the radius at which the wind speed is theoretically at a maximum and e is the base of natural logarithms. This formula was obtained from Hydrometeorological Report No. 32.

21. Data for computing pressure profiles for tropical storms were furnished in Weather Bureau memorandums. Using the normal asymptotic pressure of 29.92 inches indicated in HUR 2-4 and the pressure at R = 14 nautical miles computed to be 28.44 inches an estimate of 1.7 feet was made for the rise in water level due to the barometric pressure differential. This gives an estimated wind and pressure tide (storm surge) of 13.7 feet above mean sea level in the Gulf opposite Port Arthur. If the peak storm surge came at high diurnal tide it would be increased about 1.1 feet. The mean range of tide at Sabine Pass is 1.4 feet. A total storm tide of 14 feet is considered a reasonable estimate since the effect of the predicted normal tide could be either plus or minus. Similar computations were made for other storms.

22. Severe hurricanes of record.- A chart showing the paths of tropical cyclones affecting the Texas coast during the period 1900 through 1961 is shown as exhibit 11. The parameters of some of the more severe hurricanes that have crossed the Texas coast were used to estimate storm surges in the Gulf opposite Port Arthur from similar storms, on paths normal to the coastline, crossing the coast with centers southwest of Port Arthur at distances equal to the radii to the region of maximum wind speed. Parameters were taken from "National Hurricane Research Project Report No. 5." Table 9 lists the results.

TABLE 9

ESTIMATED STORM TIDE HEIGHTS
IN GULF OPPOSITE PORT ARTHUR
FROM SEVERE HURRICANES OF RECORD TRANSPOSED

Storm	Storm surge(1)
September 8, 1900 near Galveston, Texas	13.6
August 16, 1915 near Galveston, Texas	13.2
August 18, 1916 near Sarita, Texas	12.1
September 5, 1933 near Port Isabel, Texas	11.7
October 4, 1949 near Freeport, Texas	10.2
June 27, 1957 near Cameron, Louisiana	13.9

(1) With path normal to coastline southwest of Port Arthur a distance equal to radius of maximum wind.

23. Topographic and hydrographic features of the approaches over which storm tide surges from the Gulf of Mexico move to Port Arthur.- Between Sabine Lake and the Gulf of Mexico is a low marshy land area with elevations of about two or three feet. There are scattered ridges with elevations of 4 to 7 feet above mean sea level. Along the Sabine-Neches Waterway, between the waterway and Sabine Lake, dredge spoil has been deposited. Elevations along this spoil bank range from 5 feet to 30 feet above mean sea level, most of the spoil bank being between 10 and 15 feet above mean sea level. The spoil bank affords substantial protection against wave attack by storm waters in Sabine Lake against the Port Arthur levees that would accompany hurricane winds.

24. Design hurricane tide.- Paragraph 22 and exhibit 1 of this report indicate that a storm tide surge of 14 feet above mean sea level can be expected to occur with a frequency of once in about 160 years in the vicinity of Sabine Pass. A storm surge of this magnitude has been adopted for the purpose of designing protective works for Port Arthur. Exhibit 5 shows the estimated design or standard project hurricane tide hydrograph near the coast opposite Port Arthur. The relative times of water level elevations at the gulf shore were established in accordance with principles presented in Beach Erosion Board Technical Memorandum No. 83.

25. Water levels at Port Arthur.- The straight line distance from Port Arthur to the shore line of the Gulf of Mexico, on a line normal to the coast is about 12 miles. It is only slightly greater through Sabine Pass and the Sabine-Neches Waterway. That there would be a time lag between Sabine Pass ordinary high tides and minor storm surges and high tides at Port Arthur seems evident. Further, it also seems evident that the tide height at Port Arthur would be lower than its height at Sabine Pass. This is particularly true in cases where the high tide in the Gulf of Mexico is insufficient to submerge the land area between the Gulf and the lake, in which case water entering the lake would be limited to stream inflow plus such flow as moved through Sabine Pass and up the Sabine-Neches Waterway.

26. Records upon which to base a correlation between high storm tides at Sabine Pass and Port Arthur are statistically inadequate. Nevertheless an analysis was made of the available records. Table 10 lists the storms, the points where their centers crossed the coastline, and the peak tides at Sabine Pass and at Port Arthur. The time lags between the peaks at Sabine Pass and Port Arthur were quite scattered and were not included in this tabulation.

TABLE 10

SABINE PASS TIDE HEIGHTS
VS.
PORT ARTHUR TIDE HEIGHTS

Date	Crossed at or near	Peak (1) Port Arthur	Peak (1) Sabine Pass	Remarks
8/14/38	Port Arthur, Texas	2.4	3.3	
8/7/40	Port Arthur, Texas	2.2	3.4	
8/21/42	Gilchrist, Texas	3.6	5.1	(2)
8/30/42	Port O'Connor, Texas	1.3	1.4	
8/28/45	Palacios, Texas	2.7	3.1	
10/4/49	Freeport, Texas	4.7	5.9	(2)
8/16/15	Freeport, Texas	7.3	11.2	(2)
9/8/00	Galveston, Texas	4.5	8.0	(2)
7/21/09	Freeport, Texas	3.0	6.0	(2)
6/27/57	Sabine, Texas & Cameron, Louisiana	4.8	9.2	(2) (3)
9/11/61	Port O'Connor, Texas	7.2	8.8	(2) (4)

(1) In feet above mean sea level.

(2) Marsh in front of Port Arthur well submerged.

(3) Hurricane Audrey.

(4) Hurricane Carla.

The peaks shown in the above table are plotted on exhibit 6.

27. Hurricane Audrey, which crossed the Louisiana coast on June 27, 1957, about 13 miles east of Sabine, resulted in a maximum storm surge east of Cameron, Louisiana, of about 13.9 feet above mean sea level. At Sabine, Texas, the maximum surge was 9.2 and at Port Arthur it was about 4.8. A difference of about four feet between Sabine and Port Arthur (about the same difference as in the 1915 storm) is indicated. However, hurricane Audrey passed inland east of Sabine and Port Arthur and winds up to 60 miles per hour out of the north were blowing seaward across Sabine Lake. This condition undoubtedly resisted the storm surge as it entered Sabine Lake. It is estimated that had the center of Hurricane Audrey passed inland normal to the coastline 19 nautical miles southwest of Sabine a storm surge of 13.9 above mean sea level at the coastline opposite Port Arthur would have resulted. See table 9. According to Weather Bureau Memorandum HUR 7-51, onshore winds of about 82 miles per hour average at 30 feet above water would have been blowing across Sabine Lake. It seems probable that the storm surge at Port Arthur would have more closely approximated the surge in the Gulf at Sabine. Certainly no difference of 4 feet would have existed. During hurricane Carla the difference of tides at Sabine Pass and Port Arthur was 1.6 feet. Although hurricane Carla had a barometric pressure at the center approximately equal to that of the standard project hurricane, it must be noted that a standard project hurricane would not have affected as wide a region with maximum wind speeds and would have had a greater rate of forward travel. The wide area influenced by Carla and the slow rate of forward travel contributed much to the long duration of the hurricane surge which accompanied this storm. This long duration of the surge accounts for the decreasing difference in elevations of tides at Sabine Pass and Port Arthur. The time of duration of the surge for a standard project hurricane is shorter than that experienced during Carla and would not provide as long a period of time for the water surfaces to approach each other in elevation.

28. Considerable study effort was expended in attempting a rational computation of the response of water levels in Sabine Lake under the influence of a rise in the Gulf level represented by the computed standard project hurricane tide hydrograph which is shown on exhibit 5. No rigid solution to this complex problem is known. However, by rationalizing that an approximation could be made by computing the flow across the coastline delineated by the projection of the extremities of Sabine Lake, and that the rising waters on both sides of the delineated area would more or less prevent the escape laterally of the Gulf waters moving into the lake and thus constitute a volume to be filled, a computation was made. Flow of water from the Gulf into Sabine Lake (as delineated above) was computed. There was no firm basis on which to base the computation inasmuch as it amounted to an attempt to compute the volume of flow through an uncalibrated measuring device. However, it was rationalized that by computing the inflow from the Gulf into the lake in small time increments, errors would be compensating. For example, if computed inflow into the lake was excessive the available computed head for the next increment would be reduced. Thus it would appear that incremental errors would not be of great consequence. A hydrograph showing the computed water level elevations in Sabine Lake is plotted on exhibit 5 for comparison with the computed standard project tide hydrograph computed for the Gulf of Mexico opposite Port Arthur at Sabine Pass.

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29. On exhibit 6, in addition to the points plotted representing actual storm tide occurrences, a point is plotted showing elevation 14 at Sabine and 12 at Port Arthur. This point represents the peak of the computed standard project hurricane tide hydrograph and the peak of the water level response at Port Arthur as computed in the manner set forth in paragraph 28. By using this computed point along with points representing actual occurrences a curve has been drawn representing a rationalized relationship between storm surges or tides at Port Arthur and Sabine. It is believed that if the storm surge in the Gulf was great enough there would be no significant difference between water levels in the Gulf and at Port Arthur. Based upon data plotted on exhibit 6 this elevation appears to be about 25 feet above mean sea level. This 25-25 point is used only for convenience in shaping the rationalized curve. The probability of such a storm surge ever occurring are considered to be infinitely remote.

30. Port Arthur has been fortunate in that no great storm has crossed the coast to the southwest at a point that would produce maximum or near maximum storm surges. The several feet of tide differential that has existed between Sabine and Port Arthur (see table 10) cannot be expected to prevail during a standard project hurricane. This difference was about 4 feet during the 1915 Galveston storm but the center of this storm was nearly 100 miles away and winds across Sabine Lake were probably about 55 or 60 miles per hour. Nearly 4 feet difference existed during hurricane Audrey in June 1957 but the storm center went inland east of Port Arthur and winds of about 60 miles per hour were blowing seaward across Sabine Lake, while 1.6 feet existed during passage of Carla in 1961 about 160 miles southwest of Sabine Pass. Ordinary prudence requires the assumption that, during a standard project hurricane, having a surge in the Gulf of Mexico to 14 feet above mean sea level at Sabine, the surge at Port Arthur would exceed 10 feet. The rationalized curve on exhibit 6 is selected as representing relative surges at Sabine and Port Arthur during hurricanes. This curve, together with the hurricane tide frequency curve of the Gulf shown on exhibit 1 is used to construct the storm tide frequency curve at Port Arthur which is also shown on exhibit 1. The computed hydrograph of water level response at Port Arthur to the standard project hurricane in the Gulf, shown on exhibit 5, is adopted as the design storm hydrograph at Port Arthur. This results in a peak of 12 feet above mean sea level at Port Arthur in Sabine Lake.

31. Storm tide elevations west of Port Arthur.- As the storm tide moves inland and inundates the areas landward of the normal shore line it is in general lowered by reason of friction and velocity head losses. However, since this overland travel of the tide waters is across an extremely complex surface from a hydraulic standpoint and is accompanied by winds of great force and turbulence, its behavior is erratic and unpredictable. High water marks obtained by the U. S. Army Engineer District in New Orleans following hurricane Audrey of 27 June 1957 and shown on their drawing File No. H-20-21041 present a very erratic pattern of inundation from New Orleans, Louisiana, to Sabine, Texas. Inasmuch as a computed and rationalized slope of 2 feet in about 12 miles from the

Gulf of Mexico, across Sabine Lake, to Port Arthur was adopted, the same water surface slope was adopted for areas west of Port Arthur. It amounts to about 0.17-foot per mile and it is considered conservative.

32. Standard project hurricane waves at Port Arthur.- An analysis was made of the waves that could develop on Sabine Lake during the standard project hurricane using formulae presented in Beach Erosion Board Technical Report No. 4. At the height of the storm, as the center of the storm crossed the coast southwest of Sabine, it is estimated that significant wave heights would be 9 feet, maximum waves would be about 14 feet, and average wave heights would be about 6 feet. With reference to Sabine Lake, wave heights are limited by the water depth. However, although waves of the magnitude indicated above can be propagated on Sabine Lake, the spoil bank along the Sabine-Neches waterway would block their attack against Port Arthur levees. Elevations along this spoil bank, which is shown on plate 2 of the text, range from 5 to more than 30 feet above sea level. Most of the spoil bank is between 10 and 15 feet above sea level. No waves propagated in Sabine Lake could cross the 15-foot portions of the spoil bank. Maximum waves at the peak of the design hurricane tide in the lake (12 feet above sea level) that could cross the 10-foot portions of the spoil bank would be about 2 feet high. A few waves of the approximate magnitude of 5 or 6 feet might cross the lower or 5-foot portions of the spoil bank. However, all waves crossing the spoil bank would be short segments of waves propagated in Sabine Lake and they would be diffracted in passing through the gaps in the spoil bank. Their energy would be largely dissipated laterally.

33. For purposes of design of the levees fronting the Sabine-Neches Waterway the waves that can be generated in the waterway itself are considered applicable. The short fetch of about 600 feet limits the height of the waves that can be developed. Computations based upon Beach Erosion Board Technical Report No. 4 procedures show that waves up to a significant height of about 2 feet high could be developed within the Sabine-Neches Waterway during the standard project hurricane. The maximum wave height of about 3.2 feet would occur about 1 percent of the time.

34. Levees along the northeast side of Port Arthur would be subject to slightly less severe wave attack because of their northwest-southeast alinement. During all but the very beginning of storm, prior to excessive tide height, and after the critical part of the storm had passed, waves would be traveling parallel to these levees. The significant waves at the height of the storm would be about 4 feet high and maximum waves would be about 6 feet high. Direction of travel would be northwest.

35. Levees along the southwest side of Port Arthur would be without benefit of protection by the spoil banks of the Sabine-Neches Waterway. However, wind and wave direction would not become critical until after the storm tide had peaked and started to recede. Maximum waves would be about 7 to 9 feet high and significant waves 5 to 7 feet high about the time or shortly after the hurricane tide peaked at Port Arthur.

36. <u>Analysis of critical conditions</u>.- An analysis of the critical portion of the standard project hurricane was made to determine the severity of wave attack against existing and proposed levee and seawall structures. Wave heights were determined from an examination of the time history of the hurricane tides as shown on exhibit 5, the standard project wind pattern shown on exhibit 3, and the forward speed of the storm given as 11 knots in paragraph 19. Runup computations were based on figure 9b inclosed with an abstract from manuscript of a paper by Saville, McClendon, and Cochran dated 8 March 1961 entitled: "Freeboard Allowances for Wind-Generated Waves on Inland Reservoirs." The results of this analysis are shown in table 11. Only the conditions existing during the period that the center of the storm is on or near the coast are shown. Less severe conditions that could result during other time periods of the design storm, different approach directions, or during periods when the winds would be from other directions were investigated but are not shown in table 11. In this table, for the Port Arthur area fronting on the Sabine-Neches Waterway, the significant wave heights were computed using figure 14 on page 27 of Beach Erosion Board Technical Report No. 4. For those areas not fronting on Sabine-Neches Waterway the significant wave was computed by means of Bretschneider's shallow water formula, $H = 0.0725\ U^{.6} d^{.7}$ where H is wave height in feet, U is wind speed in knots, and d is the water depth in feet. Maximum wave heights were determined by multiplying the significant wave height by 1.58 except where the result exceeded the breaking wave height. In this case the height of the breaking wave was used as maximum. Wave periods were determined from the relationship, $T = 2.43 \sqrt{H}$ where T is the period in seconds and H is the wave height in feet. The wave length L was computed from the formula $L = 5.12\ T^2$. These latter two formulas are given in Beach Erosion Board Technical Memorandum No. 84 on pages 24 and 11, respectively.

CRITICAL PORTION
STANDARD PROJECT HURRICANE

TABLE 11

AT PORT ARTHUR

Time in hrs. after start of rise in the tide hydrograph	Wind direction in vicinity of Port Arthur (1)	Maximum sustained wind vel. m.p.h.	Sabine-Neches W.W. at Port Arthur elev. m.s.l.	Average land elev. at levee m.s.l. (2)	Average depth of water at levee in feet	Wave heights in feet		Wave crest elevations m.s.l.		Wave period seconds	Wave length feet	Wave steepness H/L		Wave runup factor R/H Smooth levee 1:3 slope		Smooth levee 1:3 slope wave run-up in feet (5)		Riprapped levee 1:3 slope wave run-up in feet (5)		Smooth 1:3 levee max. water level m.s.l. (5)		Riprapped 1:3 levee max. water level m.s.l. (5)	
						Max.	Sig.	Max.	Sig.			Max.	Sig.	Max.	Sig.	Max.	Sig.	Max.	Sig.	Max.	Sig.	Max.	Sig.
7	E	53	4.3	4.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	ESE	66	7.4	4.0	3.4	1.9	1.2	8.3	8.0	2.66	36	.053	.033	1.66	2.01	3.2	2.4	1.3	1.2	10.6	10.0	8.7	8.6
9	SE	82	9.7	4.0	5.7	2.5	1.6	10.9	10.5	3.07	48	.052	.033	1.68	2.01	4.2	3.2	2.1	1.6	13.9	12.9	11.8	11.3
10(3)	SSE	100	11.4	4.0	7.4	3.2	2.0	13.0	12.4	3.39	59	.054	.034	1.65	2.00	5.3	4.0	2.6	2.0	16.7(4)	15.4	14.0	13.4
11	S	83	12.0	4.0	8.0	3.0	1.9	13.5	13.0	3.35	57	.053	.033	1.66	2.01	5.0	3.8	2.5	1.9	17.0(4)	15.8(4)	14.5	13.9
12	SSW	66	10.3	4.0	6.3	2.4	1.5	11.5	11.1	2.97	45	.053	.033	1.66	2.01	4.0	3.0	2.0	1.5	14.3	13.3	12.3	11.8
13	SW	53	7.3	4.0	3.3	1.9	1.2	8.2	7.9	2.66	36	.053	.033	1.66	2.01	3.2	2.4	1.6	1.2	10.5	9.7	8.9	8.5
										WEST OF PORT ARTHUR & AT PORT ACRES													
6	ENE	45	2.0(6)	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	E	53	4.3(6)	3.0	1.3	1.0	0.8	4.8	4.7	2.18	24	.042	.033	1.85	2.01	1.8	1.6	0.9	0.8	6.1	5.9	5.2	5.1
8	ESE	66	7.4(6)	3.0	4.4	3.4	2.3	9.1	8.5	3.70	70	.049	.033	1.73	2.01	5.9	4.6	3.0	2.3	13.3	12.0	10.4	9.7
9	SE	82	9.7(6)	3.0	6.7	5.2	3.5	12.3	11.5	4.54	104	.050	.034	1.71	2.01	8.8	7.0	4.4	3.5	18.5	16.7	14.1	13.2
10	SSE	100	11.4(6)	3.0	8.4	6.6	4.6	14.7	13.7	5.20	138	.048	.033	1.74	2.01	11.5	9.2	5.8	4.6	22.9	20.6	17.2	16.0(7)
11	S	83	12.0(6)	3.0	9.0	7.0	4.4	15.5	14.2	5.11	133	.053	.033	1.67	2.01	11.7	8.8	5.8	4.4	23.7	20.8	17.8	16.4(7)
12	SSW	66	10.3(6)	3.0	7.3	5.1	3.2	12.9	11.9	4.35	97	.053	.033	1.67	2.01	8.5	6.4	4.2	3.2	18.8	16.7	14.5	13.5(7)
13	SW	53	7.3(6)	3.0	4.3	2.8	1.8	8.7	8.2	3.26	54	.052	.033	1.68	2.01	4.7	3.6	2.4	1.8	12.0	10.9	9.7	9.1
14	WSW	40	4.1(6)	3.0	1.1	0.9	0.6	4.5	4.4	1.90	18	.050	.033	1.71	2.01	1.5	1.2	0.8	0.6	5.6	5.3	4.9	4.7

(1) Direction from which wind is blowing.
(2) Levees facing frontal or near frontal attack.
(3) Landfall of storm's center.
(4) Obliqueness is such that wave run-up would not exceed 16 feet.
(5) With wave attack normal to the levee only. Obliqueness in effect flattens the slope and turns the wave.
(6) Tide elevation on land to west of Port Arthur assumed equal to Sabine Lake elevations.
(7) Riprap required on portions of levees S.W. of Port Arthur and adjacent to Port Acres as indicated on exhibits 7 & 8.
(8) Run-up computations based on figure 9b inclosed with an abstract from manuscript of a paper by Saville, McClendon, and Cochran dated 8 March 1961 entitled "Freeboard Allowances for Wind-Generated Waves on Inland Reservoirs."

37. Flooding under existing conditions.- Flooding under existing conditions from interior runoff is a problem which local interests have been making plans to reduce and a problem which will not be changed in any way by the plan to increase the protection against hurricane tides. The existing levees provide substantial protection against ordinary hurricane tides, but are inadequate to protect against storms which would produce water surface elevations in the Sabine-Neches Waterway over 7 feet above mean sea level. Reference to exhibit 1 shows that a storm tide of this magnitude would have a recurrence interval of once in 30 years. With a 7 foot tide in the Sabine-Neches Waterway the crest of 2-foot waves would be at elevation 8 feet mean sea level or 1 foot below the top of the existing levee. Wave runup might be sufficient to cause some spillover into the protected area for a brief period of time. The additional water inside the leveed area would in itself be a minor problem because of the substantial existing and planned pumping capacity and to the remoteness of the possibility of this spillover coming at a time when all pumping capacity is required to handle rainfall runoff.

38. Any storm tide exceeding 7 feet above mean sea level in the Sabine-Neches Waterway would be critical. Exhibit 1 shows that a tide of 7.8 feet above mean sea level in the Sabine-Neches Waterway has an expected recurrence interval of about 40 years or an exceedence frequency of 2.5 times in 100 years. The top of 2-foot waves would about equal the crest elevation of 9-foot levees. Runup would be sufficient to carry a portion of the waves across the top of the levees into the protected area. It is probable that some erosion would take place and that the levee would be partially breached. The 7.2-foot tide caused by hurricane Carla breached the levee in the Port Acres area and caused extreme flooding of residential area. The situation would be extremely critical, however near maximum conditions would prevail for a relatively short period of time. For the purpose of making damage-frequency analyses it is assumed that in the existing protected areas of Port Arthur all lands below about 1.5 feet m.s.l. would be inundated 2.5 times in 100 years.

39. Exhibit 1 shows that a storm tide of about 9 feet above mean sea level can be expected to have an average recurrence interval of about 60 years in the Sabine-Neches Waterway or to be equalled or exceeded 1.67 times per hundred years. All waves would be capable of crossing the 9-foot levee into the protected area. Serious erosion and breaching of the levees would assuredly occur. Inundation and damage would be severe. However, some parts of the levee would remain and the peak elevation of the water surface inside the leveed area would lag and be flattened. For the purpose of damage-frequency analyses, it is assumed that all areas below 3 feet mean sea level would be inundated.

40. Exhibit 1 shows that a storm tide of 10 feet above mean sea level in the Sabine-Neches Waterway would have an average recurrence interval of about 77 years or exceedence frequency of 1.3 times per hundred years. Such a storm tide would completely inundate the Port Arthur area to elevation 10 feet mean sea level. It would overtop the 9-foot elevation levees and erode and breach them most severely. The less frequent storm tides of greater height would also inundate the area to the full elevation of the water in the Sabine-Neches Waterway.

41. Subareas 9 and 10 shown on exhibit 7 have somewhat lower protection levees. They are considered adequate for tides up to elevation 5 feet in the Sabine-Neches Waterway inasmuch as they provided protection against hurricane "Audrey" which created a storm tide of 4.8 at Port Arthur in the Sabine-Neches Waterway. For the purpose of making a damage-frequency estimate it was assumed that a tide elevation of 6 feet in the Sabine-Neches Waterway would result in some damage and that a tide of 7.5 feet would result in substantial damage to the levees, bordering on failure. Tides of 8.5 feet or above were assumed to result in complete inundation of these two areas to the full elevation of the storm tide in Sabine-Neches Waterway.

42. Exhibit 1 shows the frequency of hurricane tides in the Sabine-Neches Waterway. This frequency was used as the frequency of flooding under existing conditions in unprotected areas. These are subareas 3, 5, 6, 13, and 15 on exhibit 7. Exhibits 10a through 10g presents frequency curves of tides of the Sabine-Neches Waterway at Port Arthur and the interior stages for existing conditions of protection and proposed conditions of protection for the various areas. These curves were prepared from computations at various frequencies of the volume of water likely to result from wave-overtopping of the windward levees and from any weir-flow over the existing protective works. It will be noted on exhibit 10g that the curve for interior stages under improved conditions rises to elevation 7.5 feet at an external stage of 14.5 feet; it does not rise higher until the exterior stage reaches approximately 15 feet, and then rises sharply for higher stages. The break in the curve results from the assumption that storm tide overflow would fill the Port Acres area rapidly to the crest elevation of the existing levee between the Port Acres area and the more slowly filling Alligator Bayou area. Further overflow would not increase the Port Acres stage until the stage in the Alligator Bayou area reached the stage in the Port Acres area above which both stages would rise at the same rate. This break in the interior stage-frequency curve also is shown on exhibit 13 - Snake Bayou and exhibit 14 - Rhodair Gully, which are combined in the curves on exhibit 10g. The computed elevations of exterior and interior flooding under existing conditions compared closely with actual measured elevations that occurred during hurricanes "Audrey" and "Carla." The results of these computations and observations are also presented in paragraphs 37 through 41 above. For subareas 3, 5, 6, 13 and 15 which are at this time without levee protection, flooding frequency is assumed to follow the tide frequency curve for the Sabine-Neches Waterway at Port Arthur.

43. Levee grades, general.- The data presented in table 11 were used to determine required grades of levees and seawalls and the locations where riprap is required to protect levees and prevent excessive overtopping by design hurricane waves. The same criteria were applied to both the compartmented plan (plan A) and the overall plan (plan B) shown on exhibits 7 and 8, respectively. Only the levee grades for plan B, the adopted plan will be discussed in detail herein. In the following paragraphs references to station numbers are to those shown on exhibit 1 of appendix III.

44. Levees and seawalls along the Sabine-Neches Waterway.- The northeast-southwest levee structures fronting the Sabine-Neches Waterway (approximate station numbers 16+800 to 77+300) are in part earth levee and in part concrete wall having a vertical face. The most critical conditions during a design hurricane would come about 1 hour after the storm center crossed the coast. This would be 11 hours after the water level started to rise in the Gulf of Mexico. See table 11 and exhibit 5. The water level at Port Arthur would be 12 feet above mean sea level and wind from the south would be blowing 83 miles per hour. The maximum waves that would attack the protective structures along the Sabine-Neches Waterway side of Port Arthur would be about 3 feet high. These would be the waves that were equalled or exceeded 1 percent of the time. Significant waves would be about 2 feet high. Runup against a smooth levee would not exceed elevation 16. A sheet-pile wall at the crest of these levees would effectively block runup from these waves and wave energy would be dissipated vertically. A small amount of spray might be blown across the structure. It would be of little significance. An elevation of 14 feet mean sea level would be adequate for the vertical concrete wall and 16 feet mean sea level would be adequate for earth levees.

45. The flanking levees on the northeast side of Port Arthur (station 0+000 to station 16+300) and the levee north of Groves (station -7+500 to station 0+000) would be subject to wave attack only with the simultaneous occurrence of high tides and strong northeast winds. This condition would not be experienced along these levees during the critical part of the design hurricane. During the peak of the storm, with the tide at Port Arthur standing at 12 feet above sea level, the wind would be from the south. Maximum and significant waves of 3 and 2 feet, respectively would be traveling approximately parallel to or away obliquely from these levees. The grade of this flank levee can be gradually brought down from 16 feet mean sea level at the junction with the front levee near the Sabine-Neches Waterway to the 12 foot natural ground contour and in the area north of Groves from the 12 foot natural ground contour extended at the same grade across to the 12 foot contour.

46. The tank farm area and the reservoir area (stations 0+000B to station 20+651B and station 0+000C to station 28+633C, respectively) southwest of Port Arthur, are separate enclosures outside the main protected area. On exhibit 7 they are designated as subareas 9 and 10. Portions of the levee around these areas, as shown on exhibits 7 and 8, would be subject to direct wave attack during the peak of the design hurricane and would require riprap to prevent overtopping and destruction. Waves equalled or exceeded 1 percent of the time would be 7 feet high and significant waves of 4.4 feet could be expected. As indicated in table 11 a riprapped embankment on a slope of 1 vertical to 3 horizontal with top at elevation 16 feet mean sea level would not be subject to spillover from significant waves. Such minor, brief, and infrequent spillover as indicated for maximum waves could be tolerated with little damage.

47. Flanking levees extending from the end of the front levee south of Port Arthur, in a generally northwest alinement on the left bank of Taylors Bayou, to and around the town of Port Acres, to the 12 foot contour west of Port Arthur (station 77+300 to station 142+330) would be subject to wave attack of varying severity. From the lower end of this levee to about station 96+000, substantial protection against large waves is afforded by spoil banks and other embankments and structures. At the time of peak tide the wind and the direction of wave attack would be from the south or southeast. Wave crests in some places might be as high as 15 feet above sea level. Wave runup would not be a significant factor and riprap would not be required. Nevertheless, as a safety measure, the levee grade should be 16 feet above mean sea level. Above station 96+000 to State Highway 73 (station 119+530) the levee in the vicinity of Port Acres could be subject to direct wave attack during or shortly after the peak of the design hurricane tide. Maximum waves up to 7 feet high and significant waves of over 4 feet height would be expected to attack these levees near Port Acres. As indicated in table 11 and on exhibit 8, a levee with riprapped face, with slopes of 1 vertical on 3 horizontal and a crown elevation of 16 feet would be needed to insure the safety of the structure and limit wave runup overtopping to non-damaging amounts.

48. The levee northwest of Port Acres (station 119 + 530 to station 142 + 330), which runs generally in a northerly direction to high ground north of Port Acres, would not be subject to attack by hurricane waves because of its alinement. Waves and runup would not be a factor. Further, inasmuch as it is about 16 miles from the gulf shore, the estimated maximum tide elevation at the peak of the design hurricane would be about 11 feet above mean sea level. A smooth levee with a crown at elevation gradually brought down from 16 feet to a 12 foot at natural ground contour will be adequate.

49. Summary of levee and seawall grades.- As set forth above, the front levees require a top elevation of 16 feet, back levees a top elevation of 12 feet, and flanking levees a top elevation sloping from 16 feet to 12 feet; all above mean sea level. Vertical concrete sheet-pile walls can be to elevation 14 feet. Levee and wall types, station numbers, crest elevations, and other details are shown on exhibits 1, 4, and 5 of appendix III for plan B.

50. Two plans of protection were considered. One plan designated as plan A is shown on exhibit 7 and the other, designated as plan B is shown on exhibit 8. Both plans require that certain levee reaches have riprapped surface areas to prevent overtopping during the height of the design hurricane. These reaches are indicated on exhibits 7 and 8 and noted in table 11.

51. Interior drainage, general.- The existing drainage facilities in Port Arthur consist of storm sewers, ditches, culverts, and pumping plants, together with additional facilities in the planning and installation stages. The provision of additional hurricane protection for areas now behind levees introduces no new drainage problems. The extension of the levee system to the northeast to include the Lakeview area necessitates additional drainage facilities. Local interests' plan for improvement of this area includes a pumping plant having a capacity of 1,100,000 gallons per minute. Extending the levee system to include unprotected areas between Taylors Bayou and Port Arthur, including Port Acres, involves additional problems of runoff removal.

52. The topography of Port Arthur and contiguous coastal areas is such that whenever levees are provided to protect against even minor storm tides, pumping or storing temporarily of rainfall runoff is a necessity because gravity drains become useless or inefficient because of inadequate head.

53. With respect to interior drainage, plan A breaks down into 15 separate subareas as shown on exhibit 7. Plan B would provide hurricane protection for all areas in plan A plus additional areas north of Taylors Bayou and a large undeveloped area northwest of Port Arthur as shown on exhibit 8.

54. Interior drainage of leveed areas.- Interior drainage of the leveed areas during normal tide stages would pass through gated outlet structures in the levees by gravity flow supplemented as necessary by pumping. During storm tides, excess rainfall would be stored temporarily on low-lying areas within the levees or pumped across the levees. The pump capacities required depend upon the elevation to which excess rainfall from the design storm would be allowed to rise in the ponding areas and to some extent the maximum time allowable for emptying the ponding area.

55. Unit hydrographs.- Synthetic unit hydrographs were developed for sixteen subareas listed in tables 13 and 14. The individual drainage areas are shown on exhibits 7 and 8. The formulas and methods described in EM 1110-2-1405, dated August 1959 were used. These formulas include:

$$t_p = C_t(LL_{ca})^{0.3} \text{ and } Q_p = C_p640/t_p$$

where,

t_p = "Lag" in hours

L = Length of main channel in miles

L_{ca} = Distance outlet to point opposite center of gravity of area in channel miles

Q_p = Peak rate of discharge of unit hydrograph in cfs/sq.mi.

C_t and $640\ C_p$ = Coefficients depending on units and drainage basin characteristics

There are no stream flow records on drainage channels in the Port Arthur area from which values of C_t and $640\ C_p$ can be determined. Values of these coefficients were estimated from somewhat similar areas on the Buffalo Bayou Watershed in the vicinity of Houston, Texas, where actual discharge observations have been made and coefficients evaluated. The adopted values for the Port Arthur area are $C_t = 2.8$ and $640\ C_p = 300$.

56. Exhibits 7 and 8 show a number of pumping plant locations or possible sites within the protected area which were considered in the several plans studied. For convenience in discussion these station sites have been numbered from 1 to 22 on exhibits 7 and 8.

57. Standard project storm.- The standard project storm, developed in accordance with EM 1110-2-1411, "Standard Project Flood Determinations," dated 26 March 1952, would have an average rainfall depth of 22.20 inches in 24-hours. Approximately 17.8 inches of rain in 24-hours was recorded at Port Arthur, Texas, east of the path of the July 1943 Galveston hurricane.

This is the maximum 24-hour rainfall recorded and is less than a standard project rainfall at Port Arthur.

58. Rainfall intensity-frequency coincident with high tides.- In the Port Arthur area, tides reaching elevations of 2.5 feet or more above mean sea level are of frequent occurrence and interfere with gravity drainage. Therefore, a study was made to establish a correlation between overall rainfall frequency and rainfall frequency coincident with tides reaching 2.5 feet elevation and over. The period January 27, 1923 through February 10, 1956 was used in the study. The dates of all tides of 2.5 feet or more were obtained from the tide stations records and 24-hour rainfalls on these dates were obtained from Weather Bureau publications. A curve was drawn, using Beard's plotting positions, showing inches of rainfall in 24-hours versus exceedance frequency in events per 100 years. Table 12 shows the results of this study and compares it with rainfall frequency without regard to tide conditions.

TABLE 12

RAINFALL FREQUENCY DATA

Recurrence interval in years	24-hour rainfall: without regard to tide stage (1)	24-hour rainfall: Coincident with tides 2.5 ft. or more
1	3.0	0.7
2	5.6	2.4
3	7.0	3.7
5	8.5	5.1
8	9.4	6.2
10	9.7(2)	6.8
15	10.6	7.9
20	11.7	8.6
30	12.5	9.7(2)
40	13.2	9.9
50	14.0	10.1
100	15.4	10.9

(1) Based on U. S. Weather Bureau Technical Paper No. 25.
(2) 10-year frequency becomes 30-year frequency coincident with tide 2.5 feet or more at Port Arthur.

59. Classification of drainage areas.- The drainage areas shown on exhibits 7 and 8 of this appendix were classified, using criteria and nomenclature from Engineering Manual - Civil Works Construction, Part CXIV, Hydrologic and Hydraulic Analysis, Chapter 10, Interior drainage of leveed urban areas. The classification of each subarea is shown in tables 13 and 14.

60. Drainage design rainfall for pumping.- Numerous conferences with local interests and discussions with Southwestern Division personnel resulted in consideration of a 30-year frequency rainfall coincident with tides of 2.5 feet above mean sea level or greater. As shown in table 12 a rainfall of 9.7 inches in 24-hours would occur coincident with high tides with a frequency of about once in 30-years. Another rainfall selected for investigation was the 24-hour 50-year all season rainfall. This rainfall is estimated to amount to 14.0 inches as shown in table 12 hereof. Consideration was given to discharge by pumping of runoff from a rainfall having an average frequency of occurrence of once each year. However, as shown in table 12, the 24-hour rainfall would amount to 3.0 inches. The estimated runoff would be only about 2.0 inches and it would not create a drainage problem comparable to either the 30-year coincident rainfall or the 50-year all season rainfall. As presented in paragraphs 68 through 93 the 50-year all-season rainfall produced the most critical conditions in each subarea except where large gravity structures are proposed and is therefore used as the drainage design rainfall. The above conditions satisfy the criteria set up in paragraph 10b(3) of the Engineering Manual for Civil Construction, Part CXIV, Chapter 10.

61. Most existing pumping stations in the study area are powered by diesel engines, but several are powered by electric motors. Because of the unreliability of electric power during a hurricane, internal combustion standby generating units should be provided in existing plants with electric motors, and in any new electric-powered pumping plants constructed. Axial-flow propeller pumps are desirable because of their relatively high efficiency in pumping large quantities of water against comparatively low heads. Pumping would be against a maximum static head of about 12 feet with an average of about 6 feet. The combined friction and velocity head is estimated at about 2 feet. The total average pumping head is therefore about 8 feet. The required horsepower of the pump motors can be computed by the formula:

$$\text{Brake horsepower} = GH/3960e$$

where:

G = Gallons per minute discharge

H = Average total head on pump

e = Overall efficiency or water horsepower/brake horsepower

It is estimated that the overall efficiency of the pumping installation would be about 0.70 as the product of the hydraulic, mechanical, and volumetric efficiencies. On the above basis, horsepower requirements would be approximately 2.9 per 1,000 gallons per minute of pumping capacity.

62. Gravity drainage structures.- Under either plan A or plan B a number of gravity outlet structures are needed. The locations are shown on exhibits 7 and 8, respectively. Locations requiring gravity outlet structures are also noted on tables 13 and 14.

63. Drainage outlets.- All gravity outlets through the levees, as well as the interior drainage ditches, would be designed to carry the runoff from the design rainfall. During periods of high tide stages outside the levees, gates through levees would be closed and a portion of the interior drainage runoff would be stored temporarily, with pumps removing the excess in the various areas as discussed in the following paragraphs. Ditches would be designed in accordance with Manning's formula:

$$V = \frac{1.486}{n} r^{2/3} s^{1/2}$$

where:

V = velocity in feet per seconds

r = hydraulic radius

s = slope in foot per foot

n = roughness coefficient, estimated to be 0.025

64. Conduits through the levees would be set with inverts at ditch flow line elevations and on the same grade as the ditch. When outlet conditions were favorable, both gravity outflow and pumping of water from the protected area would be accomplished simultaneously. Thus under the most favorable circumstances the combined gravity outlets and pumping plants would discharge the runoff from a slightly more than a 19-inch in 24-hour rainfall. Table 12 indicates that 19 inches in 24-hours is greater than the once in 100-year rainfall. However, since most extremely heavy rainfalls along the Gulf coast are associated with tropical disturbances, tides somewhat above the predicted normal could be expected and full design discharge capacity of the gravity structures would be realized at infrequent intervals. Nevertheless the combined design capacities of the gravity outlets and pumping stations would be sufficient to accommodate a 100-year all-season rainfall runoff with ponding to no more than one foot above the natural ground in each subarea.

65. Plan A-interior drainage.- Table 13, which follows, lists pertinent data regarding existing pumping facilities and design storm runoff rates for the 15 separate subareas under plan A, and shows for each area the classification in accordance with Part CXIV, Chapter 10

of the Engineering Manual for civil works. The pumping rates indicated are sufficient to limit ponding of rainfall runoff under design conditions to occasional minor inundation of streets and yards for short periods of time. Subarea number 13 is presently classified as U-2. However, continued development in the Port Arthur area at its present rapid rate will completely develop this area, even without adequate hurricane protection. Therefore, U-1 drainage criteria has been used for estimating all pumping requirements. Area-capacity curves for the several subareas were developed from topographic maps. These curves are shown on exhibits 9 and 9a. Mass curves of inflows of the design storm runoffs for each subarea were prepared from synthetic hydrographs. The mass curves together with draft lines representing several assumed pumping rates were used for developing the curves of installed pumping capacity versus elevation of ponded water under design rainfall conditions shown on exhibit 9b.

TABLE 13

INTERIOR DRAINAGE-PERTINENT DATA
PLAN A

Sub-area	Subarea classification	Area (acres)	Capacity of existing pumps (1000 GPM)	Required pumping capacity(3) 1 ft. of storage (1000 GPM): 9.7" rainfall	Required pumping capacity(3) 1 ft. of storage (1000 GPM): 14.0" rainfall	Pumping site No. (Exhibit No. 7)	Remarks
1	U-1	4,220	1,065	610	1,060	5,6,7,8,9 & 18	
2	U-1	1,670	461	250	461	2, 3 & 4	
3	U-1	4,480	None	680	-	1	3,260 c.f.s. gravity drain for 14" rain
4	U-1	1,630	590	330	540	19	
5	U-1	1,690	None	270	470	20	
6	U-1	510	None	None	None	-	630 c.f.s. gravity drain for 14" rain
7	U-1	950	381(2)	-	-	-	
8	U-1	910	169	-	-	10	
9	U-1	490	None	-	-	-	400 c.f.s. gravity drain for 9.7" and 14.0" rain
10	(1)	1,050	None	None	None	-	Reservoir
11	U-1	310	5	-	-	16	
12	U-1	60	17	-	-	15	
13	U-1	2,700	250	540	-	12	2,400 c.f.s. gravity drain for 14" rain
13a	U-1	1,730	30	320	-	13	1,600 c.f.s. gravity drain for 14" rain
14	(1)	380	None	None	None	-	Reservoir
15	U-1	1,030	150	-	260	14	
Total		23,810	3,118	3,000	2,791		400 c.f.s. gravity drain for 9.7" rain 8,290 c.f.s. gravity drains for 14.0" rain

(1) Not classified for urban drainage. Reservoir.
(2) There are nine pumping plants in this subarea. Total capacity is adequate.
(3) Pump capacity required to reduce flooding from runoff to 1 foot deep in lowest part of ponding area.

66. <u>Plan B-interior drainage</u>.- The total drainage area under plan B includes about 19,000 acres more than under plan A. Plan B eliminates an outfall pumping plant at site No. 20 but requires an additional large pumping installation at site No. 11. The existing pumping capacities at sites Nos. 2 through 10 are adequate. Table 14 presents pertinent data on plan B outfall drainage disposal facilities, showing existing pumping capacities and required pumping capacity for the two design conditions of rainfall.

TABLE 14

INTERIOR DRAINAGE-PERTINENT DATA
PLAN B

Sub-area	Subarea classification	Area (acres)	Capacity of existing pumps (1000 GPM)	Required pumping capacity(3) 1 ft. of storage (1000 GPM): 9.7" rainfall	Required pumping capacity(3) 1 ft. of storage (1000 GPM): 14.0" rainfall	Pumping site No. (Exhibit No. 7)	Remarks
1	U-1	1,600	365	540	740	5,6,7,8, & 9	
2	U-1	1,670	461	250	461	2, 3, & 4	
3	U-1	4,480	None	680	-	1	3,260 c.f.s. gravity drain for 14.0" rain
6	U-1	510	None	None	None	-	630 c.f.s. gravity drain for 14.0" rain
8	U-1	910	169	-	-	10	
9	U-1	490	None	-	-	-	400 c.f.s. gravity drain for 9.7" and 14.0" rain
10	(1)	1,050	None	None	None	-	Reservoir
13	U-1	2,700	250	540	-	12	2,400 c.f.s. gravity drain for 14.0" rain
13a	U-1	1,730	30	320	-	13	1,600 c.f.s. gravity drain for 14.0" rain
16	U-1	27,670	(2)	1,174	-	11	13,400 c.f.s. gravity drain for 14.0" rain
Total		42,810	1,275	3,504	1,201		400 c.f.s. gravity drain for 9.7" rain 21,690 c.f.s. gravity drain for 14.0" rain

(1) Not classified for urban drainage. Reservoir.
(2) Existing pumping sites 14, 15, 16, 17, 18, 19, 21 and 22 with existing capacities of 1,843,000 gpm, move water from local leveed areas within subarea number 16 to the main drainage system. Site No. 20 would require capacity of 573,000 gpm for interior drainage collection.
(3) Pump capacity required to reduce flooding from runoff to 1 foot deep in lowest part of ponding area.

67. Under plan B the existing pumps at locations Nos. 14, 15, 16, 17, 18, 19, 21 and 22 (totalling 1,843,000 gallons per minute) would not be outfall stations but would be lift stations to move water along drainage canals within the protected area to be discharged through the outfall facilities at site No. 11. These pumping plants would be part of the local interior drainage collection system. However, for the overall drainage system to function, discharge capacity at these locations must be equal to the outfall pumping capacity contemplated under plan A, the compartmented protection plan. All of these sites except site 22 require increased capacities. Local interests might provide this capacity, by adding more pumps, adding gravity structures to increase the capacities or be eliminating the pumps and adding only gravity drainage structures. The existing pumping capacity at site 22 is sufficient for design conditions. Site numbered 20, which has no existing drainage facilities would require pumping or a gravity capacity of 573,000 gallons per minute or 1,280 cubic feet per second for total drainage or a pumping capacity of 470,000 gallons per minute to limit flooding to one foot.

68. Interior drainage, subarea 1, Port Arthur (U-1), plan A.- This area includes about 4,220 acres and is No. 1 on exhibit 7. There are six existing pumping stations within the area, as shown on exhibit 7, with a total pumping capacity of 1,065,000 gallons per minute or 2,380 cubic feet per second. If all runoff from the 30-year coincident rainfall were stored, flooding would be to an elevation of 2.7 feet above mean sea level. Pumping capacity of 610,000 gallons per minute would remove the 2,160 acre-feet runoff from this rainfall with storage to one-foot depth. Because of the low elevation of the land, about one-foot above mean sea level near the levee, and the high degree of development within the subarea gravity drainage would not be feasible. The runoff from the 50-year all-season rainfall is 3,630 acre-feet and if stored would flood to an elevation of 3.3 feet above mean sea level. The existing pumping capacity would reduce this flooding to about 1-foot depth or 2.0 feet above mean sea level. The 50-year all-season rainfall would produce the most critical drainage conditions within subarea 1 and is considered as the drainage design rainfall.

69. Interior drainage, subarea 2, Lakeview area, (U-1), plan A.- This area includes about 1,670 acres and is No. 2 on exhibit 7. The local interests have constructed three pumping stations within the subarea with a total capacity of 461,000 gallons per minute or 1,030 cubic feet per second. If the runoff of 880 acre-feet from the 30-year coincident rainfall were all stored the elevation of flooding would be 4.6 feet above mean sea level. This elevation of flooding could be reduced to 3.2 feet above mean sea level by utilization of only 250,000 gallons per minute of the existing pumping capacity. The existing pumps would eliminate flooding from the 9.7 inch rainfall. This area is similar to subarea 1 described in the above paragraph and large gravity drainage structures are not considered feasible. The runoff of 1,475 acre-feet from the 50-year all-season rainfall could be stored to an elevation of 5.4 feet above mean sea level. This elevation of flooding would be reduced to 3.2 feet above mean sea level with the existing pumping capacity. The local interest have constructed 15 small individual pipe drainage structures. These structures range in size from 6 inches to 42 inches

and have a total cross-sectional area of approximately 40 square feet. It is estimated that the elevation of flooding would be reduced to 3.0 feet above mean sea level with the existing pumps and small gravity drainage structures. The 50-year all-season rainfall would produce the most critical drainage conditions within subarea 2 and is considered the drainage design rainfall.

70. Interior drainage, subarea 3, Crane Bayou, (U-1), plan A.- This area includes about 4,480 acres and is No. 3 on exhibit 7. There are no existing pumping plants within the subarea. The runoff of 2,025 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 4.3 feet above mean sea level. The area of flooding could be reduced to an elevation of 2.0 feet above mean sea level with the installation of pumping capacity of 680,000 gallons per minute. The runoff of 3,410 acre-feet from the 50-year all-season rainfall could be stored to an elevation of 5.1 feet above mean sea level. The installation of gravity drains is feasible in this subarea and the runoff of 3,410 acre-feet from the 50-year all-season rainfall could all be discharged through gated outlets. If discharged at a peak rate of 3,260 cubic feet per second no flooding would occur. Therefore, the 30-year rainfall frequency coincident with high tides is the drainage design rainfall.

71. Interior drainage, subarea 4, (U-1), plan A.- This area includes about 1,630 acres and is No. 4 on exhibit 7. An existing pumping plant has a capacity of 590,000 gallons per minute. The runoff of 810 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 4.9 feet above mean sea level. The area of flooding can be eliminated by 330,000 gallons per minute. For the reasons stated in paragraph 67, gravity drains are not considered feasible in this subarea. The runoff of 1,400 acre-feet from the 50-year all-season rainfall could be stored to an elevation of 5.7 feet above mean sea level. This elevation of flooding would be reduced to about 2.0 feet by 540,000 gallons per minute of the existing pumping capacity.

72. Interior drainage, subarea 5, (U-1), plan A.- This area includes about 1,690 acres and is No. 5 on exhibit 7. There are no existing pumping facilities within the subarea but two 39" conduits have been installed by the city for future pumping capacities. The runoff of 860 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 3.9 feet above mean sea level. The elevation of flooding could be reduced to 2.0 feet above mean sea level with the proposed pumping capacity of 270,000 gallons per minute. The two existing 39" conduits at the proposed site are used as gravity drains. Because of the low topography, about 1.5 feet above mean sea level near the levee, and the rapid development of the subarea gravity drains would not be feasible. The runoff from the 50-year all-season rainfall is 1,440 acre-feet and if stored would flood to an elevation of about 4.8 feet above mean sea level. The elevation of flooding could be reduced to 2.0 feet above mean sea level by the installation of the proposed pumping capacity of 470,000 gallons per minute. The 50-year all-season rainfall would produce the most critical conditions within subarea 5 and is considered the design rainfall.

73. Interior drainage, subarea 6, (U-1), plan A.- This area includes about 510 acres and is No. 6 on exhibit 7. The elevation in this subarea varies from about 8 to 15 feet above mean sea level although a small area near the natural drain is as low as 5 feet above mean sea level. There are no existing pumping facilities within the subarea. The runoff of 270 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 11.7 feet above mean sea level. The runoff from the 50-year all-season rainfall could be stored to an elevation of 12.8 feet above mean sea level. The volume of runoff from the 50-year all-season rainfall could be discharged by a gravity drainage structure having a capacity of 630 cubic feet per second. Three 60" x 60" conduits would be adequate to discharge the runoff from the 50-year all-season rainfall without ponding. The 50-year all-season rainfall would produce the most critical condition and is considered the design rainfall. Coincident tide heights sufficiently high to block drainage from runoff would have a greater frequency than once in 50-years.

74. Interior drainage, subarea 7, (U-1), plan A.- This area includes about 950 acres and is No. 7 on exhibit 7. Nine existing pumping plants have a total pumping capacity of 381,000 gallons per minute. This subarea includes three reservoirs used for fresh water storage and the question of interior drainage is not applicable to these portions of the subarea; also on approximately 400 acres of the subarea the depth of flooding is not objectionable and the duration of flooding is not critical. The existing pumps are adequate to eliminate flooding by the runoff from the 30-year coincident or the 50-year all-season rainfall.

75. Interior drainage, subarea 8, (U-1) plan A.- This subarea includes about 910 acres and is No. 8 on exhibit 7. An existing pumping plant has a capacity of 169,000 gallons per minute. The runoff of 480 acre-feet from the 30-year coincident rainfall could all be stored to an elevation of about 3.0 feet above mean sea level which could be reduced to 2.5 feet by the existing pump capacity. The runoff of 800 acre-feet from the 50-year all-season rainfall could all be stored to an elevation of about 3.6 feet above mean sea level which could be reduced to 3.0 feet by the existing pump capacity. The depth of flooding from either of the above rainfalls is not objectionable and the duration of flooding is not critical, therefore the existing pumping capacity is adequate to evacuate the stored runoff.

76. Interior drainage, subarea 9, (U-1), plan A.- This subarea includes about 490 acres and is No. 9 on exhibit 7. In this area the depth of flooding and the duration of flooding is not critical. The runoff of 260 acre-feet from the 30-year coincident rainfall could be removed by a gravity drain after the tide had returned to normal. A gravity drain with a capacity of 400 cubic feet per second would remove the water at the maximum rate of runoff from the 30-year coincident rain.

The 440 acre-feet of runoff from the 50-year all-season rainfall could be discharged through the proposed 3 - 60" x 60" slide gate gravity structure without flooding. The 30-year rainfall coincident with high tides is the drainage design rainfall.

77. Interior drainage, subarea 10, plan A.- This subarea includes about 1,050 acres and is No. 10 on exhibit 7. The question of interior drainage is not applicable to this subarea because the entire subarea is utilized as a fresh water reservoir.

78. Interior drainage, subarea 11, (U-1), plan A.- This area includes about 310 acres and is No. 11 on exhibit 7. An existing pumping plant has a capacity of 5,000 gallons per minute in this area. The runoff of 160 acre-feet from the 30-year coincident rainfall can be removed by the existing pumping capacity as the depth of flooding is not objectionable and the duration of flooding is not critical. The 270 acre-feet of runoff from the 50-year all-season rainfall can be removed by the existing pumping plant in a longer period of time.

79. Interior drainage, subarea 12, (U-1), plan A.- This area includes about 60 acres and is No. 12 on exhibit 7. The local interests have constructed a pumping plant with a capacity of 17,000 gallons per minute The runoff of 31 acre-feet from the 30-year coincident rainfall could be removed without damage due to flooding. The runoff of 53 acre-feet from the 50-year all-season rainfall could also be removed from the area without detrimental flooding.

80. Interior drainage, subarea 13, Snake Bayou, (U-2), plan A.- This area includes about 2,700 acres and is numbered 13 on exhibit 7. The local interests have constructed a pumping plant with a capacity of 250,000 gallons per minute. The runoff of 1,410 acre-feet from the 30-year coincident rainfall could all be stored within the area to an elevation of about 3.3 feet above mean sea level. This elevation of flooding would be reduced to 2.5 feet above mean sea level with the existing pumping capacity and flooding would be reduced to 1.0 foot above mean sea level with the total proposed and existing pumping capacity of 540,000 gallons per minute. The runoff of 2,370 acre-feet from the 50-year all-season rainfall could be all stored to an elevation of 4.1 feet above mean sea level. This area of flooding would be eliminated by the installation of gravity drainage structures with a capacity of 2,400 cubic feet per second.

81. Interior drainage, subarea 13a, Rhodair Gully, (U-2), plan A.- This area included about 1,730 acres and is numbered 13a on exhibit 7. The local interests have constructed a pumping plant with a capacity of 30,000 gallons per minute. The runoff of 910 acre-feet from the 30-year coincident rainfall could all be stored to an elevation of 3.8 feet above mean sea level. The elevation of flooding would be reduced to 3.6 feet above mean sea level with the existing pumping capacity and to 2.0 feet above mean sea level with the total proposed and existing pumping capacity of

320,000 gallons per minute. The runoff of 1,620 acre-feet from the 50-year all-season rainfall could be all stored to an elevation of 4.5 feet above mean sea level. This area of flooding would be eliminated by the installation of proposed gravity drainage structures with a capacity of 1,620 cubic feet per second.

82. Interior drainage, subarea 14, plan A.- This subarea includes about 380 acres and is numbered 14 on exhibit 7. The question of interior drainage is not applicable to this subarea because the entire subarea is utilized as a fresh water reservoir.

83. Interior drainage, subarea 15, (U-1), plan A.- This area includes about 1,030 acres and is No. 15 on exhibit 7. The existing pumping plant has a capacity of 150,000 gallons per minute. The runoff of 510 acre feet from the 30-year coincident rainfall could be stored to an elevation of 3.1 feet above mean sea level. This elevation of flooding would be reduced to 2.0 feet above mean sea level, a non-damaging stage, with the existing pumping capacity. The runoff of 860 acre-feet from the 50-year all-season rainfall could be all stored to an elevation of 3.7 feet above mean sea level. This area of flooding would be eliminated by the installation of the proposed 12 ft. x 20 ft. gravity drainage structure.

84. Interior drainage, subarea 1, Port Arthur, (U-1), plan B.- This area includes about 1,600 acres and is No. 1 on exhibit 8. Five existing pumping stations have a total pumping capacity of 365,000 gallons per minute. The runoff of 840 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 3.3 feet above mean sea level. This elevation of flooding would be reduced to 3.0 feet above mean sea level by utilizing 95,000 gallons per minute of the existing pumping capacity. The runoff of 1,420 acre-feet from the 50-year all-season rainfall could be stored to an elevation of 3.9 feet above mean sea level. This elevation of flooding would be reduced to 3.0 feet above mean sea level by utilizing only 260,000 gallons per minute of existing pumping capacity. Due to the low topography, about two foot above mean sea level near the levee, and the high degree of development within the subarea, large gravity drains are not considered feasible, therefore, pumps only are considered. The 50-year all-season rainfall would produce the most critical drainage conditions within subarea 1 and is considered as the drainage design rainfall.

85. Interior drainage, subarea 2, Lakeview area, (U-1), plan B.- This area includes about 1,670 acres and is No. 2 on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A, and are described in paragraph 69 of this appendix.

86. Interior drainage, subarea 3, Crane Bayou, (U-1), plan B.- This area includes about 4,480 acres and is No. 3 on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A, and are described in paragraph 70 of this appendix.

87. Interior drainage, subarea 6, (U-1), plan B.- This area includes about 510 acres and is No. 6 on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A, and are described in paragraph 73 of this appendix.

88. Interior drainage, subarea 8, (U-1), plan B.- This subarea includes about 910 acres and is No. 8 on exhibit 8. No additional improvements were considered in this part of plan B for the same reasons as given in plan A and discussed in paragraph 75 of this appendix.

89. Interior drainage, subarea 9, (U-1), plan B.- This subarea includes about 490 acres and is No. 9 on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A, and are described in paragraph 76 of this appendix.

90. Interior drainage, subarea 10, plan B.- This subarea includes about 1,050 acres and is No. 10 on exhibit 8. The question of interior drainage is not applicable to this subarea because the entire subarea is utilized as a freshwater reservoir.

91. Interior drainage, subarea 13, Snake Bayou, (U-2), plan B.- This area includes about 2,700 acres and is No. 13 on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A, and are described in paragraph 80 of this appendix.

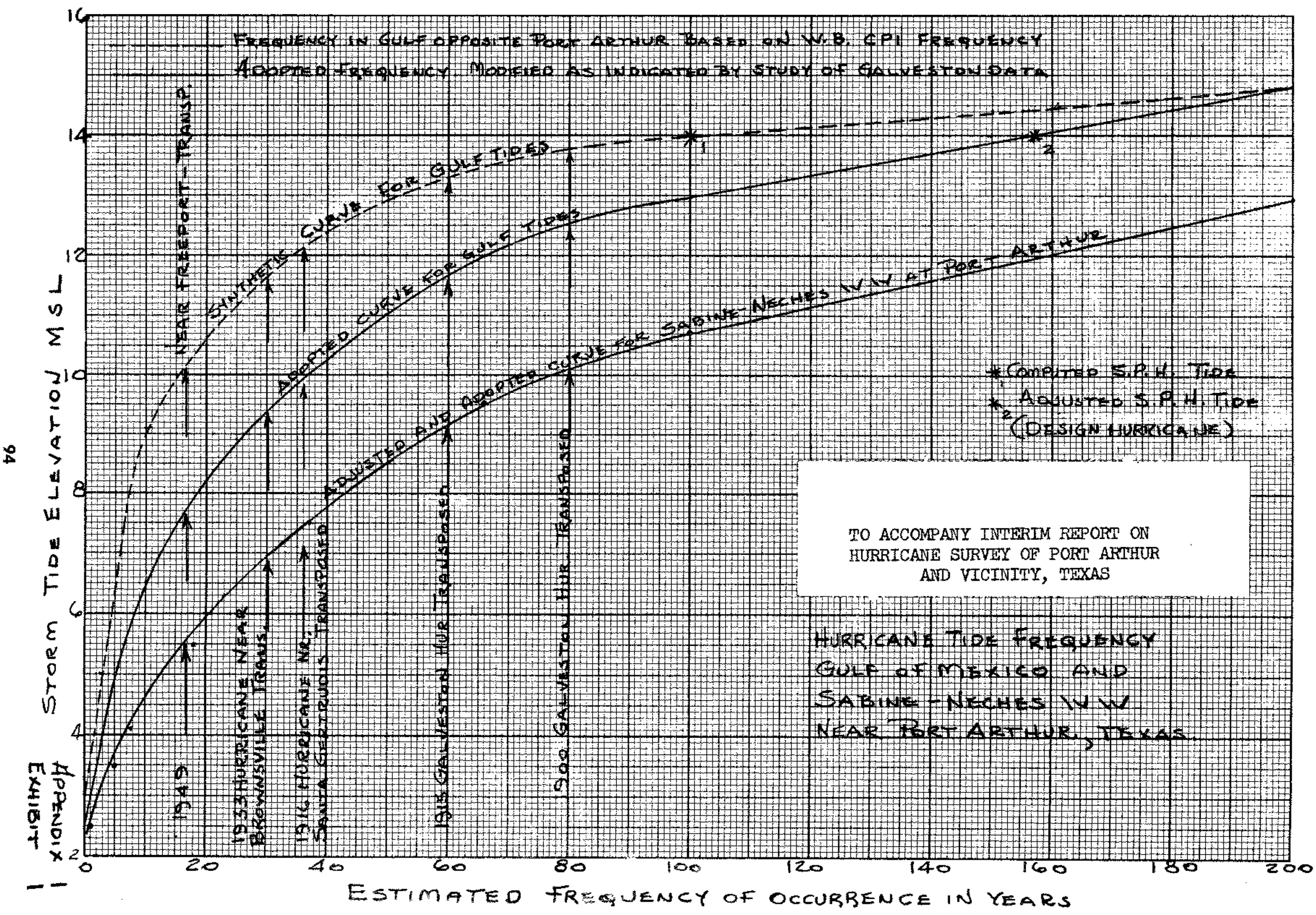
92. Interior drainage, subarea 13a, Rhodair Gully, (U-2), plan B.- This area includes about 1,730 acres and is No. 13a on exhibit 8. Improvements considered in this part of plan B are identical with those in plan A and are described in paragraph 81 of this appendix.

93. Interior drainage, subarea 16, Alligator Bayou, plan B.- This area includes about 27,670 acres and is No. 16 on exhibit 8. The area is composed of a portion of subarea 1 and all of subareas 4, 5, 7, 11, 12, 14 and 15 included in the compartmented plan A and an additional 19,000 acres not included in plan A. The additional area includes two airfields, industrial developments, and residential areas that were not included in plan A. This permits the omission of construction of a pumping plant of 470,000 gallons per minute proposed under plan A at site 20 and permits transferring this capacity to pump site 11. The runoff of 14,520 acre-feet from the 30-year coincident rainfall could be stored to an elevation of 3.6 feet above mean sea level. This elevation of flooding would be reduced to 2.5 feet above mean sea level with the pumping capacity of 1,174,000 gallons per minute at site 11. The runoff of 24,420 acre-feet from the 50-year all-season rainfall could be stored to an elevation of 4.7 feet above mean sea level. The area of flooding would be eliminated by the installation of gravity drainage structures with a capacity of 13,400 cubic feet per second.

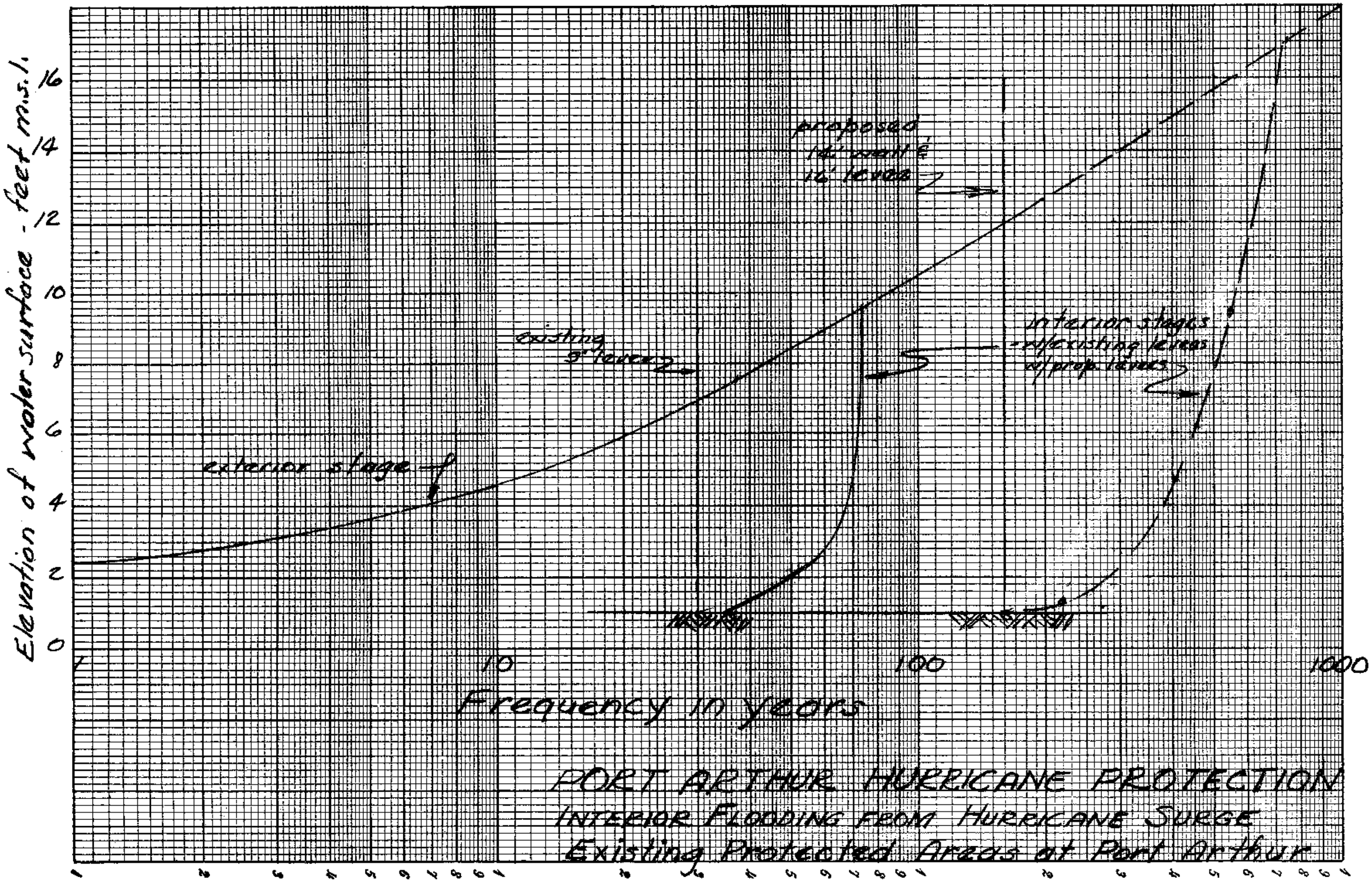
94. Frequency of flooding from storm tides under existing and improved conditions.- Because of the variation in grade, section, and condition of the existing levees protecting the Port Arthur area, precise evaluation of the frequency of tidal flooding under present conditions is not feasible. Nevertheless, the existing protection though not complete provides substantial protection for the lower tidal ranges, and an evaluation under existing conditions is necessary in order to establish the worthiness of additional protective works.

95. Exhibits 12 through 15 present an estimate of the interior flooding from hurricane tides expected under both existing and improved conditions of protection.

96. Flooding from interior rainfall runoff.- The provision of additional pumping capacity in the several subareas would lessen to some extent the frequency, elevation, and duration of ponding in the undeveloped portions of subareas numbered 3, 13, 13a, and 16 of exhibit 8. Exhibits 12 through 15 also shows, the frequencies of ponding of runoff, for the following conditions: (1) outlets are blocked by high tides under existing conditions without pumps, (2) under improved conditions with presently installed pumps, and (3) under improved conditions that would be based upon removal of runoff from interior rainfall by installing or increasing the existing pumping capacity sufficient to limit ponding in subareas 3, 13, and 13a to one foot above the existing ground elevation and in subarea 16 to one and one-half foot above the existing ground elevation.



Appendix I
Exhibit I



Appendix I Exhibit 10a
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APPENDIX II - ECONOMICS

INTERIM REPORT ON HURRICANE SURVEY OF PORT ARTHUR AND VICINITY, TEXAS

1. General.- This appendix presents the economics of proposed hurricane tide protection and drainage improvements in the vicinity of Port Arthur, Texas. The study area includes the communities of Port Arthur, Groves, Lakeview, Griffing Park, Pear Ridge, Port Acres, and El Vista, and the intervening areas. The area is divided by natural and artificial waterways and existing levee systems into seven economic subareas that are treated separately in this appendix. The economic subareas are shown on exhibits 1 and 2 of this appendix. The correlation of economic subareas of study with the drainage or hydrology areas of study, which are described in appendix I, is given in table 1.

TABLE 1

CORRELATION OF ECONOMIC SUBAREAS OF STUDY WITH DRAINAGE OR HYDROLOGY AREAS

Economic subarea	Name	Drainage subarea
A	Port Arthur	1, 2, 3, 4, 5, 6, 7, 8, 14
B	Sabine Road Tank Farm & Ethylene Plant (Gulf Oil Corp.)	9
C	Gulf Oil Water Reservoir	10
D	Miller Tank Farm (Texaco Inc.)	11
E	Additive Plant (Texaco Inc.)	12
F	Port Acres-El Vista	13, 15
G	Port Arthur Metropolitan (Port Arthur, Groves, Port Acres & intervening lands)	1 thru 5, 6, 7, 8, and 11 thru 16

2. The three sections of this appendix present data on (a) property values, (b) storm damages, and (c) benefits. The subareas are discussed individually in each of these sections. Section (a) contains estimates of the values of the physical property subject to storm tide damage within the Port Arthur area. Section (b) contains estimates of the damages from storm tides that would result from the occurrence of the design hurricane and estimates of the average annual storm tide damages. Section (c) contains data on the derivation of estimates of benefits that would be realized from each of the two proposed plans for hurricane protection.

improvements in the area and a summary of the estimated benefits that would accrue in each of the subareas. The improvements proposed under plan A generally would protect each of six presently developed areas separately, with no protection being provided for the intervening undeveloped areas. The economic subareas A, D, E, and F, north of Taylors Bayou, and B and C, south of the bayou, would comprise the six protection areas under plan A. The improvements proposed under plan B generally would protect all of the developed areas north of Taylors Bayou with one continuous levee and flood wall enclosure, and the two small industrial areas south of Taylors Bayou by separate enclosures. The economic subareas G, north of the bayou, and B and C, south of the bayou, comprise the three protection areas under plan B. All estimates of values and damages presented in this appendix are based on development in the area as of November 1959 and August 1961 price levels.

3. The estimates of property values and storm tide damages presented in this appendix are based on field inspections and surveys of the area made between November 1958 and November 1959. The surveys included inspection of all types of real properties within the area subject to storm tide inundation, determination of the value of the various properties, and the nature and estimated amounts of damages. Considerable data on values and potential storm damages were obtained from representatives of industrial plants and public utilities, real estate interests, officials of the city and county governments, business men, and private property owners. The area under investigation includes extensive petroleum refining and petro-chemical manufacturing and processing plants, including those of Texaco Inc., Gulf Oil Corp., Atlantic Refining Co., and Koppers Chemical Co. The area includes the urban areas of Port Arthur, Pear Ridge, Griffing Park, Lakeview, Groves, Port Acres, and El Vista. Also included is that part of the intervening area between Port Acres and Groves lying below the 11-foot contour line. This area is largely undeveloped marsh land, part of which is used for rice growing and pastures. Property owners were requested to furnish estimates of storm tide damages that would occur under inundation to elevation of 5, 10, or 15 feet m.s.l. The estimates were adjusted as necessary for uniformity and consistency within the various classes of property included in the survey. If the owners were unable to estimate their damages, estimates were based on data available on similar properties within the area. A small amount of land within the area is under cultivation or being used for pasture; however, for the purpose of this report, agriculture and stock raising in the Port Arthur area are of no consequence.

PROPERTY VALUES

4. Property values.- Property in the Port Arthur area consists primarily of industrial, commercial and residential properties. The total value of all physical property within the six subareas, which would be protected by improvements proposed under plan A, is estimated at $1,251,191,000. The total value of all physical property within the three subareas, which would be protected by improvements proposed under plan B, is estimated at $1,288,389,000. The value of the unimproved land is included in the estimates. An aerial mosaic of the Port Arthur area is included in this appendix as exhibit 10.

5. The following tables 2 and 3 present estimates of values by use classifications of property in each of the subareas considered for hurricane tide protection by the improvements proposed under plans A and B, respectively.

TABLE 2

PROPERTY VALUES IN THE PORT ARTHUR AREA - IMPROVEMENT PLAN A

Class of property	Economic study subareas						Total value of all areas
	A	B	C	D	E	F	
	(In thousands of dollars)						
Residential	363,483	0	0	0	0	16,168	379,651
Commercial	82,351	0	0	0	0	6,406	88,757
Churches	15,397	0	0	0	0	545	15,942
Schools	22,894	0	0	0	0	1,396	24,290
Industrial	576,692	79,944	3,760	11,530	3,391	6,813	682,130
Hospital	3,371	0	0	0	0	0	3,371
Utilities	15,030	0	0	0	0	1,240	16,270
Municipal	28,785	0	0	0	0	1,226	30,011
Federal	3,674	0	0	0	0	0	3,674
Unimproved land	4,923	0	0	0	0	2,172	7,095
Totals	1,116,600	79,944	3,760	11,530	3,391	35,966	1,251,191

TABLE 3

PROPERTY VALUES IN THE PORT ARTHUR AREA - IMPROVEMENT PLAN B

Property	Economic study subareas B	C	G	Total values of all areas
	(in thousands of dollars)			
Residential	0	0	379,651	379,651
Commercial	0	0	88,757	88,757
Churches	0	0	15,942	15,942
Schools	0	0	24,290	24,290
Industrial	79,944	3,760	625,126	708,830
Hospitals	0	0	3,371	3,371
Utilities	0	0	16,270	16,270
Municipal	0	0	30,011	30,011
Federal	0	0	3,674	3,674
Unimproved land	0	0	17,593	17,593
Totals	79,944	3,760	1,204,685	1,288,389

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STORM TIDE DAMAGES

6. Historical.- The developed area in the vicinity of Port Arthur has not sustained serious damages from hurricane tides since the 1915 storm. Severe storms are reported to have caused high tides at Sabine Pass and in the Port Arthur area in 1872, 1886 and, by some early residents, in 1897. However, prior to 1900 the area was sparsely settled and no information is available concerning tide heights or damages caused by the reported storms. The area was affected by the 1900 hurricane which devastated the city of Galveston. Tides of 8.0 feet at Sabine Pass and 4.5 feet in the Port Arthur vicinity were reported but damages are believed to have been small because of the sparse development.

7. Experienced damages.- Extensive damages resulted in Port Arthur from effects of the 1915 storm, which crossed the coast near Freeport about 100 miles to the southwest. Tides of 11.2 feet m.s.l. at Sabine Pass and 7.3 feet at Port Arthur were reported. Practically all of Port Arthur was inundated, with water being several feet deep in most of the houses and buildings. Six lives were lost and property damages were estimated at several million dollars. The city was placed under martial law for a period following the storm. Photographs of the flooding at several locations within the city are included as exhibit 11 of this appendix.

8. Following the 1915 flooding, earth levees were constructed to provide a measure of local protection to portions of the city. In 1932-33, the protection was expanded by construction of the existing earth levee which encircles the older part of the city. The 4.7-mile reach of concrete sheet-pile bulkhead along the Sabine-Neches Canal in front of the city was constructed at this time to provide erosion protection to the levee. These levees, supplemented by the system of earth levees and flood walls constructed by the Gulf Oil Corp. and Texaco, Inc., for their respective properties, constitute the existing protective system in the area. Generally the top elevation of existing levees is about 9 feet above mean sea level. The concrete sheet-pile bulkhead along the Sabine-Neches Waterway has failed at numerous locations, resulting in exposure of the earth levee to erosion from waves, vessel wash, and currents in the canal. In recent years many improvements have been built on low ground outside the limits of the existing protective system. Tides and waves produced by the design hurricane would overtop all existing protective structures for the area and would inundate all of the area considered for protection in this report.

9. On June 26-27, 1957, hurricane "Audrey", moving northward across the Gulf of Mexico, crossed the coast about 15 miles eastward from Port Arthur. Maximum tide elevations reached 9.2 feet at Sabine Pass and 4.8

feet at Port Arthur. Extensive wind damages occurred at Port Arthur and some flood damages were caused in the low areas near Port Arthur; however, these were not extensive. This storm devastated Cameron, Louisiana, about 35 miles east of Port Arthur, with a loss of over 500 lives. Tides of from 13 to 14 feet occurred along the coast east of Cameron for a distance of about 15 miles.

10. On September 11, 1961, hurricane "Carla" struck the Texas coast near Port O'Connor with reported winds of over 150 m.p.h. and tides exceeding 15 feet. On September 8, the hurricane was headed in a direction that could have crossed the coastline between Galveston and Port Arthur. Had this happened, it is estimated that the entire project area under study would have been inundated; the local protection would have been ineffective, and the damages would have exceeded $200,000,000. The center of the storm actually crossed the coast about 190 miles to the west of Port Arthur. Tides of 8.8 feet at Sabine Pass and about 7.2 feet m.s.l. at Port Arthur were experienced. Except in the Port Acres area the properties within the levee systems were protected, but the low-lying areas to the east of Port Arthur including the community of Groves were flooded with approximately 195 homes being inundated. To the west of Port Arthur the community of Port Acres was flooded after the levee system failed and about 500 homes were inundated. The damages in the Port Arthur area from tidal inundation caused by hurricane "Carla" are estimated at $5,000,000.

11. <u>Classes of damages</u>.- Inundation damage estimates were made separately for each of the subareas shown on exhibits 1 and 2 of this appendix. The estimates were computed on the basis of data obtained through field surveys and physical inspection of all property. The entire area was divided into sections of like physical characteristics, which were, in turn, further divided into smaller sections and blocks to facilitate evaluation of damages. Inundation damage estimates were made by considering a number of factors, including the type of loss, the kind and value of structure or improvement, depth of inundation, and location. Damage estimates were made separately for the various types of property classified by use as industrial, commercial, municipal, residential, schools, churches, hospitals and clinics, utilities, and unimproved land.

12. Primary damages in the area were estimated as the tangible losses that would occur through (1) physical damage to structures, machinery, and stock and cost of cleanup and repairs and (2) non-physical losses such as unrecovered loss of business, wages, or production, increased cost of operation and cost of temporary facilities for relief and rehabilitation of storm victims.

13. The primary damages were estimated by direct inspection and evaluation of losses by the property owners or field investigators. The non-physical portion of the primary loss for a given business or enterprise is sometimes difficult to evaluate on the basis of information available. When this situation was encountered, estimates were based on the known relationship between physical and non-physical losses for similar businesses in the area.

14. Secondary damages comprising loss to the national economy such as loss of production, transportation cost, or wages outside the project area because of loss of production in the project area have not been determined. Other intangible losses including loss of life and adverse effects related to public health, security and national defense have not been evaluated.

15. Damages from hurricane tides and rainfall.- Estimates of damages that would occur from storm tides were made for each of the subareas. Damages from storm tide inundation would start at exterior tide of 6 feet elevation at the Gulf Oil Corp. Sabine Road Tank Farm and the Texaco El Vista Tank Farm. Damages to El Vista and Rosemont would start at about 4 feet and in Port Acres at about 6 feet. Damages would reach major proportions in these communities and the lowest sections of Groves, which are without protection, at about 7 feet. Most of the refinery properties of the Gulf Oil Corp. and Texaco, Inc. have protection to elevations of 9 to 10 feet, but tides above those levels would overtop existing protection and resulting damages would be extensive. Damages in Lakeview and the part of Port Arthur enclosed by the existing levees would start after the tide had overtopped or breached the existing levees, which have an elevation of about 9 feet. Tides from the design hurricane would cause damage in all areas below the 11-foot contour line. Estimates were made of the damages that would result within each of the subareas A through G under existing conditions from inundation at various elevations from the stage at which flooding begins to 15 feet m.s.l. Stage-damage curves were made for the inundation damages that would occur under existing development and protection in each of the subareas, designated on exhibits 1 and 2 of this appendix. One composite stage-damage curve was made for all the areas included in plan A and one for plan B. These curves are shown on exhibits 3 and 5 of this appendix. These curves show damages throughout the areas for respective tide stages.

16. Damages from non-hurricane related rainfall.- Under existing conditions, inundation occurs from non-hurricane related rainfall runoff, particularly in the leveed areas. The interior stage-damage relationship for non-hurricane related inundation is the same as for hurricane related inundation.

17. Damages from design hurricane.- It is estimated that the design hurricane would produce a tide of about 12 feet in the Taylors Bayou vicinity along the southern edge of the Port Arthur area, decreasing to about 11 feet in the northerly parts of the area. Damages within each of the subareas for inundation to these elevations are estimated from the stage-damage curves. A summary of the estimated flood damages that would result from the design hurricane tide under existing conditions of development and protection in each of the subareas is given in tables 4 and 5. The estimated damages, which are shown by classes of property, include only damages caused by inundation, wave action, and scour. The total flood damages in the Port Arthur area from an occurrence of the design hurricane are estimated at $226,000,000 for the areas included in improvement plan A, and $228,000,000 for the areas included in improvement plan B.

TABLE 4
IMPROVEMENT PLAN A

ESTIMATED DAMAGES FROM DESIGN HURRICANE
UNDER EXISTING CONDITIONS OF DEVELOPMENT AND PROTECTION

Item	Economic subarea						Total areas
	A	B	C	D	E	F	
	(in thousands of dollars)						
Residential	64,810	0	0	0	0	4,948	69,758
Commercial	30,443	0	0	0	0	525	30,968
Churches	6,401	0	0	0	0	163	6,564
Schools	1,386	0	0	0	0	75	1,461
Industrial	98,328	5,794	1,088	412	262	588	106,472
Hospitals	1,425	0	0	0	0	0	1,425
Utilities	6,932	0	0	0	0	75	7,007
Municipal	1,581	0	0	0	0	182	1,763
Federal	582	0	0	0	0	0	582
Total	211,888	5,794	1,088	412	262	6,556	226,000

TABLE 5

ESTIMATED DAMAGES FROM DESIGN HURRICANE
UNDER EXISTING CONDITIONS OF DEVELOPMENT AND PROTECTION

IMPROVEMENT PLAN B

Item	Economic subarea B	Economic subarea C	Economic subarea G	Total all areas
	(in thousands of dollars)			
Residential	0	0	70,127	70,127
Commercial	0	0	30,968	30,968
Churches	0	0	6,564	6,564
Schools	0	0	1,461	1,461
Industrial	5,794	1,088	101,221	108,103
Hospitals	0	0	1,425	1,425
Utilities	0	0	7,007	7,007
Municipal	0	0	1,763	1,763
Federal	0	0	582	582
Total	5,794	1,088	221,118	228,000

18. Average annual damages.- Average annual damages to existing development were computed by combining the interior stage-damage relationships under existing conditions (see para. 15 and exhibits 3 and 5) with the tidal flood stage-frequency relationships (see exhibit 7) to establish the damage-frequency relationships shown on exhibits 4 and 6. The area under each curve represents the total amount of damages that would occur within a 100-year period in the project area under the existing protection and degree of development, from which the average annual damages for hurricane tide inundation are obtained.

19. A summary of the estimated average annual damages for plans A and B is presented in table 6. The total average annual damages are estimated at $4,700,000 for the area to be protected under plan A, and $4,825,000 for the area to be protected under plan B.

TABLE 6

ESTIMATED AVERAGE ANNUAL DAMAGES
IN SUBAREAS OF PORT ARTHUR VICINITY
UNDER EXISTING CONDITIONS

Plan	Average annual damages
A	$4,700,000
B	4,825,000

20. Future growth.- In estimating the future growth and development of Port Arthur and vicinity, consideration must be given to the industrial potential of the area and to space limitations imposed by the small amount of area suitable for industrial, commercial, and residential development under present conditions. Table 1 of the text shows that, during the 10-year period 1940 to 1950, the area population increased about 31 percent, and in the period 1950 to 1960, it increased about 42 percent. During the period 1940-1950, the population growth of the city of Port Arthur proper was considerably smaller than that of the general area. At that time, the city limits roughly corresponded to the existing levee system, where comparatively little space for development remained. However, in recent years extensive areas outside of the levee system have been incorporated into the city. In these areas, development has been rapid on ground higher than 6 feet elevation and desirable land suitable for development again is becoming scarce. Of the other incorporated towns adjacent to Port Arthur, only Groves has any sizable amount of desirable undeveloped land remaining. Improvement plan A would do little to alleviate the problem of suitable expansion space since, essentially, only the presently developed areas would be protected. The improvements proposed under plan B would afford adequate storm protection to additional large areas which otherwise probably would not be developed or would be developed in a manner that would virtually assure large future damages.

21. The Texas Business Review publication of October 1959, issued by the University of Texas, quotes an estimate of the Chemical Manufacturing Association that the petro-chemical industries in the Sabine-Neches area will increase their production 325 percent between 1955 and 1975. These plants are supplied with ethylene and other basic products by the petroleum refineries in Port Arthur; consequently, considerable growth and expansion of the refineries would be expected. Since petroleum refining and processing is the basic industry in Port Arthur, any change in the activities of the refineries would be reflected strongly in the over-all economy of the city. However, because of the trend toward automation in the petroleum industry, it is unlikely that increased employment would be directly proportional to the expected increase in production capacities of the plants. There is no doubt that the population and development of Port Arthur and vicinity will continue to grow and increase during the life of the proposed improvements. Particularly, with the improvements proposed under plan B, where several thousand acres of land would be opened to development, would a rather large growth be expected.

22. Without the proposed improvements growth and development would continue within the existing protected area and on the small amount of suitable lands outside the protected area and these areas would be filled in a relatively short time. In the Port Acres area and in the Crane Bayou area northeast of Port Arthur a pattern of development with a low degree of storm protection has been established by local developers and has been approved by home financing agencies. In this pattern, various sized tracts of low land are inclosed with levees ranging from 4 to 7 feet elevation and averaging about 5 feet. Pumps are provided to remove interior drainage from the inclosed areas. Because of the acute shortage of vacant land with higher elevations, it is believed that this pattern of development will continue until virtually full development of these two areas has been completed.

23. Little development of low lands has taken place up to this time in the large Alligator Bayou area west of Port Arthur, probably, because of the lack of convenient highway access. A recent relocation of State Highway 73 now extends along the easterly side of this area and it is probable that development of the same type that has occurred in the Port Acres and Crane Bayou areas will be started in the low lands of the Alligator Bayou area. Projected estimates of the population growth were made for the Port Arthur vicinity and an analysis was made of the land requirements for containing the overall development that would accompany the population growth. Based on this analysis, it was estimated that the Port Acres and Crane Bayou areas would be fully developed by about the year 2000, and that about one-half of the Alligator Bayou area below 6 feet elevation and all of the area above 6 feet elevation would be developed during the 100-year period considered for analysis of the proposed hurricane protection project. In keeping with the practices which have been followed in the existing developments occupying low lands, it is believed that developers would provide sufficient pumping for each small inclosure to limit ponding of runoff from non-hurricane related rainfalls to the streets and yards where little damage would result.

24. Damages from hurricane-related rainfall.- In the existing developed areas of Port Arthur and vicinity which are inclosed by levees with various degrees of protection from tidal flooding, pumping facilities generally are adequate for removing interior drainage. During short periods of intense rainfall, runoff accumulates and ponds in the lowest area. However, the ponding generally is limited to streets and yards in the lowest areas and only minor damage results. In the Snake Bayou and Rhodair Gully vicinities of Port Acres, the installed pumping capacity is deficient and frequent flooding is a problem in these areas. In the Crane Bayou and Alligator Bayou areas, existing drainage is by gravity flow and the degree of flooding in the lowest parts of the areas varies with the tide levels.

25. As discussed in appendix I, interior drainage of leveed areas may be either by gravity flow during normal or low tide periods or by pumping, which is independent of the exterior tide level. In most cases, the most economical solution is found by a combination of the two methods. Although more costly, pumping of all interior drainage is usually the most satisfactory method for extensively developed areas. With this method, deep sumps at the pumping stations permit adequate flow gradients for both subsurface and surface drainage collection facilities. As discussed, also, in appendix I, it was determined that an adequate degree of protection from interior flooding by rainfall would limit ponding to non-damaging levels from rainfall occurring coincident with exterior tides sufficiently high to block gravity outflow, with a frequency not exceeding once in 30 years. Pumping capacities, based on this criterion, and used in combination with gravity flow outlets, generally would limit ponding to non-damaging levels from an all-season rainfall (without consideration of exterior tide levels) having a frequency of about once in 50 years. The 24-hour rainfall for the two conditions in the Port Arthur area was determined to be 9.7 inches and 14 inches, respectively.

26. Based on the criterion stated above, it was determined that adequate hurricane protection for the Port Arthur area would include installation of pumping facilities in the Crane Bayou area, northeast of Port Arthur, the Snake Bayou and Rhodair Gully vicinities of Port Acres, and the Alligator Bayou area, west of Port Arthur. The pumping capacities proposed for installation in each location are shown in the plan of improvement.

BENEFITS

27. General.- The proposed improvement of the existing storm protection system would provide benefits as follows:

a. The prevention of most of the damages to existing developed areas that would result from flooding by hurricane tides accompanying hurricanes.

b. The prevention of damages to future development within the area protected from flooding by hurricane tides and

c. The enhancement from increased utilization of low undeveloped lands located outside of the existing levees which would be afforded storm protection under the proposed plan of improvement.

28. Residual damages - levee improvements.- The proposed levee improvements would prevent most of the damages from storm tide flooding that now occur to existing properties or that would occur to future development under the present degree of protection. However, some damages would continue to occur after the proposed levee improvements were installed. These residual damages would result from a small amount of wave overtopping and washover into parts of the protected areas during the peak of the design hurricane. The very infrequent hurricanes larger than the design storm would produce the same result to a somewhat greater degree. Runoff from interior rainfall within the leveed areas would pond in the lowest parts of the areas during the period that gravity outflow is blocked by the high hurricane tides. The accumulation of water from these sources would cause some flooding and damages. However, the residual damages for the levee improvements would be materially reduced by the pumps which have been installed in the existing leveed areas and the additional pumps which would be provided under the plans of improvement. The remaining residual damages would be small and would not warrant the significant additional costs which would be required to eliminate all damages.

29. Prevention of damages to existing developments.- Most of the damages from inundation and scour, caused by hurricane tides, to property within the locally constructed levees would be eliminated by the improvements to the existing levees proposed herein. Damages from inundation and scour to existing properties located outside of the existing levees would be prevented by the extension of adequate levees to protect the areas which are now developed but have no storm tide protection. Estimates of benefits from the prevention of inundation damages to existing properties were derived by computing the average annual residual damages, or the damages that would continue to occur after the proposed levee improvements were constructed, and deducting those amounts from the estimated average annual damages that occur under existing conditions. The benefits claimed for the proposed improvements are limited to the prevention of damages from storm tides up to the design stage of 12 feet. Estimates of average annual damages, residual damages, and damages prevented to existing properties for both plans of improvement are tabulated in table 7.

30. <u>Prevention of damages to future growth developments</u>.- As discussed in paragraph 23, development is expected to continue in the Port Arthur vicinity, both on the small amount of vacant land in the existing developed areas, and in the large areas of adjacent low lands. The proposed levee improvements would prevent hurricane flood damages to all future developments built on land of less than 12 feet elevation in the same manner that damages would be prevented to existing properties. For the future development of vacant land in the existing developed areas, the damages that would be prevented to future growth were computed as a percent of the estimated damages prevented to existing properties, with the percent being determined by the ratio of vacant land and developed land at the same general elevation in each existing developed area. This method was used for all areas except the Crane Bayou and the Alligator Bayou areas.

31. Existing developed areas adjacent to Crane Bayou and Alligator Bayou are small compared with the large area of low, vacant land. As discussed in paragraph 23, projections were made of the expected growth and development into these areas, with a low degree of protection assumed to permit development, and a limit of the expected future development was established for each area with the estimated date for this limit of development. Stage-damage, stage-frequency, and damage-frequency relationships were estimated for the future development and, in a manner similar to that used for existing properties, average annual damages, residual damages, and damages prevented, were estimated. Since the computations were based on future development, compound interest methods were used to determine the average annual equivalent benefits for the damages prevented to future growth developments. The average annual equivalent benefits are shown in table 7.

TABLE 7

ESTIMATED AVERAGE ANNUAL BENEFITS
FROM PREVENTION OF DAMAGES BY LEVEE IMPROVEMENTS
(EXCLUDING PUMPS)

Plan	Avg. annual damages to existing property	Residual damages(1)	Prevention of damages to: Existing properties	Growth and development(2)	Total benefits
A	$4,700,000	$2,500,000	$2,200,000	$2,273,000	$4,473,000
B	$4,825,000	$2,225,000	$2,600,000	$3,577,000	$6,299,000

(1) Does not consider the effect of pumps provided for interior drainage.
(2) Average annual equivalent benefits.

32. Damages prevented by proposed pumps.- Separate determinations of the benefits to be derived from the proposed installation of pumps were made for each watershed in which pumps are proposed. The benefits would accrue from prevention or reduction of the damages caused by flooding of properties within the protective levees by: (1) runover of waves from infrequent hurricanes that approach the magnitude of the design storm or greater, and (2) the ponding of water from heavy rainfall accompanying hurricanes which cannot run off because of the hurricane tide. The benefits were determined by constructing stage-damage curves to include both existing and future development. The future development was estimated to include residential, commercial, industrial, utility, and municipal properties in about the same proportions as existing developed areas. In the Rhodair Gully and Snake Bayou areas of the Port Acres vicinity, local developers have provided pumps which remove some water from the areas. The pumps, however, are not installed or housed in a manner to insure their operation during the severe physical conditions of a major hurricane. This was demonstrated in the recent hurricane "Carla" flooding when all pumps failed. It is believed that any installations of pumps made by local developers in the Alligator Bayou or Crane Bayou areas for future development would be similar. Also, in the Alligator Bayou area, it is unlikely that the pumps installed by developers would be located to discharge water out of the area. It is probable that such pumps would only remove water from small localized inclosures and would discharge into the remaining part of the over-all area. Accordingly, stage-frequency curves were constructed without consideration of the effects of locally installed pumps for these areas. Two sets of stage-frequency curves were developed, one with the proposed pumps, and one without. The two sets of stage-frequency curves were correlated with the stage-damage curves to produce two sets of damage-frequency curves, reflecting conditions with and without the proposed pumps. Average annual damages were computed from both sets of damage-frequency curves and the benefits were computed as the difference in damages under the two conditions.

33. Since the damages would be prevented to both existing properties and future growth by the proposed pumps, a separation was made for each area, based on the ratio of the estimated values of existing properties and future growth that would be benefited by the pumps. The portion attributed to future growth was reduced to average annual equivalent benefits by compound interest methods. The estimates of damages prevented by the proposed pumps in each subarea are summarized in the following table 8.

TABLE 8

BENEFITS FROM DAMAGES PREVENTED IN EACH SUBAREA BY INSTALLATION OF PUMPS

Plan, economic subarea and location	Damages prevented to: Existing properties	Growth & development (1)	Total damages prevented
PLAN A			
A (Crane Bayou)	$12,000	$ 69,000	$ 81,000
A (Groves)	9,000	39,000	48,000
F (Rhodair Gully)	2,000	26,000	28,000
F (Snake Bayou)	3,000	44,000	47,000
Total, plan A	26,000	178,000	204,000
PLAN B			
G (Crane Bayou)	12,000	69,000	81,000
G (Rhodair Gully)	2,000	26,000	28,000
G (Snake Bayou)	3,000	44,000	47,000
G (Alligator Bayou)	0	55,000	55,000
Total, plan B	17,000	194,000	211,000

(1) Average annual equivalent benefits

34. In the Alligator Bayou area, under plan B, additional benefits from the pumps would be derived from the reduction in the frequencies and depths of ponding on the remaining undeveloped land, which would not be occupied by the expected growth and development. The use of this land would be changed from ponding to residential and it would be enhanced in value; however, the enhancement would result also from removal of the storm tide threat by construction of the levee improvements. The enhancement of this land is discussed more fully in paragraphs 35 and 36.

35. Increased utilization or enhancement benefits.- The projected future growth and development in the Port Arthur vicinity is estimated to require use of all vacant land within the limits of the protected area except in the large Alligator Bayou area west of Port Arthur. As discussed in paragraphs 23 and 31, damage prevention benefits would be realized from the improvements proposed in plan B in about one-half of the part of this area below 6 feet elevation, which would be developed with a low degree of storm protection provided by the developers. Provision of the levees and pumps proposed under plan B also would permit development of the remaining part of the area located between 6 feet elevation and 2.5 feet elevation, or the ponding elevation for interior drainage with the pumps. The provision of adequate protection should result in a considerable and immediate increase in value of this land, with the increase being estimated at over a thousand dollars per acre. However, development of similar areas is occurring in the Port Acres vicinity by provision of a similar type of low-degree storm protection by developers. It is believed that a more realistic and conservative measure of the increased utilization benefit would be the estimated cost of providing the low type of storm protection, since this also would permit the development to occur. The average cost of this type of protection has been estimated at about $550 per acre, equally divided between levee costs and pump costs.

36. Of the one-half of the land in the Alligator Bayou area for which increased utilization benefits are estimated, 2,200 acres are located between 6 feet elevation and 3.6 feet elevation, the level at which interior drainage from the design rainfall would pond without pumps. Enhancement of this land would result solely from the provision of storm protection and is credited to the levees. The pumps provided for this area in plan B would lower the level of ponding to 2.5 feet elevation, and would enhance the value of an additional 2,250 acres of land. The total estimated enhancement for 4,450 acres of land in the Alligator Bayou area is $2,448,000 which, reduced to an annual basis over the 100-year period of analysis for the project, is $122,000 annually, of which $61,000 is credited to the levees and $61,000 is credited to the pumps.

37. Reduction in scare costs.- In addition to hurricane tide damages, other significant losses would be sustained in areas susceptible to storm tide damages. These losses stem from the costs of temporary measures to minimize losses, plant shutdown, and related costs. Contacts with business, municipal, and industrial representatives reveal

that, even though adequate protection from inundation by hurricane tides is provided, these scare costs would still be incurred because of the high hurricane winds. In order to minimize the damage from high winds, property owners, businessmen, city officials, and industrial operators would continue to take temporary protection measures differing little in cost from those now taken. These costs often are incurred when a hurricane threatens, even though the hurricane later does not affect the locality. Since scare costs from the threat of high tides cannot be accurately separated from those attributable to high winds and, also, since the scare costs probably would be about the same with or without hurricane tide protection, no benefits from reduction of scare costs have been credited to the proposed improvements.

38. Intangible benefits.- In addition to tangible benefits, certain benefits of an intangible nature would be realized. These would include elimination of loss of life from storm tides, reduction of sanitary and health hazards, and a reduction in fire hazards. No attempt has been made to evaluate benefits of this nature.

39. Summary of benefits.- The annual benefits that would be derived from the improvements proposed under plans A and B have been evaluated on the basis of October 1961 prices. The total annual benefits estimated for the proposed improvements for hurricane tide protection for improvement plans A and B and in each of the economic subareas in the vicinity of Port Arthur, Texas, are summarized in the following table 9.

TABLE 9

ESTIMATED AVERAGE ANNUAL BENEFITS FOR
IMPROVEMENT PLANS A AND B
HURRICANE FLOOD PROTECTION
PORT ARTHUR AND VICINITY, TEXAS

Plan	Prevention of damages to: Existing properties: By levees	By pumps	Growth & development(1): By levees	By pumps	Increased utilization or enhancement	Total benefits
A	$2,200,000	$26,000	$2,273,000	$178,000	$ 0	$4,677,000
B	$2,600,000	$17,000	$3,577,000	$194,000	$122,000	$6,510,000

(1) Average annual equivalent benefits.

40. <u>Comparison of benefits and costs</u>.- The annual benefits accruing to each economic subarea in the Port Arthur vicinity were developed as described in the foregoing paragraphs of this appendix. Benefits accruing to the local protective works have been excluded from the analysis of the benefits derived from the proposed improvements. The estimates of annual charges incurred by the improvements were extracted from the detailed computations shown in appendix IV of this report. The annual charges include the maintenance, operation, and repair of the additional protective and appurtenant works.

41. The estimated first costs, annual benefits, annual charges, and ratio of benefits to charges for the proposed improvements are given in the following table 10.

TABLE 10

COMPARISON OF BENEFITS AND CHARGES
IMPROVEMENT PLANS A AND B
IN THE VICINITY OF PORT ARTHUR, TEXAS

Plan of improvement	Total first cost (1)	Total annual charges	Total annual benefits (1)	B/C ratio
Plan A	$ 33,900,000	$1,140,000	$4,677,000	4.1
Plan B	33,400,000	1,150,000	6,510,000	5.7

(1) Does not include additional pumps for interior damage.

42. <u>Comparison of benefits and costs of pumps</u>.- A comparison of the estimated annual benefits and annual charges for the pumps proposed for installation in the several subareas under both improvement plans A and B is shown in the following table 11. The estimated annual charges were extracted from the detailed cost estimates in appendix IV. The estimated benefits are described in paragraph 32 through 36 of this appendix.

TABLE 11

COMPARISON OF BENEFITS AND CHARGES
FOR ADDITIONAL PUMPS PROPOSED IN VARIOUS SUBAREAS

Locality	Additional pumping capacity proposed (G.P.M.)	Included in improvement plans	Total annual benefits	Total annual charges	B/C ratio
Crane Bayou	680,000	A & B	$ 81,000	$57,000	1.4
Groves	470,000	A	48,000	39,000	1.2
Snake Bayou	290,000	A & B	47,000	23,000	2.0
Rhodair Gully	290,000	A & B	28,000	23,000	1.2
Alligator Bayou	1,170,000	B	116,000	90,000	1.3

INTERIM REPORT ON
HURRICANE SURVEY OF
PORT ARTHUR AND VICINITY,
TEXAS

APPENDIX III

ENGINEERING AND DESIGN

GENERAL

1. Scope.- This appendix contains information concerning the engineering and design of the plans for improvements to provide hurricane flood protection to Port Arthur and vicinity, Texas. Information on geology, foundations and materials, pertinent to the structural and mechanical design are also presented.

2. Surveys and explorations.- Field surveys including profiles and cross sections were made in 1958 of the existing flood protection system and the routes of proposed extensions. Subsurface explorations were made at representative locations. Considerable data relative to existing structures and protection facilities were obtained from engineering departments of the city of Port Arthur, the Gulf Oil Corp., Texaco Inc., and Jefferson County Drainage Districts No's 4 and 7. All elevations used in this report refer to mean sea level datum. Data relative to subsurface explorations are discussed in paragraphs 24 through 28.

3. Existing storm protection works.- The existing storm protection works at Port Arthur consist of earth levees, floodwalls and pump stations, which are described in the following paragraphs and shown on plate 2. Those portions which would be affected by the improvements proposed herein are described in conjunction with the description of the new works.

4. The existing protective system has a total perimeter length of about 29 miles and encloses generally the older parts of the developed area, including portions of the cities of Port Arthur and Groves, the towns of Lakeview, Griffing Park and Pear Ridge and the industrial plants of the Gulf Oil Corp. and Texaco Inc. In addition there are about 3 miles of interior levees along common boundaries of the city of Port Arthur and the Gulf and Texaco refineries. The crest elevation of the existing levees generally is about 9 feet. The city of Port Arthur has constructed about 4.9 miles of floodwalls along the Sabine-Neches Canal to protect the earth levees from wave wash and erosion along the canal.

5. About 1,700 feet of the seawall consists of interlocking steel sheet-piles and 24,166 feet consists of concrete sheet-piles. The bottoms of the concrete piles generally are at an elevation of -15 feet. The wall has a concrete cap with a top elevation of +4.3 feet and is anchored

by steel tie rods and concrete deadmen at 12 feet centers. The steel sheet-pile wall, which is along the front of the Sabine Transportation Company marine repair yard, has a top elevation of +9 feet and a bottom elevation of -45 feet mean sea level.

6. Failures in the concrete pile seawall have occurred at several points during the last 10 to 12 years. Local interests attribute these failures to erosion of the side slopes of the canal. Erosion of the shore along the city front has been a continuous problem both prior to and subsequent to construction of the navigation channel. The shore was actively eroding when it was an open lakeshore, prior to construction of the canal. Erosion was also a problem along the west bank of the Sabine-Neches canal following its original construction to a depth of 10 feet in 1908. The problem was greatly reduced in front of the city by construction of the seawall in 1933. Comparative cross-sections of the canal indicate that from 1931 to 1951, the maximum erosion along the channel side of the seawall was about 13 feet, and the average erosion over the 20-year period was about 5 feet. The navigation channel in front of the seawall was deepened from 31 feet to 37 feet during the 20-year period, but no widening was done on the side of the channel adjacent to the seawall.

7. Investigation reveals that some of the failures of the seawall resulted in an overturning movement of the top of the wall toward the channel. In most of the failures of this type, it was found that tie-rods anchoring the seawall to deadmen on the landward side had broken and allowed the top of the wall to lean channelward, with little apparent movement of the toe of the wall. At other locations, failure had resulted in an outward movement of the bottom of the sheet-piles due to erosion along the wall. The city of Port Arthur from time to time has repaired some of the more serious sections of failure; however, at this time there are at least five unrepaired failures totaling 570 feet in length. The cost of making these repairs has averaged about $285 per linear foot of wall. The levee embankment behind the seawall erodes rapidly following each failure. Because of the evident general deterioration of the tie-rods and continuing erosion along the front of the seawall, it is apparent that failures will continue at an increasing rate. At this time, the entire existing wall appears to be approaching the end of its useful life.

8. The area enclosed by the existing levee system is drained primarily by pumping. A number of small localized areas along the Sabine-Neches Canal are drained by gravity flow into pipe conduits extending through the seawall. Drainage through these outlets is blocked by tides slightly above normal. The city of Port Arthur operates fourteen existing pumping stations with total capacity of 1,956,000 g.p.m. and Jefferson County Drainage District No. 7 operates two stations, one with 590,000 g.p.m. capacity west of Park Place, and the other with 150,000 g.p.m. capacity south of El Vista. All of the underground drainage system within the leveed area is designed for gravity flow into deep sumps at the various pumping stations. The Gulf Oil Corp. and Texaco Inc. refineries have seven principal pumping stations for interior drainage of their plants.

Eight of the stations operated by the city and two by the refineries discharge into the Sabine-Neches Canal. The remaining stations discharge into Taylors and Alligator Bayous. The pumping stations operated by the city and the drainage district are identified as follows:

Name or location	Pumping capacity (g.p.m.)
Lakeview	275,000
Stadium Road	6,000
Del Mar	180,000
DeQueen Blvd.	120,000
Shreveport Ave.	80,000
Houston Ave.	10,000
Grannis Ave.	15,000
Foley Ave.	140,000
Central	700,000
Memorial Blvd.	590,000
Rhodair Gully	30,000
Snake Bayou	160,000
Snake Bayou (east)	60,000
Snake Bayou (west)	30,000
El Vista	150,000

9. Plans investigated.- Several plans were considered initially for providing protection to the city of Port Arthur, from flooding by hurricane tides and rains. Preliminary analysis of these plans revealed that only two plans warranted further investigation. The two plans that were developed in detail are identified as plan A, shown on plate 3, and plan B, shown on plate 2.

10. The protection system proposed under plan A would enclose four separate areas north of Taylors Bayou and two small, separate industrial areas south of Taylors Bayou. These areas would approximate the presently developed portions of Port Arthur and vicinity. Plan B would provide for a single enclosure of the entire area north of Taylors Bayou and separate enclosures for the two small areas south of the bayou. The improvements proposed under plan B would protect substantial amounts of low undeveloped land and would make this land suitable for residential and industrial development.

11. As discussed in paragraphs 75 and 76 of the text, plan B was found to be the more desirable plan. Plan B is described in detail in the following paragraphs. Only a brief description is given of plan A in paragraphs 50 through 56.

12. Improvements proposed under plan B.- The improvements proposed under plan B would consist of reconstructing and raising 4.9 miles of concrete and steel sheet-pile seawall along the Sabine-Neches Canal; reconstructing and raising various reaches of existing concrete and steel sheet-pile floodwalls totaling about 1.7 miles; constructing 0.3 mile of new concrete and steel sheet-pile floodwalls; enlarging and raising 10.6 miles of existing earth levees; constructing 18.7 miles of new earth levees; and constructing miscellaneous appurtenant structures including highway, road and street ramps, gate closure structures, structural modifications to existing pump stations, four additional drainage pumping stations, and various gravity drainage outlet structures. The combined length of protective walls and levees would be about 35.2 miles, including 28.3 miles of earth levees, 4.9 miles of concrete seawall, and 2 miles of concrete and steel sheet-pile floodwalls. These lengths do not include a reach of about 1.5 miles along the Sabine-Neches canal, where spoil deposits from waterway dredging have raised ground elevations higher than 16 feet and a reach of concrete floodwall 490 feet long, located along Taylors Bayou, which does not require alteration.

13. The levees and floodwalls proposed under plan B would protect an area totaling about 60 square miles which is subject to flooding by hurricane tides. The new earth levees would begin north of Groves at the 12-foot contour and extend southeastward about 4.8 miles along the Neches River marsh line to the Sabine-Neches canal; thence southwestward for about 3 miles along the canal to the Lakeview pump station; thence following the route of the existing protective system along the canal with new concrete sheet-pile floodwalls as follows: about 2.4 miles of type 2 floodwall extending to Woodworth Blvd. (the several types of floodwall are described in paragraphs 40 to 48); about 2 miles of type 3 floodwall and levee extending to Houston Ave.; about 0.3 mile of type 4 and 0.2 mile of type 2 floodwalls extending to the slip located between the Sabine Towing Co. and the Gulfport Shipbuilding Co.; thence following the route of the existing earth levees northwestward to West Procter St. and generally southwestward to Taylors Bayou; thence northwestward along Taylors Bayou with levees and floodwalls to the southwest corner of the existing protective system enclosing the Gulf Oil Corp. refinery; thence generally west along Taylors Bayou with new earth levees to Rhodair Gully and northward along Rhodair Gully to the 12-foot contour near the Jefferson County airport. The locations of this enclosure and the two small enclosures south of Taylors Bayou are shown on plate 2 of this report. A plan of stationing for the proposed protection system and a tabulation of reaches and types of the various levees and floodwalls are shown on exhibit 1 of this appendix. An aerial photograph mosaic of the enclosed area is included as exhibit 10 of appendix II.

14. Levees and floodwalls.- The new and enlarged levees would have a crown width of 12 feet and crest elevations ranging from 16 feet along the south side of the area to be protected to 12 feet along the north side and along reaches not subject to wave attack. The floodwalls vary in height from 14 feet in reaches subject to wave attack to 12 feet in reaches not subject to waves. The levees would have side slopes 1 on 3 and would be riprapped where exposed to possible severe wave action. The levee crown would be protected by a 6-inch layer of bituminous treated shell surfacing. All slopes of levees not riprapped would be protected by a turf cover. Typical sections of the levees and floodwalls are shown on exhibit 4 and 5.

15. Highway and railroad crossings.- The improved levees and floodwalls would intersect 5 railroads, 5 state highways, several county roads, and a number of city streets and industrial plant roads. No alteration of railroad grades would be required. Gate closure structures would be provided at all railroad crossings. A typical closure structure is shown on exhibit 5. The enlarged and new levees would be adapted to road and highway crossings by suitable ramping or by gate closure structures as deemed most feasible. Several of the ramps would be adapted to provide access to the service road on top of the levee. A tabulation of the facilities to be crossed by the proposed improvements and the types of structures proposed for each crossing is given in the following table 1.

TABLE 1

HIGHWAY AND RAILROAD CROSSINGS
PROPOSED UNDER PLAN B

Location (Station)	Facility intersected	Type of crossing	Elevation (feet) Levee	ground
North of Groves				
-5+820	State Highway 366	Ramp	12	9
-2+700	Port Neches Atlantic Road	Ramp	12	9
Northeast of Groves to Lakeview pump station				
7+700	Road to Atlantic wharf	Ramp	12	4
12+150	Highway 87	Ramp	16	2
27+500	County Road	Ramp	16	2
28+850	KCS RR Spur to Burton Shipbuilding Co.	Gate	16	3
30+550	Road to Burton Shipbuilding Co.	Ramp	16	5
Lakeview pump station to Sabine Towing Co.				
46+194	Woodworth Boulevard	Gates	14	5
55+030	Waco Avenue	Gate	14	5
55+184	Seawall Drive	Gate	14	5
59+300	Sabine Towing Co. personnel gates	Gates (5)	14	5
Sabine Towing Co. to Taylors Bayou turning basin				
59+850	West Lake Shore Drive	Ramp	16	3
60+250	Kansas City Southern R.R.	Gate	16	3
68+000 to 72+000	Texaco 7th St. tank farm maintenance roads (10)	Ramp	16	2
72+200	Texaco Terminal Road	Ramp	16	2
74+888	Southern Pacific R.R.	Gate	16	3
75+238	Kansas City Southern R.R.	Gate	16	3
75+590	Road to Gulf parking lot	Ramp	16	3
76+883	Road to Gulf barge terminal	Ramp	16	8
Taylors Bayou turning basin to Alligator Bayou				
77+290	Gulf Marine Ways	Ramp	16	4
79+395	Road to Gulf wharves	Ramp	14	4
81+100	Gulf wharves personnel gates	Gates(3)	14	5
83+035	Southern Pacific R.R.	Gate	14	4
83+510	State Highway 87	Ramp	14	4
Alligator Bayou to Highway 73 (south of Port Acres)				
119+530	State Highway 73	Ramp	16	5
Highway 73 (south of Port Acres to Midcounty airport)				
132+00	State Highway 365	Ramp	12	3

TABLE 1 (Cont'd)

Location (Station)	Facility intersected	Type of crossing	Elevation (feet) Levee	ground
Sabine Road Tank Farm				
0+250B	Spur to Gulf Tank Farm	Gate	14	5
0+425B	Spur to Gulf Tank Farm	Gate	14	5
0+430B	Spur to Gulf Tank Farm	Gate	14	5
0+250B	Road - Main Entrance Road	Ramp	14	5
0+250B	Road - Entrance Road	Ramp	15	5

16. Gravity flow drainage structures.- Gravity flow of interior drainage at the major outlets of Crane Bayou, Alligator Bayou, Snake Bayou and west of Port Acres into Rhodair Gully would be obtained through gated structures of the type shown on exhibit 7. All of these structures would be equipped with 20 feet by 12 feet vertical lift gates and with automatic flap gates. The structure proposed for the main outfall canal near Alligator Bayou would replace an existing salinity control structure. The vertical lift gates would be closed only when an abnormally high tide was expected. The drainage structures would be designed to withstand hydrostatic and wave pressures resulting from a 12-foot tide and a 2-foot wave. They would be reinforced concrete supported on timber piles. Uplift pressures would be reduced by the installation of an asphalt moisture barrier in front of the structure. Present data is not sufficiently accurate to determine exact limits of ponding areas and gravity structures have been sized to take care of all water. Detail project studies might determine that the structure size should be reduced. Topography and limits of ponding areas are not delineated beyond extent necessary to estimate costs for survey scope accuracy. Design of gravity outlet structures and costs estimated therefor have been based on the maximum estimated condition of runoff and times of concentration. These facts would be studied and re-estimated in greater detail in post authorized studies, and it is possible some reduction in design capacities would result.

17. At various locations interior drainage pipes and conduits equipped with both automatic flap gates and manually controlled gates would be required. During period of high tides it would be necessary for local interests to close the manual gates and keep the automatic flap gates free from trash or debris which might prevent the gates from closing. The locations of the principal gravity drainage outlets are given in the following table 2.

TABLE 2

GRAVITY DRAINAGE OUTLET CROSSINGS
PROPOSED UNDER PLAN B

Location (Station)	Drainage outlet intersected by proposed improvements	Type of closure structure
North of Groves area		
-6+020	Drainage ditch by water treatment plant	2 - 60" x 60" slide gates
-4+500	Drainage ditch along Port Neches-Atlantic Road	60" x 60" slide gate
Northeast of Groves to Lakeview pump station		
8+800	Atlantic refinery drainage ditch	48" gated pipe - 35 ft. long
9+900	Atlantic refinery waste water ditch	48" gated pipe - 35 ft. long
12+200	Highway #87 drainage ditch	60" gated pipe - 60 ft. long
27+580	Crane Bayou	3 - 20 ft. x 12 ft. gated structure
Lakeview pump station to Sabine Towing Co.		
Various locations	Minor drainage pipes of various sizes	Combine and provide gates
Sabine Towing Co. to Taylors Bayou turning basin		
Various locations	Minor drainage pipes of various sizes	Combine and provide gates
Taylors Bayou turning basin to Alligator Bayou		(None)
Alligator Bayou to Highway 73 (South of Port Acres)		
89+900	Alligator Bayou drainage channel	10 - 20 ft. x 12 ft. gated structure
91+900	Texaco outfall canal	3 - 5 ft. x 5 ft. gated structure
111+300	Snake Bayou	2 - 20 ft. x 12 ft. gated structure
Highway 73 (South of Port Acres to Midcounty Airport)		
131+600	Rhodair Gully drainage ditch	1 - 20 ft. x 12 ft. gated structure
Sabine Road Tank Farm		
14+900B	Old Salt Bayou ditch	3 - 60" x 60" slide gates

18. The city of Port Arthur has initiated a program to divert all sanitary sewers which now empty into the Sabine-Neches Canal and Alligator Bayou, into a disposal plant northeast of the city. It is expected that this program will be completed prior to commencement of work on storm protective facilities. As a part of the plan of improvement all storm sewer lines crossing the levees or floodwalls would be diverted into pump stations wherever practical. Where it is not practical to divert them into pump stations these lines would be combined if possible and gated at the levee crossing. Both manually operated slide and automatic flap gates would be used on all conduits.

19. Pumping stations.- Four pumping stations are proposed, at the four major gravity drainage outlets, for removal of interior rainfall runoff during periods when high tides block gravity drainage. The pumping stations are proposed under plan B in the locations and capacities shown in the following tabulation:

Location	Pumping capacity gallons per minute
Crane Bayou	680,000
Alligator Bayou	1,170,000
Snake Bayou	290,000 additional
Rhodair Gully west of Port Acres	290,000 additional
Total	2,430,000

20. Pumphouses for the proposed pumping stations would be of reinforced concrete construction and founded on timber piles. The bottom of the intake sumps would be at elevation minus 13.5 feet. Trash racks would be provided at the entrance to the sump pit. The pumps would be driven by diesel or butane engines. The individual pumps would range in size from 100,000 g.p.m. to 350,000 g.p.m. capacity. Details of a typical pumping station are shown on exhibit 6.

20a. Encroachment of ponding area.- Local interests are responsible for maintaining the existing storage capacities of the present ponding areas as follows:

a. Crane Bayou area, approximately 165 acre-feet in an area approximately 360 acres, with the ponding water elevation not exceeding 2.0 feet m.s.l.

b. Alligator Bavou area, approximately 6,500 acre-feet in an area approximately 6,700 acres, with the ponding water elevation not exceeding 2.5 feet m.s.l.

c. Snake Bayou area, approximately 40 acre-feet in an area approximately 80 acres, with the ponding water elevation not exceeding 1.0 foot m.s.l.

d. Rhodair Gully area, approximately 90 acre-feet in an area approximately 190 acres, with the ponding water elevation not exceeding 2.0 feet m.s.l.

21. Lands and rights-of-way.- Right-of-way required for enlarging the existing levees would include only the additional width necessary for the enlargement and would not include the area occupied by the existing levees. The rehabilitation of the existing seawall and levee along the Sabine-Neches Canal would not require additional rights-of-way. The right-of-way required for new levees would include sufficient width for the parallel drainage ditch along the inside of the levees, which would carry runoff to the various additional pumping stations. In reaches where side borrow material cannot be used for levee construction, allowances have been made in the estimates for off-site borrow areas. The estimated amounts of rights-of-way required in the various reaches are tabulated in the following table 3.

TABLE 3

RIGHTS-OF-WAY REQUIRED
(PLAN B)

Location	Amount required (Acres)
North of Groves area	14
Northeast of Groves to Lakeview pump station	118
Lakeview pump station to Sabine Towing Co.	None
Sabine Towing Co. to Taylors Bayou turning basin	29
Taylors Bayou turning basin to Alligator Bayou	8
Alligator Bayou to Highway 73	98
Highway 73 to Midcounty Airport	54
Gulf Oil Corp. fresh water reservoir (south of Taylors Bayou)	49
Sabine Road tank farm (south of Taylors Bayou)	40
Total	410

22. Maintenance and operation.- Maintenance and operation of the various structures and levees, proposed under plan B of this report would involve such items as repairing erosion damage to and mowing of the levee slopes; maintenance of the access road along the top of the levees; periodic inspection, painting and greasing of the various gated drainage structures and closure structures; periodic inspection and maintenance of the pumps and pump houses, including running of the pumps; and operation of the various facilities during high tide periods. This would include closing manually operated gates, placing sandbags in the gated closure structures, and operating the proposed drainage pumps. The costs of operating and maintaining the various features on an annual basis are estimated as follows:

Item	Estimated annual operation and maintenance
Levees and floodwalls	$ 35,000
Pumping stations	25,000
Gravity drainage structures and conduits	18,000
Drainage outlet and intercepting ditches	8,000
Closure structures	14,000
Total annual cost	100,000

Note: The costs of maintaining the existing protective system and drainage pumps are not included in these figures.

SOILS INVESTIGATIONS

23. Physiography.- Port Arthur, its suburbs and outlying industrial areas are situated along the west side of Sabine Lake. Since the formation of Sabine Lake, its size and depth have been reduced by deposition of materials transported into the lake by the Neches and Sabine Rivers and by smaller streams and bayous. Marsh areas in and around the city during the last few decades have been steadily reduced in area by the construction of drainage ditches and by the reclamation of areas by filling. The lack of deep organic deposits in the marsh areas is believed due to the relatively short time the areas have been marshes. The marshes more or less surround the city on all sides except on the easterly side along the lake.

24. Stratigraphy.- The surface soils in the general area consist of terrace silts, sand and sandy clays deposited by the Neches and Sabine Rivers and by windblown sands and silts. Some of the clayey surface soils were formed by weathering of the Beaumont clay formation. Organic marsh deposits are relatively thin and of limited extent. Below the surface soils the Beaumont clay formation is encountered. This formation is from 400 to 500 feet thick with a dip to the southeast. It extends beneath the beach sands and waters of the Gulf as far as the continental shelf. The Beaumont clay is a stiff to hard marine and lagoonal deposit consisting of about 60 percent clay, 20 percent silt and 20 percent sand. The clay is usually red to brown and occasionally bluish gray in color, and is generally calcareous.

25. Exploration and testing.- During February-March 1958, seventeen undisturbed borings were drilled in the area. Eleven borings were drilled along the existing seawall and the others were drilled in areas northeast from Port Arthur. Samples obtained from materials encountered were tested for moisture content, density, Atterberg limits, mechanical analysis, shearing strength, and consolidation. Consolidated drained direct shear tests were used to determine the shearing strengths of foundation materials. Locations of the borings are shown on exhibit 2, and logs of the borings and soil profile are shown on exhibit 3.

26. General soil conditions.- The boring logs indicate that the soil consists of plastic to stiff, lean to fat clays to a depth of about 14 feet below the ground line. Below these clays to a depth of approximately 24 feet soft, sandy clays were found with occasional layers of sand and silts. Below this material is a stiff, lean clay which grades into a plastic to stiff, fat clay at a depth of approximately 40 feet below the ground line. Fat clays extend to depths greater than 60 feet. Water was encountered in 14 of the borings at an average depth of 7.0 feet.

27. Results of tests.- Laboratory tests on samples from the areas drilled indicate the material can be divided into five groups as shown in table 4.

TABLE 4

SOILS ANALYSIS

Material	Dry weight lbs/cu.ft.	Liquid limit	Moisture content (percent)	Shear strength: Angle of internal friction (degrees)	Shear strength: Cohesion (tons/sq.ft.)
Existing levees elev.+10.0 to +5.0	95	50	27	12	0.30
Lean & fat clays elev.+5.0 to -9.0	90	56	32	13	0.12
Sandy clays and sands elev.-9.0 to -19.0	103	30	23	25	0.02
Lean clays elev.-19.0 to -35.0	90	40	32	15	0.17
Fat clays elev.-35.0 to -55.0	75	67	47	15	0.17

28. Borrow materials.- No borings were made to locate borrow areas; however, visual inspection of the area indicates that borrow materials for construction of the levees can be obtained in the general vicinity. The material would be lean to fat clays which are impervious and which would develop good shearing strength with moderate compaction. In the area northeast of Port Arthur sufficient material satisfactory for levee construction can be obtained by excavation of side drainage ditches and from nearby sources. Some difficulties may be encountered in obtaining sufficient borrow material in the areas around the existing reservoirs, the Gulf Refinery, and immediately north of these facilities. In these areas the natural ground is low and marshy. However, visual inspection of existing structures in the area indicates that satisfactory borrow material can be obtained below the marsh deposit which is from two to three feet thick. The existing levee around the Gulf reservoir, which appears to be in good condition, was constructed of material obtained from adjacent areas. The Texas Highway Department has obtained satisfactory embankment material for highway construction from similar areas. The material used extended to a maximum depth of 20 feet below the ground line. Special provisions will have to be made for the operation of construction equipment in the areas of marsh deposit. The area around Port Acres is similar to that northeast of Port Arthur and satisfactory borrow material can be obtained in the vicinity.

29. The findings in the foregoing paragraphs were based on limited soil investigation and testing. However, they are sufficiently accurate for estimating purposes in this report.

LEVEE AND FLOODWALL DESIGN

30. Design of earth levees.- A brief description of the levees and factors pertinent to selection of the types designed are given in the paragraphs below. Design of the levees was made in accordance with criteria and procedures in the following publications:

a. Engineering and Design, Earth Embankments, Engineering Manual for Civil Works, 1110-2-2300.

b. Soil Mechanics Design, Stability of Slopes and Foundations, Engineering Manual for Civil Works, 1110-2-1902.

30a. The design of the protective wall and levee along the city is on the basis that the spoil bank (Pleasure Island) between Sabine-Neches waterway and Sabine Lake will endure throughout the life of the project. Since the island is the first line of defense against wave attack, it was necessary to determine if the island could be relied on for the life of the project.

30b. Estimates of the erosion rate have been made and it has been found that the spoil deposit island will erode during the life of the project from a maximum of approximately 300 feet to a negligible amount. It was estimated that the spoil deposit island would still be existing after 100 years with sufficient height and width to provide the needed protection against wave attack for the design storm without the necessity of having to check the spoil bank erosion with riprap or by other means. However, the local people have riprapped the bank on the canal side along the golf course and the other developments nearby.

31. Foundation conditions.- The foundation materials for the new levees to be constructed northeast from Port Arthur range from fair to good. In part of the area the levees will be only a few feet in height above natural ground; therefore, little, if any, settlement will occur in these areas. However, in some sections levees with crown elevations of up to 16 feet above mean sea level will be constructed near or in the low marsh area. The marsh deposit, which is relatively thin, will be excavated as necessary to reach the underlying stiff, medium lean, and fat clays, which are satisfactory foundation materials. The foundation conditions in the areas west of Port Arthur are similar to those encountered northeast of the city. However, the marshy areas are considerably larger. Levees and highways constructed in these areas appear to be stable and show little evidence of settlement. Raising of the existing levees would not present any unusual foundation problems as in most cases only a few feet of additional height would be added to existing levees.

32. Levee sections.- The existing levees were constructed to an elevation about 9 feet above mean sea level. In various reaches, the height of these levees would be increased to elevations ranging from 14 to 16 feet above mean sea level. New levees would be constructed to elevations varying from 12 to 16 feet above mean sea level. The slopes of existing levees are approximately 1 on 3. It is proposed to maintain the 1 on 3 slopes for both the enlarged levees and new levees. This slope would have an adequate safety factor against sliding, and erosion would be slight. Grass maintenance, which can be performed with power mowers on a 1 on 3 slope, would not be a serious problem. During postauthorization, detailed planning stages, consideration would be given to retaining one slope of existing levees during enlargement, to avoid stripping and returfing in areas of established sod. However, many of the existing levees are in areas where space for enlargement is limited. This and other detailed design problems would be resolved during the design memorandum stage. Roads would be provided along the tops of new and enlarged earth levees. They would consist of a 6-inch layer of compacted shell with a single bituminous surface treatment. The roads would provide access to the levees for maintenance equipment and protect the levee top from erosion. Typical levee sections are shown on exhibit 4. The plan

of improvement would contain three general types of levees as follows:

Type I levees would be constructed with compacted fill to the design heights starting on natural ground elevation after removal of the vegetation and/or marsh deposits.

Type II levees would be constructed with compacted fill to a designated height by enlarging the existing levees after removal of the vegetation. If located where it would be exposed to severe wave erosion, the type II levee would be constructed with riprap on the exposed side.

Type III levees would be constructed by riprapping the exposed side of a type I levee.

33. Slope protection.- Slope protection for portions of the levees not subject to wave action would consist of turfing. Bermuda grass would be established by sprigging and overseeding on slopes that are not protected by riprap. Native soil on the site from which the levee would be constructed would be used as it comes from the borrow area as the media on which to grow grass. Adequately fertilized borrow-run soil will support a good cover of Bermuda grass without incurring the extra expense of plating levees with topsoil. An initial application of 100 lbs. of available nitrogen, 100 lbs. of available phosphoric acid and 50 lbs. of available potash applied to each acre of seed-bed as it is being prepared and 80 lbs. of available nitrogen applied 20 to 30 days following sprigging would provide an adequate Bermuda grass cover.

34. On the exposed levee slopes subject to severe wave attack, type "B" riprap would be provided consisting of a 27-inch layer of graded quarry stone on 18-inch layer of bedding material. The rock would be in random sizes evenly distributed between a minimum of 800 pounds to a maximum of 2,400 pounds for the armored layer and from 1/2 inch to 200 pounds for the bedding material. On the exposed levee slopes subject to moderate wave attack, type "A" riprap would be provided consisting of an 18-inch layer of stone on 12-inch layer of bedding material. The armored layer would be in random sizes evenly distributed between a minimum of 200 pounds to a maximum of 400 pounds and the bedding material from ½-inch to 50 pounds. The stone is available from deposits in central Texas, as shown on exhibit 8.

35. Construction procedure.- The existing levees to be raised would be stripped of vegetation with a motorized grader and the height increased with fill placed by dragline from side borrow ditches or hauled to the site from borrow areas. A reasonably dense levee can be obtained by using a bulldozer for spreading and compacting the fill. The new levees would be similarly constructed over a stripped subgrade.

36. Design of concrete floodwalls-general.- Eleven different types of flood walls have been designed for various reaches of the improvement. Typical section of these walls are shown on exhibit 5. A brief description of the walls and factors pertinent to selection of the types proposed in the various reaches are given below. Design of the walls was made in accordance with the following publications:

a. Shore Protection Planning and Design, Technical Report No. 4 Beach Erosion Board, O.C.E.

b. Wall Design, Flood Walls, Engineering Manual for Civil Works 1110-2-2501.

c. Design of Miscellaneous Structures, Piling, Engineering Manual for Civil Works 1110-2-2906.

37. Foundation conditions.- The stability of the various wall sections, and reconstructed seawall was determined using the soil constants given in paragraph 27 above. In the design of the sheet-pile walls, the soil above elevation minus three (point of estimated maximum draw down) was considered to be saturated whenever this condition was critical. Below this elevation the soil was considered to be buoyant. The resisting pressure was considered to be single passive.

38. Stability analyses were performed on sections taken through the proposed reconstructed seawall including the levee behind the wall. These sections were considered the most critical of the various wall sections that would be used in the flood protection system. Results of these studies indicate the wall and levee would be stable with a safety factor slightly greater than 1.0; however, in determining the stability of the wall and levee, the resisting force of the piling was not taken into account.

39. Most of the floodwalls would be constructed by increasing the height of the existing facilities a few feet. This additional height would not cause any undue stress in the foundation materials. The cantilevered floodwall would be similar to that used for flood protection at Orange, Texas. Foundation conditions in the Port Arthur area are generally better than those encountered in Orange; therefore, it is believed that floodwall would be stable with an adequate factor of safety and the settlement would be small. Facilities constructed in the vicinity of the proposed floodwall have not shown any distress caused by settlement.

40. Wall, type 1.- Walls similar to the type 1 wall are commonly used in flood protection systems. The type 1 wall would be an inverted "T" section constructed of reinforced concrete. The key on the section that is turned down would be of sufficient depth to prevent piping and to minimize uplift pressures. The bed would be sloped in order to increase the stability of the wall. The type 1 wall is designed to resist hydrostatic pressures only since it would not be subjected to wave action in the two locations where it would be used.

41. Wall, type 2.- Residential development along the water front between the Lakeview pump station and Woodworth Boulevard presents a special problem. Some houses are located only 45 feet back from the existing wall. The backs of these houses are on a line with the land-side toe of the existing levee. In this area it is not practicable to enlarge the levee because of the existing improvements. A floodwall against or only a few feet from the houses would be very objectionable. Accordingly, it is proposed that a new wall would be constructed with a top elevation of 14 feet, as shown on exhibit 5. The area between the existing levee and the new wall would be filled to 10 feet elevation to facilitate drainage and to avoid an objectionable depression near the

houses. The new wall would consist of prestressed concrete sheet-piles 64 feet long, capped with concrete, and tied back near the existing ground line. Below the ties the piles would be 12 inches thick and above the ties they would be 10 inches thick. The difference in thickness is needed in order that the strands can be properly placed to compensate for the reversal of stress above the ties. The anchor system would consist of $2\frac{1}{2}$-inch steel rods anchored to a continuous deadman, 12 inches thick and 9 feet high. The tie rods would be coated with corrosion resistant materials. The type 2 wall also would be used in front of the Sabine Towing Co.; however, in this area no back fill would be required.

42. Wall, type 3.- In the 8,990-foot reach between Woodworth Boulevard and the Pleasure Pier bridge a concrete paved roadway is located between the existing seawall and the levee. The road provides a scenic drive along the ship canal. A high wall along the canal would, of course, obstruct the scenic view. For this reason the protection would be separated into two parts, a low concrete sheet-pile wall on the water side of the road, and a higher concrete sheet-pile wall on the land side. The low wall would have a top elevation of +4.3 feet, the high wall an elevation of +14.0 feet. After construction of the new low wall, salvagable piles from the existing wall in this reach plus some from the reach northeast of Woodworth Blvd. would be pulled and redriven to form the high wall in the existing levee. The new wall would be anchored to the redriven wall in the levee by 1 1/4-inch steel tie rods on 12-feet centers. Thus, the redriven wall would serve as both auxiliary floodwall and deadman anchor for the front wall. The tie rods would be protected from corrosion. The type 3 wall would be constructed also in the reach between Pleasure Pier bridge and Houston Avenue.

43. Wall, type 4.- In the 1,720-foot reach beginning at Houston Avenue and continuing along the property of the Sabine Towing Co., the existing protection consists of a steel sheet-pile wall with a timber navigation fender system in front. The sheet-piles are 55 feet long and are anchored to a continuous concrete deadman, 15 inches thick by 9 feet high, located 80 feet back of the wall. The ties are $2\frac{1}{2}$-inch steel rods on 8-foot centers. There have been no failures in this wall but the steel sheet-piles are severely corroded. The steel tie rods were installed below the normal water table and should be in fair condition. The poor condition of the steel sheet-piles makes a new wall necessary in this reach. The new wall would consist of concrete sheet-piles 64 feet long, capped at elevation +14.0 feet. The piles would be similar to those described in paragraph 41 above. They would be anchored to the existing steel sheet-pile wall and tie rods by means of tie bars encased in a new concrete filler beam between the two walls. Since this area is used for maintenance of boats, several narrow closure structures would be provided to afford wharf level passageways for working personnel, in accordance with the desires of the owner of the adjacent property. The existing fender system in front of the steel sheet-pile wall would be relocated in front of the new wall. Concrete mattresses on a shell filter blanket would also be installed along the canal bottom in front of the new wall for erosion protection.

44. <u>Wall, type 5</u>.- This cantilevered concrete sheet-pile wall would be used in numerous areas where sufficient room for the design levee is not available. It also would be used for transitions between levees and other types of walls. The sheet-piles would be either 10 inches thick and 20 feet long or 12 inches thick and 30 feet long, depending on the elevation of the ground where used.

45. <u>Wall, type 6</u>.- The package and grease plant and the package and grease warehouse of the Gulf Refining Co. were constructed adjacent to each other and share a common wall. A barge slip 12 feet deep and 65 feet wide, enters one end of the warehouse and five railroad spur lines enter the other end. The floors of both the plant and the warehouse are at elevation +11.0 feet. Officials of the Gulf Oil Corp. suggested that these buildings be protected by a levee on the east side of the warehouse with a movable floodgate to close the barge slip. It was determined that the cost of the floodgate would be excessive. An alternate plan to construct a wall along the landside bank of the barge slip was rejected because of restrictions that the wall would place on loading operations. Since no plan to protect the warehouse appears feasible, this building is excluded from the plan of improvement. The portions of the north wall of the warehouse that are not common with the package and grease plant would be made watertight to elevation +13.0 feet by welding a steel plate with channel stiffeners between the existing columns of the building. No wave action is expected inside the building and the new wall would be designed to resist hydrostatic pressure only. The portion of the wall common to the warehouse and the package and grease plant is made of masonry and is sufficiently strong and watertight. In the event of flooding to an elevation above 11 feet, the package and grease plant could be protected by closing and sand-bagging three large and one small doors. Damage within the warehouse would be limited to cardboard cartons and product containers. The products themselves would be protected by individual metal containers.

46. <u>Walls, types 7, 8, 9 and 10</u>.- The Gulf Oil Corp. refinery presently is protected in the wharf area by four types of walls. The tops of all existing walls are at elevation +10.0 feet. These walls are indicated as "existing" structures in the detail drawings for proposed wall, types 7, 8, 9 and 10, shown on exhibit 5. All new walls would have a top elevation of 14.0 feet. The existing walls in the short reach to be protected by types 7 and 9 walls consist of concrete sheet-piles anchored to concrete deadmen. The existing tie rods are encased in concrete. The new walls would consist of concrete sheet-piles, 12 inches thick and 55 feet long, anchored to the existing walls by means of concrete filler beams at the ground line. The existing fender system would be relocated in front of the type 9 wall. A wharf 1,050 feet long, was constructed at the Gulf refinery in 1911. It was extended in 1916 and again in 1922. The wharf consists of a reinforced concrete superstructure supported by concrete piles which vary in length from 32 to 63 feet. Backfill is retained at the rear of the wharf by means of sheet-pile bulkheads, which are anchored to concrete deadmen with 2 1/4-inch steel tie rods encased in concrete. The rods are spaced 22 feet

apart. There have been no apparent failures in the anchorage system. The bulkheads in the 1916 and 1922 extensions were constructed of reinforced concrete sheet-piles from 33 to 40 feet long. The bulkhead in the original 1,050 feet of wharf is composed of 4-inch thick Wakefield piles 20 feet long. These timber piles would be replaced with Z-27 steel sheet-piles 32 feet long. The tops of these piles would be capped with concrete below the normal water table in order to minimize corrosion. Additional storm protection would be provided by constructing a reinforced concrete wall on the wharf in front of the existing floodwall. Closure structures would be provided at the three openings in the existing wall. The 16-pipe trenches in the wharf would be raised to elevation +14.0 feet, and minor dock facilities would be relocated as necessary.

47. The type 10 wall would consist of modifying an existing concrete buttress wall. The existing wall is supported by timber piles. The buttresses are 20 feet apart. The front of the wall is protected by a steel sheet-pile bulkhead constructed in 1953. The proposed modification would consist of increasing the height of the wall four feet, constructing new buttresses between the existing ones, and providing tiebacks for the bulkhead below the water table.

48. Wall, type 11.- A portion of the existing storm protection system for the Gulf Oil Corp. water treatment plant consists of a wall for a coagulation basin. The top of this wall is at about elevation +10.0 feet. It is not feasible to modify the wall. A new concrete wall with a top elevation of +14.0 feet would be constructed along and tied to the basin wall by a concrete filler-cap on top of the existing wall. Since the existing structure would be damaged by the driving of piles the new wall would be constructed by trenching and backfilling.

DESIGN OF STRUCTURES

49. Pumping stations and gravity drain structures.- The pumps would be of the low head, high discharge type shown on exhibit 6. They would be driven by diesel or butane engines. Since the maximum water surface elevation of 12.0 feet would last only a short time the pumps would be designed to operate most efficiently at a somewhat lower head. Back flow would be controlled by slide gates. The pump house structure would be of reinforced concrete supported on treated timber piles. This type of foundation is commonly used in the Port Arthur area. Preliminary investigations indicate that a tapered timber pile 45 feet long and 12 inches butt diameter has a safe bearing capacity of 15 tons per pile for single piles and 10 tons per pile for piles in group. All of the existing larger pump stations are housed in brick structures. The exposed walls of these structures are reinforced with concrete to elevation 10.0. This reinforcement would be extended to elevation 14.0 for the five larger pump houses along the Sabine-Neches Canal. Most of the pumps in these stations are powered by electricity. The pump discharge lines would be equipped with slide or flap gates to prevent back flow when the pumps are inoperative.

49a. Gate closure structures.- The gate closure structures are designed to withstand the weight of the hydrostatic head plus fifty percent additional for wave pressure. All gates are a single-leaf swing type which swing outside the seawall so that the hydrostatic pressure helps to seal the gate. Rubber seals will be provided along the bottom and along the vertical edges of the gates. The larger gates will require the pipe about which they swing to be extended above the gate so that a tie rod with turnbuckle can be run from the end of the gate to the top of the pipe. The gates can then be anchored to concrete deadmen with struts and tie rods. The swing type gate closure structure has been selected to facilitate the operation and to enable one man operation of the gates in a fairly short time of operation.

49b. Highway and road ramp crossings.- Suitable ramp crossings for each road or highway would be constructed. The design of the road ramps is based on a vertical curve of non-passing sight distance for 30 miles per hour on thoroughfares and on roads with less traffic a gradient of as steep as 10% is used where the usual distance is obstructed. Highway ramp design is based on a vertical curve of non-passing sight distance for 70 miles per hour.

DESCRIPTION OF PLAN A

50. <u>Description of the plan A.</u>- The single enclosure around Port Arthur, Groves, Griffing Park, Pear Ridge, Lakeview, and the main plants of the three refineries, area A, would begin north of Groves at the same place as plan B and continue around the developed area along the same route with the same improvements as plan B to the southwest corner of the Gulf refinery near Alligator Bayou. From this point the improvements under plan A would extend northwest approximately 1,000 feet at the same levee height of 14 feet and then northeast with a 12 ft. levee following existing levees along the west side of the Gulf Oil Corp. and Texaco, Inc. main plants to the northwest corner of the Texaco fresh water reservoir. From this point the levee would continue northward along the existing levee adjacent to the Texaco fresh water canal, a distance of 13,200 ft. to State Highway 347. The levee would be enlarged and raised to 12 feet elevation. The enlargement would be placed on the side away from the water canal to avoid covering the pipelines on the existing levee. After crossing State Highway 347 with a ramp, the levee would continue on the same alinement for 600 feet with a new levee thence northwestward along the Kansas City Southern railroad for approximately 6,200 ft. to high ground at the 12 ft. contour.

51. The enclosure around the Texaco Miller tank farm, adjacent reservoir and research center, area D, would follow the existing protective levee or fire wall levees. These levees would be enlarged to a crest elevation of 12 ft.

52. The enclosure around the Texaco additive plant, area E, would follow the existing storm protective levee which would be enlarged to a crest elevation of 12 ft.

53. The enclosure around Port Acres, El Vista and Rosemont, Area F, would follow the same route as Plan B along the south and west sides of Port Acres. Along the north and east sides of the area the levee would parallel the Southern Pacific Railroad, the city of Port Arthur fresh water canal and the Alligator Bayou drainage canal, as shown on plate 3.

54. The two enclosed areas south of Taylors Bayou would be enclosed by improvements identical to those described under plan B.

55. Four pumping stations would be provided under plan A. Two in the Port Acres area at Snake Bayou and Rhodair Gully would be the same as those provided in plan B. The third, with 470,000 g.p.m. pumping capacity, would be located adjacent to the Alligator Bayou drainage canal northwest of Pear Ridge and southwest of Groves. The fourth in the Crane Bayou area would be the same as that provided in plan B.

56. As in plan B, numerous floodwalls, ramps, gated closure structures, gated drainage structures, and other appurtenant structures would be provided under plan A. These structures are not described in detail but are included in the detailed estimate of cost in appendix IV.

INTERIM REPORT ON
HURRICANE SURVEY OF
PORT ARTHUR AND VICINITY,
TEXAS

APPENDIX IV

ESTIMATES OF FIRST COSTS AND ANNUAL CHARGES

1. General.- This appendix presents information pertaining to the detailed estimates of first cost, investment, and annual charges of all of the improvements considered in the text of the report.

2. Cost estimates.- Detailed estimates of first cost in this appendix include the costs for construction, lands and damages, contingencies, engineering and design, and supervision and administration and the costs of preauthorization surveys and studies. Estimates of annual costs of the various improvements include interest on the initial investment, amortization of the investment and costs of annual maintenance of the improvements. Factors considered in determining the first costs and annual charges were the unit prices of construction items and rights-of-way, the estimated construction period, estimated life of structures, and maintenance and operation costs of the various structures and interior drainage pumps. A brief summary of each factor is given in the following paragraphs.

3. Unit prices.- In the cost items for constructing new levees and enlarging existing levees, the cost of site preparation is included in the cost of the compacted earthwork. The costs of fill for the new and enlarged levees are based on averages of approximately 25 percent being obtained from borrow alongside the levee and 75 percent hauled from borrow areas within 2 miles of the work sites. The unit prices of construction used in determining the first costs are based on experienced costs of similar work during September 1961.

4. Contingencies, engineering and overhead.- The estimates include an allowance to cover contingencies during construction. The estimates of design costs include all post-authorization surveys and planning including preparation of plans and specifications. Supervision and administration costs include engineering and supervision and inspection during construction, and project and district office overhead. These items are shown in the summaries of tables 1 and 2.

5. Preauthorization survey and study costs.- The sum of $96,000 has been expended for preauthorization survey and study costs, including the preparation of this report. Since improvement plans A and B, presented in the report, are alternate plans, the entire sum has been included as a charge to each plan.

6. Rights-of-way.- The estimates of rights-of-way costs were based on real estate appraisals made in August 1958 and October 1959, which were revaluated in September 1961.

7. Apportionment of first cost.- The apportionment of first cost of the project between the Federal and non-Federal interests is based on the apportionment of costs given in paragraph 100 and table 8 of the text of this report.

8. Construction period.- It has been assumed that sufficient funds would be contained in each appropriation to permit continuous prosecution of the work necessary to complete protection for one or more of the smaller segments of the area wherein closure could be obtained within a twelve-month period in both plans A and B. For the main enclosure of the Port Arthur area in plan A and the entire area north of Taylors Bayou in plan B, the construction period has been estimated at 60 months. Accordingly, interest on the Federal investment has been included in the estimates of costs only for the two main enclosures north of Taylors Bayou in plans A and B.

9. Estimated life of structures and equipment.- For economic analysis, the useful life of the levees, pumps, and drainage outlet structures with adequate maintenance has been estimated at 100 years. The comparatively long life for pumps and equipment is based on infrequent use only when interior drainage is blocked by high tides.

10. Estimated annual charges.- Estimates of interest and amortization of construction costs included in the annual charges are based on 2.625 percent interest on the Federal investment and 3 percent interest on the non-Federal public investment. The non-Federal interest rates used in the report are representative of the rates local interests would have to pay on borrowed money for construction and for financing costs of land. The loss of productivity of the land is insignificant because the land required in the project is a relatively small area needed for the levee R.O.W. Most of these lands where there is no levee border large grazing areas and the small amounts of land removed from production will have practically no effect in the loss of the total area. Amortization of the investment is computed for a period of 100 years. The annual charges also include the estimated costs for operation and maintenance of the proposed improvements, as discussed in appendix III. These charges are shown in tables 3 and 4.

11. Summary of first costs-and annual charges.- A detailed breakdown by principal features, quantities and unit prices of the estimated first costs of the work proposed in plan B is shown in table 1 and a summary is given on page 16. The estimates of annual charges are summarized in table 3. The detailed estimates of first cost for the investigated plan A are shown in table 2 and summarized on page 29. The estimates of annual charges for plan A are given in table 4. The stationing by reaches shown in the detailed estimates of first costs refer to the stationing plan drawing shown as exhibit 1 of appendix III.

12. Apportionment of costs between interests.- The apportionment of first costs between Federal and non-Federal interests shown in the summaries of tables 1 and 2 is in accordance with policy established in Public Law 85-100, 85th Congress, S. 3910 dated July 3, 1958. This policy provides that the first cost of constructing the project including the cost of lands, easements, and rights-of-way, but excluding the cost of preauthorization surveys, will be apportioned at least 30 percent to non-Federal interests and not to exceed 70 percent to the Federal Government. Lands, easements, and rights-of-way will be provided by non-Federal interests without cost to the United States, and the reasonable value therefor will be credited toward the local contribution.

13. First costs and annual charges for interior drainage improvements.- To permit evaluation of the interior drainage improvements included in the plan of improvement on an incremental basis, the estimated first costs and annual charges of these improvements have been extracted from table 1 and are presented separately in table 5. The annual benefits were computed from the stage damage curves based on the reduction of the ponded water elevation.

TABLE 1
ESTIMATES OF FIRST COST
PLAN B

(RECOMMENDED IMPROVEMENT)

Item No.	Item	Unit	Quantity	Unit cost	Cost
A.	Total project cost				
1.	Area G (Single enclosure north of Taylors Bayou)				
	(a) Sta. -7/500 to Sta. 0/000				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac.	14	$1,250.00	$ 17,500
(2)	Non-Federal acquisition costs	Tract	12	700.00	8,400
	Subtotal				25,900
	Contingencies (land & damages)				4,100
	Total (lands & damages)				30,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	12,000	1.00	12,000
	(b) Enlarge existing levees	C.Y.	1,000	1.00	1,000
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	1,330	4.75	6,300
	(b) Bit. surface treat., single	S.Y.	8,000	1.25	10,000
(3)	Erosion protection				
	(a) Turfing	Ac.	2	300.00	600
(4)	Gated control struc.(3)				
	(a) Reinf. concrete, culvert	C.Y.	45	80.00	3,600
	(b) Slide gates 60"x60"	Ea.	3	2,600.00	7,800
(5)	Atlantic fresh water canal				
	(a) Reinf. concrete	C.Y.	10	80.00	800
	(b) Slide gate 60"x60"	Ea.	2	2,600.00	5,200
(6)	Hwy. 366 ramp				
	(a) Remove existing pavement	S.Y.	200	1.00	200
	(b) Compacted earth fill	C.Y.	200	1.00	200
	(c) Shell base, 6"	C.Y.	42	4.75	200
	(d) Bit. surface treat., single	S.Y.	200	1.25	250
	(e) Culvert pipe, 30"	L.F.	52	11.50	600
	(f) Steel guard rail	L.F.	200	3.00	600
(7)	Port Neches-Atlantic Road Ramp				
	(a) Remove existing pavement	S.Y.	200	1.50	300
	(b) Compacted earth fill	C.Y.	400	1.00	400
	(c) Shell base, 6"	C.Y.	42	4.75	200
	(d) Bit. surface treat., single	S.Y.	200	1.25	250
	(e) Culvert pipe, 30"	L.F.	52	11.50	600
	(f) Steel guard rail	L.F.	200	3.00	600
	Subtotal (levees and floodwalls)				51,700
	Contingencies				8,300
	Total (levees and floodwalls)				60,000

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit Price	Cost
	(b) Sta. 0/000 to Sta. 33/580				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	118	$1,250.00	$147,500
(2)	Non-Federal acquisition cost	Tract	6	700.00	4,200
	Subtotal				151,700
	Contingencies (land & damages)				23,300
	Total (lands & damages)				175,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	284,460	1.00	284,460
	(b) Enlarge existing levees	C.Y.	18,000	1.00	18,000
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	7,261	4.75	34,490
	(b) Bit. surface treat., single	S.Y.	42,392	1.25	52,990
(3)	Erosion protection				
	(a) Bedding mat'l for type A riprap	Ton	2,220	6.00	13,320
	(b) Riprap, type A	Ton	3,330	8.00	26,640
	(c) Turfing	Ac	27	300.00	8,100
(4)	Gated control structures (4)				
	(a) Corr. metal pipe, 48"	L.F.	104	25.00	2,600
	(b) Corr. metal pipe, 60"	L.F.	60	38.00	2,280
	(c) Reinf. concrete	C.Y.	20	80.00	1,600
	(d) Slide gates, 48" w/well	Ea	3	1,600.00	4,800
	(e) Slide gate, 60" w/well	Ea	1	2,600.00	2,600

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(5)	Concrete floodwall, type 1 (4'-10")	L.F.	800	$38.00	$30,400
(6)	Concrete floodwall, type 5	L.F.	100	50.00	5,000
(7)	Road ramp, 22'				
	(a) Compacted earthfill	C.Y.	3,060	1.00	3,060
	(b) 6" compacted shell base	C.Y.	110	4.75	520
	(c) Bit. Surf. Treat. single	S.Y.	660	1.25	830
	(d) Turfing	Ac	0.1	300.00	30
(8)	Gate closure struc., (17' x 9') R.R.				
	(a) Reinf. conc.	C.Y.	40	80.00	3,200
	(b) Struc. steel gates	Lb	4,550	.22	1,000
(9)	State Hwy. 87 ramp				
	(a) Remove existing pavement	S.Y.	2,700	1.50	4,050
	(b) Compacted earth fill	C.Y.	13,160	1.00	13,160
	(c) Conc. paving, 10"	S.Y.	2,940	7.00	20,580
	(d) Culvert, conc. (3' x 6')	L.F.	100	40.00	4,000
	(e) Turfing	Ac	0.8	300.00	240
	(f) Steel guard rail	L.F.	2,020	3.00	6,060
	(g) Bypass road	Job	1	LS	4,000
(10)	Road ramps, 16' (2)				
	(a) Compacted earth fill	C.Y.	9,830	1.00	9,830
	(b) 6" compacted shell base	C.Y.	284	4.75	1,350
	(c) Bit. surface treat., single	S.Y.	1,706	1.25	2,130
	(d) Culvert, conc. (3' x 6')	L.F.	200	40.00	8,000
	(e) Turfing	Ac	0.4	300.00	120
(11)	Gravity drainage structure				
	(a) Bypass channel, excavation	C.Y.	10,700	0.50	5,350
	(b) Cofferdam	Job	1	LS	22,000
	(c) Excavation, structural	C.Y.	1,200	2.00	2,400
	(d) Reinforced concrete	C.Y.	700	50.00	35,000
	(e) Timber piles, untreated	L.F.	9,850	3.00	29,550
	(f) Steel sheet-pile cutoff wall	S.F.	2,250	5.00	11,250
	(g) Steel sheet-pile tie-in wall	S.F.	1,800	5.00	9,000
	(h) Asphalt seepage barrier, ½"	S.F.	4,500	0.25	1,130

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit Cost	Cost
	(i) Lift gates, steel	Ea	3	$17,000.00	$ 51,000
	(j) Flap gates, steel	Ea	3	8,000.00	24,000
	(k) Riprap	Ton	910	8.00	7,280
	(l) Shell blanket for riprap	C.Y.	260	4.00	1,040
	Subtotal, (levees and floodwalls)				768,440
	Contingencies				116,560
	Total, (levees and floodwalls)				885,000
(13.0)	PUMPING PLANTS				
(1)	Crane Bayou	MGPM	680	1,600.00	1,008,000
	Contingencies				222,000
	Total, (pumping plants)				1,310,000
(c)	Sta. 33+580 to Sta. 59+546				
(01.0)	LANDS AND DAMAGES				None
(11.0)	LEVEES AND FLOODWALLS				
(1)	Concrete seawall, type 2	L.F.	13,384	498.00	6,665,230
(2)	Concrete seawall, type 3	L.F.	10,762	380.00	4,089,560
(3)	Concrete seawall, type 4	L.F.	1,720	372.00	639,840
(4)	Concrete mats on shell blanket	L.F.	25,626	20.00	512,520
(5)	Concrete sheet-pile wall (12" x 30')	L.F.	100	80.00	8,000
(6)	Relocate wood fender system (50% salvage)				
	(a) Timber piles 40 ft. long, pull & redrive	L.F.	11,240	2.00	22,480
	(b) Timber piles, 40 ft. long, new	L.F.	11,240	2.50	28,100
	(c) Fender timbers (6" x 10")	MBF	45	600.00	27,000
(7)	Personnel gated closure struc., (5 gates) (8' x 5')	Lb	5,000	.22	1,100
(8)	Gate closure struc. street, 2 (25' x 9')				
	(a) Reinf. concrete	C.Y.	40	80.00	3,200
	(b) Struc. steel gates	Lb	10,600	.22	2,330

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(9)	Gate closure structure, street (30' x 9') (2)				
	(a) Reinforced concrete	C.Y.	70	$ 80.00	$ 5,600
	(b) Structural steel gates	Lb	12,720	0.22	2,800
(10)	Structural modifications, existing pump stations	Job	6	15,000.00	90,000
(11)	Gates, gravity drains				
	(a) Slide gate and well, 10"	Ea	1	180.00	180
	(b) Slide gate and well, 12"	Ea	1	300.00	300
	(c) Slide gate and well, 19"	Ea	2	450.00	900
	(d) Slide gate and well, 24"	Ea	2	500.00	1,000
	(e) Slide gate and well, 30"	Ea	5	700.00	3,500
	(f) Slide gate and well, 36"	Ea	4	900.00	3,600
	(g) Slide gate and well, 40"	Ea	1	1,050.00	1,050
	(h) Slide gate and well, 42"	Ea	1	1,150.00	1,150
	(i) Slide gate and well, 48"	Ea	1	1,600.00	1,600
	(j) Slide gate and well, 54"	Ea	2	2,100.00	4,200
(12)	Combine existing storm drains				
	(a) Concrete pipe, 8"	L.F.	400	3.50	1,400
	(b) Concrete pipe, 10"	L.F.	150	3.75	560
	(c) Concrete pipe, 12"	L.F.	1,784	5.00	8,920
	(d) Concrete pipe, 15"	L.F.	120	6.30	760
	(e) Concrete pipe, 18"	L.F.	1,330	6.70	8,910
	(f) Concrete pipe, 24"	L.F.	50	8.40	420
	(g) Concrete pipe, 30"	L.F.	50	11.50	580
	Subtotal (levees and floodwalls)				12,136,790
	Contingencies				1,863,210
	Total (levees and floodwalls)				14,000,000
(d)	Sta. 59/546 to Sta. 76/883				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	29	3,500.00	101,500
(2)	Non-Federal acquisition cost	Tract	10	700.00	7,000
	Subtotal				108,500
	Contingencies (lands & damages)				16,500
	Total (lands & damages)				125,000

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit Cost	Cost
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	9,130	$ 1.00	$ 9,130
	(b) Enlarge existing levees	C.Y.	235,260	1.00	235,260
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	3,266	4.75	15,510
	(b) Bit. surface treat., single	S.Y.	19,603	1.25	24,500
(3)	Erosion protection				
	(a) Turfing	Ac	34	300.00	10,200
(4)	Steel flap gate, 48"	Ea	1	680.00	680
	Steel flap gate, 45"	Ea	2	800.00	1,600
(5)	Concrete floodwall, type 5, 10" x 20'	L.F.	900	50.00	45,000
	Concrete floodwall, type 5, 12" x 30'	L.F.	910	80.00	72,800
(6)	Steel floodwall, type 6	L.F.	335	11.75	3,940
(7)	Structural modifications, exist. pump station	Job	2	L.S.	10,000
(8)	Tank farm road ramps, 12'(10)				
	(a) Compacted earth fill	C.Y.	7,680	1.00	7,680
	(b) 6" compacted shell base	C.Y.	627	4.75	2,980
	(c) Bit. surface treat., single	S.Y.	3,720	1.25	4,650
	(d) Turfing	Ac	0.4	300.00	120
(9)	Road ramp, 22' (3)				
	(a) Compacted earth fill	C.Y.	16,420	1.00	16,420
	(b) 6" compacted shell base	C.Y.	588	4.75	2,790
	(c) Bit. surf. treat., single	S.Y.	3,519	1.25	4,400
	(d) Turfing	Ac	0.6	300.00	180
(10)	Road ramp, 25'				
	(a) Compacted earth fill	C.Y.	5,550	1.00	5,550
	(b) 8" conc. pave.	S.Y.	733	6.40	4,690
	(c) Wall, type 5	L.F.	20	50.00	1,000
	(d) Turfing	Ac	0.3	300.00	90
(11)	Railroad gate closure struct. (2)				
	(a) Reinforced concrete	C.Y.	60	80.00	4,800
	(b) Struct. steel gates	Lb	9,100	0.22	2,000
	Subtotal (levees and floodwalls)				485,970
	Contingencies				74,030
	Total (levees and floodwalls)				$ 560,000

87779 O-62—11

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
	(e) <u>Sta. 76+883 to Sta. 85+980</u>				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	8	$ 3,500.00	$ 28,000
(2)	Non-Federal acquisition cost	Tract	4	700.00	2,800
	Subtotal				30,800
	Contingencies				4,200
	Total (lands and damages)				35,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	19,080	1.00	19,080
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	259	4.75	1,230
	(b) Bit. surface treat., Single	S.Y.	1,544	1.25	1,930
(3)	Erosion protection				
	(a) Turfing	Ac	3	300.00	900
(4)	Gated control structure				
	(a) 24" slide gate with 15' well	Ea	2	500.00	1,000
(5)	Concrete floodwalls				
	(a) Sheet-pile, type 5	L.F.	105	80.00	8,400
	(b) "T" wall, type 1	L.F.	1,247	40.00	49,880
	(c) Sheet-pile 12" x 55', type 5	L.F.	183	170.00	31,110
	(d) Wall on wharf deck, type 8	L.F.	2,880	35.00	100,800
	(e) Sheet-pile, 12" x 40', type 9	L.F.	317	170.00	53,890
	(f) Raise buttress wall, type 10	L.F.	260	41.00	10,660
	(g) Sheet-pile, 10" x 20', type 5	L.F.	400	50.00	20,000
(6)	Steel floodwalls, sheet-pile (22" x 32')	L.F.	1,050	120.00	126,000
(7)	Extend existing pipe chases Reinforced conc. wall	C.Y.	32	50.00	1,600
(8)	Alter existing personnel gate closure structures				
	(a) Steel gates 3' x 6'	Lb	1,500	0.22	330

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(9)	Road ramp, 22' x 9'				
	(a) Compacted earth fill	C.Y.	7,872	$ 1.00	$ 7,870
	(b) 6" conc. pavement	S.Y.	1,082	6.40	6,900
	(c) Turfing	Ac	0.3	300.00	90
(10)	Road ramp, 12' x 9'				
	(a) Compacted earth fill	C.Y.	2,500	1.00	2,500
	(b) 6" compacted shell base	C.Y.	170	4.75	810
	(c) Single surface treatment	S.Y.	800	1.25	1,000
	(d) Turfing	Ac	0.3	300.00	90
(11)	Railroad gate closure struct. 24' x 4'				
	(a) Reinforced concrete	C.Y.	20	80.00	1,600
	(b) Structural steel gate	Lb	4,185	.22	920
(12)	State highway 87 ramp				
	(a) Remove existing pavement	S.Y.	2,450	1.50	3,680
	(b) Compacted earth fill	C.Y.	8,440	1.00	8,440
	(c) Conc. paving, 10"	S.Y.	2,450	7.00	17,150
	(d) Culvert, conc. 3' x 6'	L.F.	100	40.00	4,000
	(e) Turfing	Ac	0.5	300.00	150
	(f) Steel guard rail	L.F.	2,000	3.00	6,000
	(g) Bypass road	Job	1	L.S.	4,000
	Subtotal, (levees and floodwalls)				492,010
	Contingencies				77,990
	Total, (levees and floodwalls)				570,000
(f)	Sta. 85+980 to Sta. 119+530				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	98	1,000.00	98,000
(2)	Non-Federal acquisition cost	Tract	20	700.00	14,000
	Subtotal				112,000
	Contingencies (lands & damages)				18,000
	Total (lands & damages)				130,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	781,700	1.00	781,700
	(b) Enlarge existing levees	C.Y.	14,720	1.00	14,720
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	7,850	4.75	37,290
	(b) Bit. surface treat., single	S.Y.	47,100	1.25	58,870
(3)	Erosion protection				
	(a) Bedding mat'l for riprap	Ton	69,400	6.00	416,400
	(b) Riprap, type A&B	Ton	103,600	8.00	828,800
	(c) Turfing	Ac	62	300.00	18,600

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(4)	Gated control structure				
	(a) Flap gate, 16"	Ea	1	$ 200.00	$ 200
(5)	Seal pipe trough				
	(a) Galv. sheet metal sleeves and caulking	L.F.	2,000	0.50	1,000
	(b) Concrete wingwalls	C.Y.	60	80.00	4,800
	(c) Concrete plug	C.Y.	80	15.00	1,200
(6)	Concrete floodwall, 12" x 25', type 5	L.F.	770	70.00	53,900
(7)	Water discharge outlet				
	(a) Texaco outfall ditch				
	(1) Slide gates 60" x 60"	Ea	3	2,600.00	7,800
	(2) Concrete piles, precast 8"x16"x25'	Ea	34	85.00	2,890
	(3) Concrete pile, precast 8"x12"x37'	Ea	4	95.00	380
	(4) Reinforced concrete wall	C.Y.	5	80.00	400
	(b) Gulf fresh water canal				
	(1) Slide gates 60" x 60"	Ea	4	2,600.00	10,400
	(2) Concrete piles, precast 8"x16"x25'	Ea	38	85.00	3,230
	(3) Concrete piles, precast 8"x12"x37'	Ea	5	95.00	480
	(4) Reinforced concrete wall	C.Y.	7	80.00	560
(8)	Gravity drainage structures				
	(a) Alligator Bayou				
	(1) Bypass channel, excavation	C.Y.	34,000	0.50	17,000
	(2) Cofferdam	Job	1	L.S.	73,500
	(3) Excavation, structural	C.Y.	4,000	2.00	8,000
	(4) Reinforced concrete	C.Y.	1,960	50.00	98,000
	(5) Timber piles, untreated	L.F.	23,640	3.00	70,920
	(6) Steel sheet-pile cutoff wall	S.F.	6,460	5.00	32,300
	(7) Steel sheet-pile tie-in wall	S.F.	1,800	5.00	9,000
	(8) Asphalt seepage barrier, $\frac{1}{2}$"	S.F.	10,800	0.25	2,700
	(9) Lift gates, steel	Ea	10	17,000.00	170,000
	(10) Flap, gates, steel	Ea	10	8,000.00	80,000
	(11) Riprap	Ton	15,100	8.00	120,800
	(12) Shell blanket for riprap	C.Y.	4,320	4.00	17,280
	(b) Snake Bayou				
	(1) Bypass channel, excavation	C.Y.	7,000	0.50	3,500
	(2) Cofferdam	Job	1	L.S.	14,700

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
	(3) Excavation, structural	C.Y.	800	$ 2.00	$ 1,600
	(4) Reinforced concrete	C.Y.	567	50.00	28,350
	(5) Timber piles, untreated	L.F.	7,880	3.00	23,640
	(6) Steel sheet-pile cutoff wall	S.F.	1,800	5.00	9,000
	(7) Steel sheet-pile tie-in wall	S.F.	1,800	5.00	9,000
	(8) Asphalt seepage barrier, ½"	S.F.	3,600	0.25	900
	(9) Lift gates, steel	Ea	2	17,000.00	34,000
	(10) Flap gates, steel	Ea	2	8,000.00	16,000
	(11) Riprap	Ton	812	8.00	6,500
	(12) Shell blanket for riprap	C.Y.	232	4.00	930
	Subtotal (levees and floodwalls)				3,091,240
	Contingencies				468,760
	Total (levees and floodwalls)				3,560,000
(13.0)	PUMPING PLANTS				
(1)	Alligator Bayou	MGPM	1,170	1,600.00	1,872,000
(2)	Snake Bayou	MGPM	290	1,600.00	464,000
	Subtotal (pumping plants)				2,336,000
	Contingencies 20%				474,000
	Total (pumping plants)				2,810,000
(g)	Sta. 119/530 to 142/330				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	54	1,000.00	54,000
(2)	Non-Federal acquisition cost	Tract	20	700.00	14,000
	Subtotal (lands & damages)				68,000
	Contingencies				7,000
	Total (lands & damages)				75,000

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levees	C.Y.	220,150	$ 1.00	$ 220,150
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	5,068	4.75	24,070
	(b) Bit. surface treat., single	S.Y.	30,400	1.25	38,000
(3)	Erosion protection				
	(a) Turfing	Ac	20	300.00	6,000
(4)	State Hwy 73 ramp				
	(a) Remove existing pavement	S.Y.	2,840	1.50	4,260
	(b) Compacted earth fill	C.Y.	13,580	1.00	13,580
	(c) Conc. paving, 10"	S.Y.	2,840	7.00	19,880
	(d) Culvert, conc. 3' x 6'	L.F.	50	40.00	2,000
	(e) Turfing	Ac	0.5	300.00	150
	(f) Steel guard rail	L.F.	2,000	3.00	6,000
	(g) Bypass road	Job	1	L.S.	4,000
(5)	Hwy 365 ramp				
	(a) Remove existing pavement	S.Y.	2,220	1.50	3,330
	(b) Compacted earth fill	C.Y.	7,440	1.00	7,440
	(c) Conc. paving, 10"	S.Y.	2,222	7.00	15,550
	(d) Culvert, conc. 3' x 6'	L.F.	48	40.00	1,920
	(e) Turfing	Ac	0.5	300.00	150
	(f) Steel guard rail	L.F.	1,824	3.00	5,470
	(g) Bypass road	Job	1	L.S.	3,000
(6)	Gravity drainage structure (Rhodair Gully)				
	(a) Bypass channel, excavation	C.Y.	4,200	0.50	2,100
	(b) Cofferdam	Job	1	L.S.	7,000
	(c) Excavation, structural	C.Y.	400	2.00	800
	(d) Reinforced concrete	C.Y.	432	50.00	21,600
	(e) Timber piles, untreated	L.F.	5,910	3.00	17,730
	(f) Steel sheet-pile cutoff wall	S.F.	1,350	5.00	6,750
	(g) Steel sheet-pile tie-in wall	S.F.	1,800	5.00	9,000
	(h) Asphalt seepage barrier, $\frac{1}{2}$"	S.F.	2,720	0.25	680
	(i) Lift gates, steel	Ea	1	17,000.00	17,000
	(j) Flap gates, steel	Ea	1	8,000.00	8,000
	(k) Riprap	Ton	665	8.00	5,320
	(l) Shell blanket for riprap	C.Y.	190	4.00	760
	Subtotal (levees and floodwalls)				471,690
	Contingencies				73,310
	Total (levees and floodwalls)				545,000

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(13.0)	PUMPING PLANTS				
	(a) Rhodair Gully	MGPM	290	$ 1,600.00	$ 464,000
	Contingencies				96,000
	Total (pumping plants)				560,000
2.	Area B (Sabine Road Tank Farm)				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	40	1,000.00	40,000
(2)	Non-Federal acquisition cost	Tract	9	700.00	6,300
	Subtotal (lands and damages)				46,300
	Contingencies				8,700
	Total (lands and damages)				55,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	(a) New levee	C.Y.	196,600	1.00	196,600
	(b) Enlarge existing levee	C.Y.	118,000	1.00	118,000
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	4,531	4.75	21,520
	(b) Bit. surface treat., single	S.Y.	27,190	1.25	33,990
(3)	Erosion protection				
	(a) Bedding mat'l for riprap	Ton	22,500	6.00	135,000
	(b) Type B, riprap	Ton	33,750	8.00	270,000
	(c) Turfing	Ac	40	300.00	12,000
(4)	Gated control structures				
	(a) Slide gate and well, 24"	Ea	1	500.00	500
	(b) Slide gate and well, 36"	Ea	6	900.00	5,400
	(c) Culvert pipe, 36"	L.F.	240	11.00	2,640
	(d) Slide gate and well, 60"	Ea	1	2,600.00	2,600
	(e) Alter existing flume to 60" conc. box culvert	Job	1	L.S.	2,400
(5)	Railroad gate closure structures, 20' (2)				
	(a) Reinforced concrete	C.Y.	72	80.00	5,760
	(b) Structural steel gates	Lb	9,000	0.22	1,980

TABLE 1 (CONT'D)

Item No.	Item	Unit	Quantity	Unit cost	Cost
(6)	Railroad gate closure structure, 24'				
	(a) Reinforced concrete	C.Y.	37	$ 80.00	$ 2,960
	(b) Structural steel gates	Lb	5,400	0.22	1,190
(7)	Road ramps, 16' (2)				
	(a) Compacted earth fill	C.Y.	8,730	1.00	8,730
	(b) Shell base, 6"	C.Y.	184	4.75	870
	(c) Single surface treatment	S.Y.	1,102	1.25	1,380
	(d) Turfing	Ac	0.3	300.00	90
(8)	Gravity drainage structure				
	(a) Slide gates 60"x60"	Ea	3	2,600.00	7,800
	(b) Concrete piles, precast 8" x 16" x 25'	Ea	34	85.00	2,890
	(c) Concrete piles, precast 8" x 12" x 37'	Ea	4	95.00	380
	(d) Reinforced conc. wall	C.Y.	5	80.00	400
	Subtotal (levees and floodwalls)				835,080
	Contingencies				129,920
	Total, (levees and floodwalls) Area B				965,000
3.	Area C (Gulf fresh water reservoir)				
(01.0)	LANDS AND DAMAGES				
(1)	Rights-of-way	Ac	49	1,000.00	49,000
(2)	Non-Federal acquisition cost	Tract	10	700.00	7,000
	Subtotal (lands and damages)				56,000
	Contingencies				9,000
	Total (lands and damages)				65,000
(11.0)	LEVEES AND FLOODWALLS				
(1)	Compacted earth levee fill				
	Enlarge existing levee	C.Y.	708,480	1.00	708,480
(2)	Maintenance road				
	(a) 6" compacted shell base	C.Y.	6,271	4.75	29,790
	(b) Bit. surface treat., single	S.Y.	37,630	1.25	47,040
(3)	Erosion protection				
	(a) Bedding mat'l for riprap	Ton	46,700	6.00	280,200
	(b) Type B, riprap	Ton	70,050	8.00	560,400
	(c) Turfing	Ac	57	300.00	17,100
(4)	Gated control structure				
	(a) Slide gates 54" with well	Ea	3	2,100.00	6,300
(5)	Concrete floodwalls				
	(a) Sheet-pile, type 5, 12"x30'	L.F.	300	80.00	24,000
(6)	Strengthen pumphouse wall				
	Reinf. conc. wall 12" x 4'	S.F.	600	2.20	1,320
	Subtotal (levees and floodwalls)				1,674,630
	Contingencies				250,370
	Total, (levees and floodwalls) Area C				1,925,000

TABLE 1 (CONT'D)

SUMMARY - PLAN B

Area	:Lands & :damages : (01.0)	:Levees & :floodwalls : (11.0)	: Pumping : plants : (13.0)	: Total : cost
B. Total first cost				
1. Area B (Sabine Road Tank Farm)	$ 55,000	$ 965,000	$ 0	$ 1,020,000
2. Area C (Gulf Fresh Water Res.)	65,000	1,925,000	0	1,990,000
3. Area G (Single enclosure north of Taylors Bayou)				
Sta. 7/500 to Sta. 0/000	30,000	60,000	0	90,000
Sta. 0/000 to Sta. 33/580	175,000	885,000	1,310,000	2,370,000
Sta. 33/580 to Sta. 59/546	0	14,000,000	0	14,000,000
Sta. 59/546 to Sta. 76/883	125,000	560,000	0	685,000
Sta. 76/883 to Sta. 85/980	35,000	570,000	0	605,000
Sta. 85/980 to Sta. 119/530	130,000	3,560,000	2,810,000	6,500,000
Sta. 119/530 to Sta. 142/330	75,000	545,000	560,000	1,180,000
Subtotals, Area G	570,000	20,180,000	4,680,000	25,430,000
Totals, plan B	690,000	23,070,000	4,680,000	28,440,000
Total constr. cost, plan B				28,440,000
(30.0) ENGINEERING & DESIGN				2,270,000
(31.0) SUPERVISION & ADMINISTRATION				2,690,000
TOTAL FIRST COST TO BE APPORTIONED, PLAN B				33,400,000
(29.0) PREAUTHORIZATION STUDIES				96,000
TOTAL FIRST COST, PLAN B				33,496,000
C. Federal first cost				
a. Federal share apportioned cost (70%)				23,400,000
b. Preauthorization studies				96,000
TOTAL FEDERAL FIRST COST				23,496,000

TABLE 1 (CONT'D)

SUMMARY - PLAN B (CONT'D)

D.	Non-Federal first cost	
a.	Lands and damages	$ 690,000
b.	Non-Federal share apportioned cost (30% less lands and damages)	9,310,000
	TOTAL NON-FEDERAL FIRST COST	10,000,000

NOTE: Prices are as of September 1961.

TABLE 3

ESTIMATES OF ANNUAL CHARGES

PLAN B

(RECOMMENDED IMPROVEMENT)

Item	Amount
Estimated construction period, months	60
Federal investment	
Total estimated Federal first cost	$23,496,000
Interest during construction	1,542,000
Total Federal investment	25,038,000
Federal annual charges	
Interest on Federal investment (2.625%)	657,000
Amortization (100 years) (.213%)	53,000
Maintenance and operation	None
Total Federal annual charges	710,000
Non-Federal public investment	
Total estimated non-Federal first cost	10,000,000
Interest during construction	750,000
Total non-Federal public investment	10,750,000
Non-Federal public annual charges	
Interest on non-Federal public investment (3.0%)	322,500
Amortization (100 years) (0.16%)	17,500
Maintenance and operation	100,000
Total non-Federal public annual charges	440,000
Total annual charges	
Total Federal annual charges	710,000
Total non-Federal public charges	440,000
Total annual charges	1,150,000

TABLE 5

ESTIMATES OF FIRST COST AND ANNUAL CHARGES

INTERIOR DRAINAGE PUMPING PLANTS

(INCLUDED IN PLAN B)

Drainage Area	Total first cost (1)	Interest & amortization on first costs	Maintenance and operation	Annual charges
Crane Bayou	$ 1,700,000	$ 50,000	$ 7,000	$ 57,000
Alligator Bayou	2,640,000	78,000	12,000	90,000
Snake Bayou	655,000	20,000	3,000	23,000
Rhodair Gully	655,000	20,000	3,000	23,000
Totals	5,650,000	168,000	25,000	193,000

(1) Includes contingencies, engineering and overhead.

INTERIM REPORT
ON
HURRICANE SURVEY
OF
PORT ARTHUR AND VICINITY,
TEXAS

APPENDIX V

COMMENTS AND VIEWS OF OTHER AGENCIES

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
P. O. BOX 1306
ALBUQUERQUE, NEW MEXICO

SOUTHWEST REGION
(REGION 2)
ARIZONA
COLORADO
KANSAS
NEW MEXICO
OKLAHOMA
TEXAS
UTAH
WYOMING

ADDRESS ONLY THE
REGIONAL DIRECTOR

2-RBS

July 14, 1960

District Engineer
Corps of Engineers, U. S. Army
P. O. Box 1229
Galveston, Texas

Dear Sir:

The Bureau of Sport Fisheries and Wildlife presents herein its report on the effects of the proposed plan of development for the hurricane protection of Port Arthur and vicinity, Texas, on fish and wildlife resources. Our comments are based on engineering data provided by personnel of your office on February 9 and March 14, 1960. This report, intended to accompany the Corps of Engineers survey report, has been prepared in accordance with the Fish and Wildlife Coordination Act, 48 Stat. 401, as amended; 16 U.S.C. 661 et seq. The report has been coordinated with the Bureau of Commercial Fisheries and has received concurrence of the Texas Game and Fish Commission by letter from Executive Secretary Howard D. Dodgen, dated July 8, 1960.

It is our understanding that the plan of improvement is designed to protect Port Arthur and vicinity from hurricanes capable of producing tides of 12 feet above mean sea level in the waterway alongside the city of Port Arthur and producing waves of 2 feet. Hurricanes of this magnitude are anticipated about once in 100 years.

The plan of improvement will provide ring levees for two separated areas south of Taylor's Bayou and one main levee from high ground north of the community of Groves east to the Sabine-Neches Waterway, thence south and northwest around Port Arthur and Port Acres, terminating at high ground at the Texas and New Orleans Railroad north of Port Acres and west of the south end of the County Airport. Interior drainage will be provided by pumping stations and by eight gravity-flow structures with capacities sufficient to pass drainage from 22.20 inches of rainfall per 24-hour period during normal tides. About 11.5 miles of existing levees will be improved, and about 25.5 miles of new levee will be constructed. A total of 419 acres of additional land will be required for right-of-way and borrow areas. Interior drainage ditches will be improved by local interests as necessary to route surface water runoff into sumps at new pumping stations.

Port Arthur and vicinity lies on the west bank of the Sabine Lake in a heavily populated and highly industrialized area of Jefferson County in southeast Texas. The 1957 population estimate for Port Arthur and its suburbs was 90,000. Beaumont, about 16 miles northwest, had a 1957 population estimate of 130,000. The population in this trading area is expected to increase about 180 percent by the year 2010.

About 39,500 acres will receive some degree of protection by the proposed project development. No significant fishery exists within the area, and wildlife is of minor importance. A small acreage of ricelands supports an estimated 50,000 waterfowl-day use annually and produces a small population of minks.

Population and industrial trends and topographic features indicate that the project area will eventually be developed for housing and industrial purposes and eliminate the waterfowl use and the small population of minks.

The plan of improvement, as proposed, will cause insignificant losses to wildlife resources and offers no opportunities for improvement of the fish and wildlife resources.

Sincerely yours,

Lewis R. Garlick

Lewis R. Garlick
Acting Regional Director

Copies (10)

Distribution:

(3) Executive Secretary, Texas Game and Fish Commission, Austin, Texas
(1) Director, Marine Laboratory, Texas Game and Fish Commission, Rockport, Texas
(2) Regional Director, Bureau of Commercial Fisheries, Region 2, St. Petersburg Beach, Florida
(1) Director, Biological Laboratory, Bureau of Commercial Fisheries, Galveston, Texas
(2) Field Supervisor, Branch of River Basin Studies, Bureau of Sport Fisheries and Wildlife, Fort Worth, Texas

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
P. O. BOX 1306
ALBUQUERQUE, NEW MEXICO

November 27, 1961

AIRMAIL

District Engineer
Corps of Engineers, U. S. Army
P. O. Box 1229
Galveston, Texas

Dear Sir:

Reference is made to Mr. T. W. Elam's letter of November 14, 1961, requesting our comments on your proposed Interim Report on Hurricane Survey of Port Arthur and Vicinity, Texas.

Your proposed Survey Report presents our views correctly and we have no general comment to offer.

This opportunity to review your report is appreciated.

Sincerely yours,

/s/ Lewis R. Garlick
Lewis R. Garlick
Acting Regional Director

cc:
Field Supervisor, Branch of River Basin Studies, Bureau of Sport Fisheries and Wildlife, Fort Worth, Texas

87779 O–62—12

GAME AND FISH COMMISSION
AUSTIN, TEXAS

November 28, 1961

Mr. Kenneth Heagy, Chief
Engineering Division
U. S. Army Engineer District
Corps of Engineers
606 Santa Fe Building
Galveston, Texas

Dear Mr. Heagy:

Reference is made to the advance copy of the Interim Report on Hurricane Protection of Port Arthur and Vicinity, Texas (SWNGW-2d). The proposed work as shown in your report will have no detrimental effect on either the marine fishery or wildlife habitat.

The opportunity for reviewing this report is appreciated.

Sincerely yours,

/s/ Eugene A. Walker
Eugene A. Walker, Director
Program Planning

TRL:bh

INTERIM REPORT ON
HURRICANE SURVEY OF
PORT ARTHUR AND VICINITY, TEXAS

INFORMATION CALLED FOR BY
SENATE RESOLUTION 148, 85TH CONGRESS,
ADOPTED JANUARY 28, 1958

1. Authority.- The following information is furnished in response to Senate Resolution 148, 85th Congress, adopted January 28, 1958.

2. Requests by local interests.- At the public hearing in Port Arthur on March 21, 1958, local interests requested the construction of hurricane protection improvements that would furnish adequate protection against flooding, erosion, and damages caused by hurricanes to the cities of Port Arthur and Groves; the towns of Lakeview, Pear Ridge and Griffing Park and the industrial plants of the Gulf Oil Corp., Texaco, Inc., Atlantic Refining Co., and Koppers Co. Specific improvements requested were as follows:

a. Repair and strengthen as necessary the existing seawall along the Sabine-Neches Canal and the earthen levees which now inclose the protected parts of the area; and

b. Extend protection by suitable earthen levees to the unprotected parts of the area.

3. Hurricane protection improvements considered.-

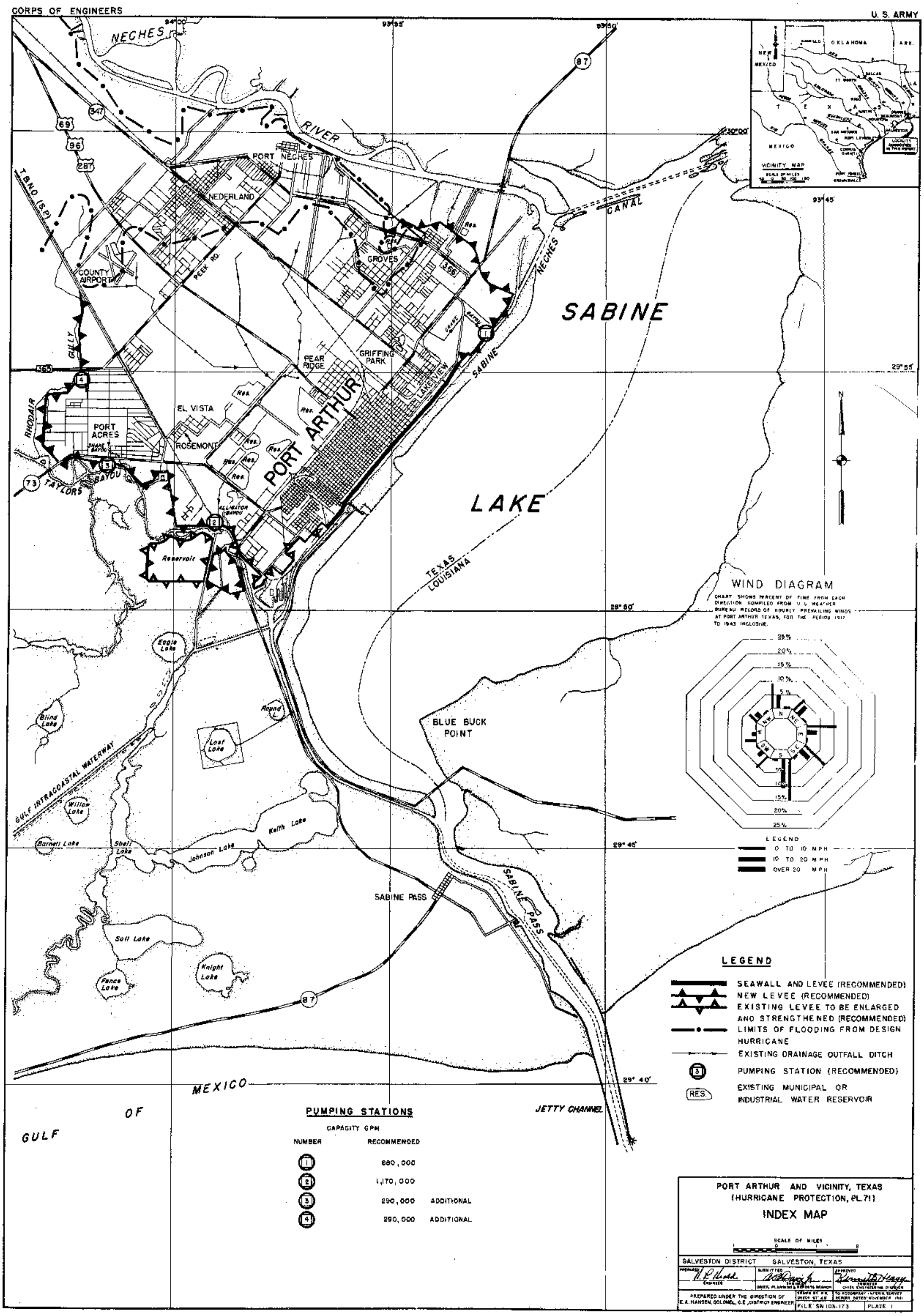
a. Two alternate plans, designated as plans A and B, were developed for consideration of hurricane protection improvements for Port Arthur and vicinity in accordance with the desires of local interests. The improvements proposed under either plan would protect the areas included from flooding effects of the design hurricane, which has an estimated recurrence interval of once in about 160 years. The plans also provide for interior drainage facilities adequate to prevent damaging flooding from the drainage design rainfall of 9.7 inches in 24 hours occurring coincident with exterior tides sufficiently high to block gravity outflow from the inclosed areas. This condition has an estimated recurrence interval of once in about 30 years.

b. The principal difference in the two plans would be the protection of a large and practically undeveloped area of low-lying land in the Alligator Bayou vicinity, west of Port Arthur, under plan B, which would not be protected under plan A. The improvements proposed under either plan would protect virtually all of the area that is developed at the present time. Plan A would provide for four separate inclosures by levees in the area north of Taylors Bayou and two separate inclosures south of Taylors Bayou. The largest of the six inclosures would be the Port Arthur-Groves vicinity and the main plant facilities of the major industries.

The five smaller inclosures, including two south of Taylors Bayou, would be for separated industrial facilities and the Port Acres -Rosemont-El Vista residential communities.

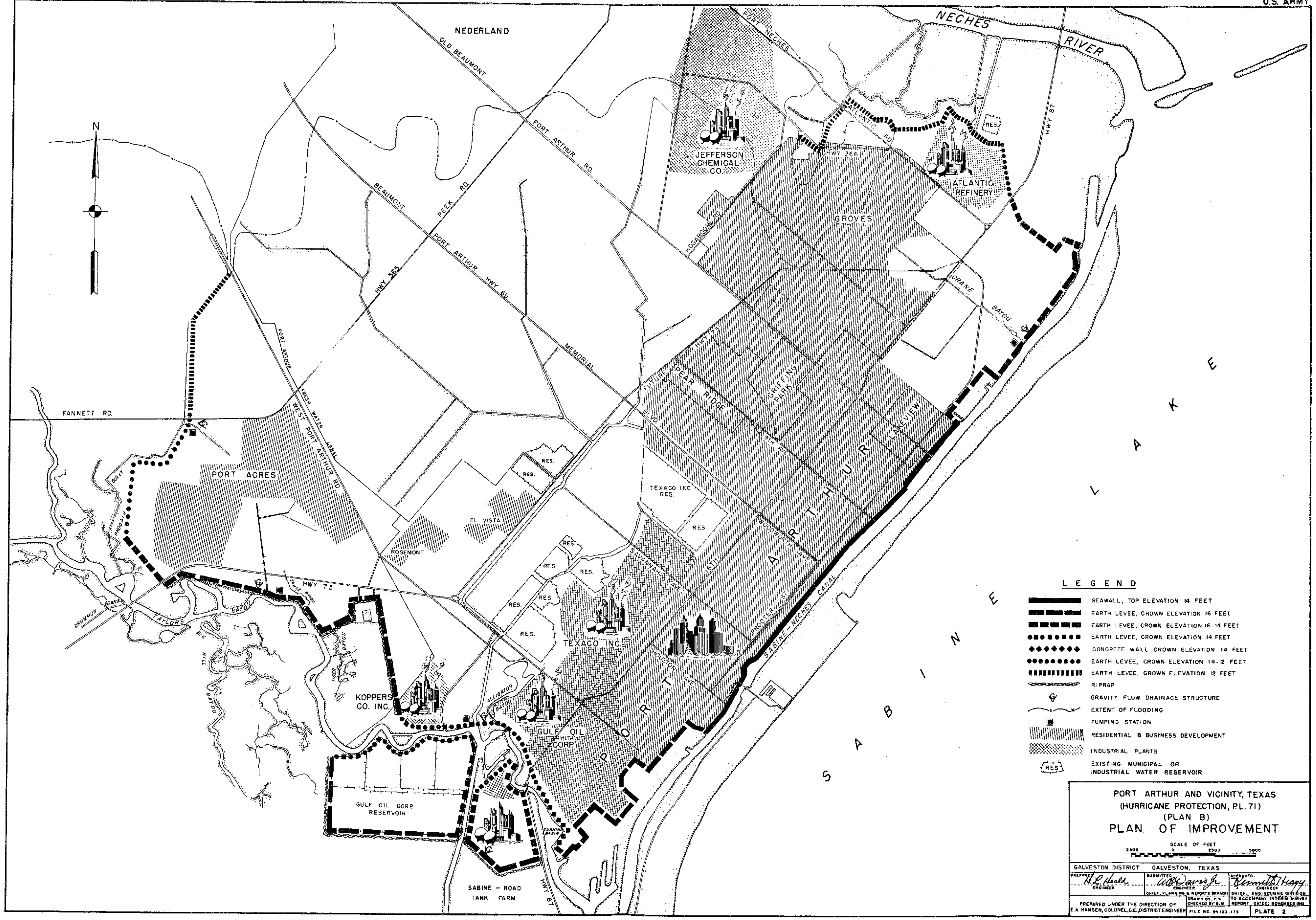
c. Detailed descriptions of the two plans are contained in paragraphs 75 through 85 of the text and in appendix III of the report. Cost analyses are based on a 100-year project life for each plan of improvement.

4. Reasons for recommending plan B.- The two plans were found to have very favorable benefits to cost ratios of 4.1 and 5.7 for plans A and B respectively. The improvements proposed under plan B offer a larger excess of benefits over costs than those proposed under plan A and numerous other advantages to the area would be found in plan B. The entire area north of Taylors Bayou would be protected by a single, integrated protective system under plan B, thus permitting a logical and orderly pattern of future growth and development. Under the separated inclosures proposed in plan A, future development would be restricted largely to the vicinity of existing developed areas, which have only limited amounts of suitable remaining space. The considerable amount of undeveloped land which would be protected under plan B is essential to continuation of the rapid growth which the area has experienced in the past. During periods of high hurricane tides, the separate areas of plan A would be isolated with no means of moving emergency vehicles or equipment between the various areas. Local interests strongly favor the improvements proposed in plan B. In view of the many advantages of plan B, it has been selected as the recommended plan.


CORPS OF ENGINEERS
U. S. ARMY
NECHES RIVER
PORT NECHES
NEDERLAND
GROVES
COUNTY AIRPORT
PEEK RD.
SABINE
LAKE
PEAR RIDGE
GRIFFING PARK
LAKEVIEW
EL VISTA
PORT ACRES
ROSEMONT
PORT ARTHUR
TAYLORS BAYOU
RHODAIR
GULLY
Reservoir
NECHES CANAL
SABINE
TEXAS
LOUISIANA
Eagle Lake
Blind Lake
Round
Lost Lake
GULF INTRACOASTAL WATERWAY
Willow Lake
Barnett Lake
Shell Lake
Johnson Lake
Keith Lake
BLUE BUCK POINT
SABINE PASS
SABINE PASS
Salt Lake
Knight Lake
Fence Lake
GULF OF MEXICO
JETTY CHANNEL
VICINITY MAP
WIND DIAGRAM
CHART SHOWS PERCENT OF TIME FROM EACH DIRECTION COMPILED FROM U. S. WEATHER BUREAU RECORD OF HOURLY PREVAILING WINDS AT PORT ARTHUR TEXAS, FOR THE PERIOD 1917 TO 1943 INCLUSIVE.
LEGEND
0 TO 10 MPH
10 TO 20 MPH
OVER 20 MPH
LEGEND
SEAWALL AND LEVEE (RECOMMENDED)
NEW LEVEE (RECOMMENDED)
EXISTING LEVEE TO BE ENLARGED AND STRENGTHENED (RECOMMENDED)
LIMITS OF FLOODING FROM DESIGN HURRICANE
EXISTING DRAINAGE OUTFALL DITCH
PUMPING STATION (RECOMMENDED)
RES.
EXISTING MUNICIPAL OR INDUSTRIAL WATER RESERVOIR
PUMPING STATIONS
CAPACITY GPM
NUMBER RECOMMENDED
1 680,000
2 1,170,000
3 290,000 ADDITIONAL
4 290,000 ADDITIONAL
PORT ARTHUR AND VICINITY, TEXAS
(HURRICANE PROTECTION, PL.71)
INDEX MAP
SCALE OF MILES
GALVESTON DISTRICT GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF E. A. HANSEN, COLONEL, C.E., DISTRICT ENGINEER
FILE SN 103-173
PLATE 1

CORPS OF ENGINEERS

U.S. ARMY



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