A FIELD INVESTIGATION OF ROLLOVER FISH PASS, BOLIVAR PENINSULA, TEXAS

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ABSTRACT

A field study of Rollover Fish Pass, an artificial tidal inlet connecting Galveston East Bay, Texas, with the Gulf of Mexico, was conducted. The objectives of this study were, 1) to evaluate the flow and stability characteristics of the inlet, 2) to investigate the propagation of the tidal wave through the connected bay system, and 3) to evaluate the effect of the inlet on tidal fluctuations and flushing of East Bay. Field work included hydrographic surveys of the inlet and adjacent Gulf beaches, collection and analysis of sediment samples from the inlet and beaches, measurement of tidal fluctuations at selected locations in East Bay, and current measurements in the inlet. Tidal data from the Gulf, provided by the Galveston District, Corps of Engineers, were analyzed along with the field data.

PREFACE

The research described in this report was conducted as part of the continuing research program in Coastal Engineering at Texas A&M University.

The authors wish to express their appreciation to several persons who voluntarily assisted in the field studies: Jack Apgar, Geral Greer, Duncan Fitzgerald, Richard Holder, Raulie Irwin, Dick Manley, David Riley, Won Oh Song and Bob Taylor. Special thanks are due to Ed Schmeltz who helped the authors in numerous ways and often under trying conditions, to Jim Lawson for his long hours in reducing field data, and to Arthur Janecka of the Galveston District, Corps of Engineers for his time, trouble and valuable consultation. Dr. Robert Schiller also offered many helpful suggestions in his usual good-hearted manner. The review of this paper by Dr. Wayne Ahr and Dr. David Basco is gratefully acknowledged.

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INTRODUCTION

Many of the world's coastal areas are characterized by barrier islands paralleling the mainland and separating shallow lagoons or bays from the oceans. These littoral barriers are depositional structures continually changed by waves, tidal currents, and winds. Often the only connections between the open ocean and the bays are small restricted channels through the barrier beaches. These channels, or tidal inlets, range in size from small fish passes to major navigation channels several miles wide. They may be either natural or artificial. Ideally, their continued existence depends upon the currents produced by the rise and fall of the ocean tides, which act to remove any alluvial material deposited in their channels. Some inlets open and close periodically, responding to changes in their environment; others remain open indefinitely, often stabilized by jetties, sheet pilings, weirs, or other devices.

All inlets are affected to some degree by any of several variables, including surface runoff, astronomical tides, wave action, winds and wind-generated tides, and littoral drift. Any of these variables will tend to alter the inlet's appearance over long time intervals. Also, tidal inlets are subject to shorter period changes. A single storm may drastically change an inlet's configuration, in extreme cases closing an existing channel or opening a new one. Even under normal conditions, an inlet may tend toward closure, and artificial means then must be used to insure that the channel remains open and free-flowing.

It is important that tidal inlets remain open, not only because they connect mainland ports with the ocean, but because they also allow an interchange of water between bays and the ocean. This is vital in controlling the water salinities in the bays. At the present time, many inlets are dredged periodically to insure free passage of shipping, or unrestricted water flow. This is necessitated by the deposition of sand in and around the inlet by wave and current action. Sometimes coastal structures can be used exclusively to maintain open channels, and in some cases the inlets themselves are of a stable configuration and remain open without assistance.

The majority of Texas' coastline is generally typical of a barrier island system. There are roughly a dozen inlets marking the state's Gulf coastline, with many being dredged periodically to maintain their channel depth. Considering their relative importance in maintaining desirable water qualities in the bay and providing travel to the open oceans, very little research has been done concerning these inlets. Some studies have been conducted on the behavior of natural inlets (23,32), but the availability of detailed studies of artificially stabilized inlets is somewhat limited. In view of this, a study was undertaken to investigate a small artificial fish pass on the Texas coast, the objectives of which were to

1) determine the flow and stability characteristics of the inlet, 2) investigate the propagation of the tidal wave through the connected bay system, and 3) study the associated environmental impact of the inlet on its surroundings.

The pass selected was Rollover Fish Pass, located about twenty miles northeast of Galveston, Texas, as shown in Figure 1. It is ideal for the purposes expressed in that it is convenient and relatively small. It is the sole connection between East Galveston Bay and the Gulf of Mexico, and acts in conjunction with Galveston Pass and San Luis Pass to exchange Gulf waters and those of the Galveston Bay system. The field investigations of Rollover Fish Pass began in October, 1971, and continued through February, 1972. Before discussing the results of the actual study, however, a review of previous works and a general introduction to inlet characteristics is presented.

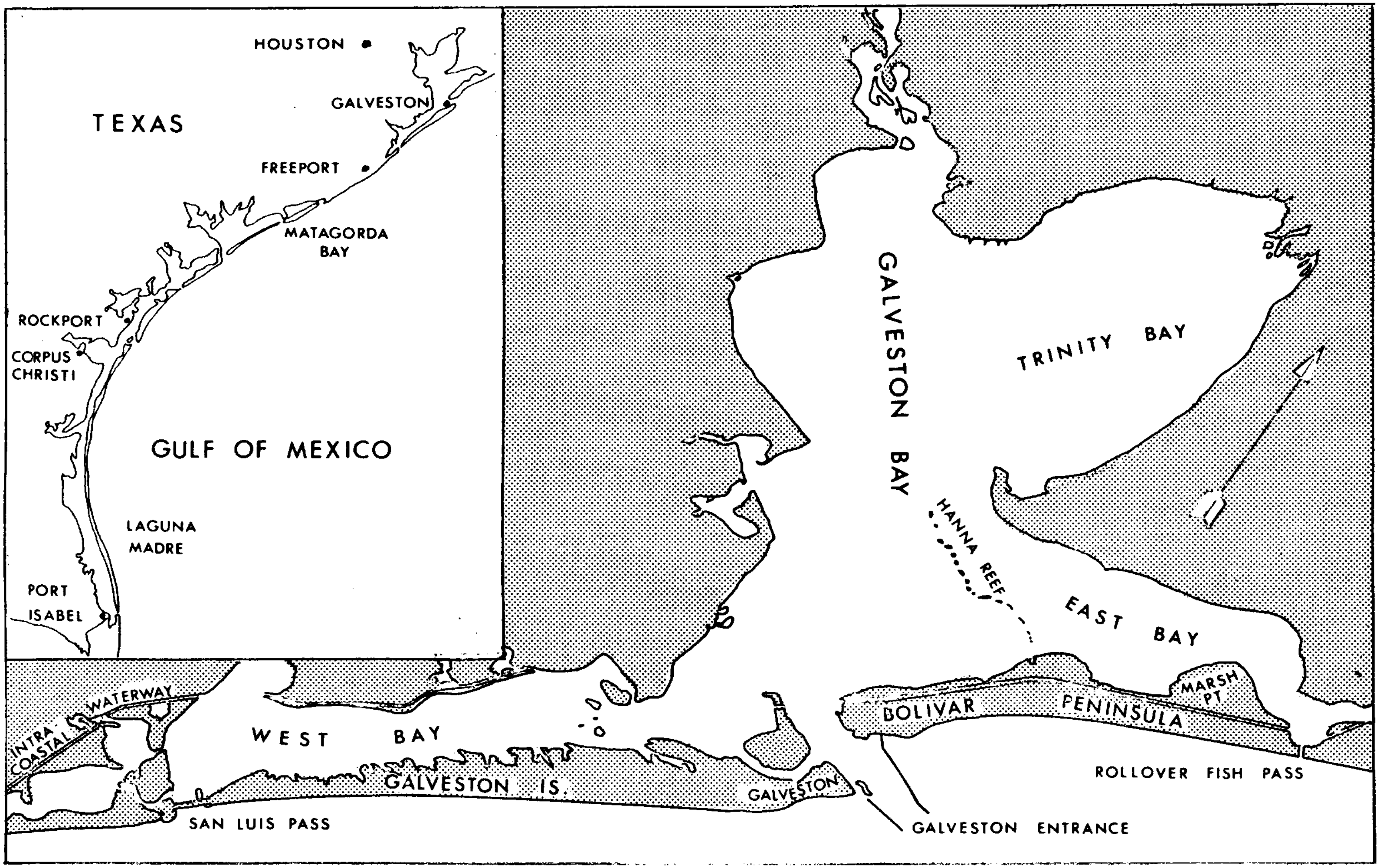


FIGURE 1.--AREA MAP SHOWING LOCATION OF ROLLOVER FISH PASS.

LITERATURE REVIEW

Tidal inlets on sandy beaches have been the object of study for some time. As early as 1878 a criteria for inlet design was prepared by Eads (see O'Brien, ref. 26). Johnson (17), in another early work, realized the effects of wave and current activities on the formation and maintenance of these passes. The first major work was undertaken by Brown (2), however, in which he presented a detailed study of inlet characteristics as well as mathematical relationships between tidal prisms and current velocities through the channels. It was not long until O'Brien presented his linear relationship between the inlet cross-sectional area and the tidal prisms of the bay for a number of Pacific Coast inlets (24). Study of inlets along the Atlantic and Gulf Coasts showed similar behavior; thus his equations provide a means of predicting stability for any inlet with a known tidal prism (25). Further work by Brunn (3) and Bruun and Gerritsen (5), looked into the actual environmental processes affecting channel stability. They also documented the effects of littoral drift on various inlets (4). Carothers and Innis have prepared an inlet design procedure that considers several variables often ignored during inlet planning (8). Graf (14) presented a detailed review of channel design in alluvial matter, and showed the shear stress values required for stable design to be fairly well established.

Price was one of the first to begin major work along the Texas Coast (28,29,30) and showed the importance of north winds on the existence and orientation of many Texas inlets. He also found that the characteristic patterns displayed by the tidal current channels of Texas inlets could be extended to those along other coasts as well (32). Some inlet feasibility studies by engineering consulting firms in Texas, mostly in conjunction with overall plans to reduce the hypersalinities in certain Texas bays, are available (21,22). While these reports apply current technology to inlet designs none of the proposed channels have as yet been constructed. However, an offshoot of such a report has resulted in the construction of an inlet now nearing completion near Corpus Christi, Texas. Rather than constructing the inlet in accordance with recommended inlet design procedures, this pass is being built without any such analysis. This, of course, prohibits any evaluation at this time of the design methods used in the reports, although some data may be forthcoming.

Considerable effort has been expended on the predictions of current velocities based on a knowledge of the tidal cycle. Brown developed a mathematical solution to this problem in 1928 (2), and Keulegen presented a much more detailed solution sometime later which is still widely used (18). Additional work has been produced by a number of others, including Baines (1), Caldwell (7), Shemdin and Forney (35) and Van de Kreeke (19).

Some research has been accomplished concerning the coastal processes affecting natural inlets. Evans (13) investigated spit growth across inlet entrances, and realized the importance of wave refraction in such cases. Hayes (13) reported wave refraction to be the cause of some large-scale, sedimentary phenomena. Recently, Mason and Sorensen reported in some detail on the history and environmental processes affecting an isolated inlet on the Texas Coast (23).

Attempts to measure frictional resistance in channels have been well explored (11). Some methods of evaluation have been developed by linearizing equations (1). However, Shemdin and Forney retained second order terms and evaluated bottom shear coefficients in bays with some success (35). Van de Kreeke also attempted to evaluate frictional terms by linearization (19). Actual field correlation with predicted values is somewhat scarce, and the studies performed at Rollover Fish Pass will be presented later to expand on this subject.

Previous investigation involving Rollover Fish Pass have been a Corps of Engineers' report on recommendations to stabilize the inlet in 1958, (38) and a number of cross-sectional profile studies by the Texas Parks and Wildlife Department. These will be drawn on later in this report.

This brief literature review is intended merely to highlight important works in the study of coastal inlets. More detailed considerations will be given to these and other investigations, where applicable, in this paper.

INLET FORMATION

It is a generally recognized fact that the continued existence of tidal inlets is due to the currents generated through their channels by the difference in tidal elevations. Many inlets are formed during large storms, and while the exact mechanics of this type of formation are not clear, two possible methods have been proposed. Both are associated with rises in the level of the surrounding waters.

Johnson (17) credits inlet formation through a barrier island to the combined wave and high water activity on the ocean side. Low points on the barrier beach are inundated and subsequent formation of a natural inlet occurs. Shaler (34), however, believes that inlet formation is due to rapid rises in the water levels of the bays. This causes a break in the island toward the ocean and quickly scours a well formed, hydraulically efficient channel through the beach. Pierce (27), in his review of various formation processes, concludes that such currents as those resulting from ocean wave activity will be insufficient to scour deep channels except on narrow islands. The friction losses, which cause a decrease in velocity, are deemed too large on wide barrier beaches to permit sufficient scour.

Breakthroughs also have been found to be caused by gradual buildups of water in the bays, followed by wind shifts to an offshore direction (27). This tends to be supported by Price's findings on the north-south alignment of natural inlets along the Texas coast (29).

The formation of a natural inlet will occasionally result from oblique wave activity at a bay or lagoon entrance causing the growth of a sand spit or bar across the opening. This process continues until only a narrow opening connects the enclosed bay and the ocean. If the tidal prism is large enough, the induced currents finally halt the spit growth and an inlet is established. Assateague Anchorage, Virginia, is an example of such a formation (2).

Another method of inlet formation generally recognized is the artificial creation of passes by dredging, bulldozing, or blasting. Care must be exercised in these cases to avoid possible undesirable side effects. An otherwise stable beach may be severely disturbed by the sudden change in its environment caused by a "non-natural" inlet. The longshore transport of sand is interrupted, and unless sand is supplied from another source to the downcoast side of the inlet, erosion of the beach is practically guaranteed. In some cases, the tidal currents produced through such an inlet may be so great as to cause rapid erosion of the channel banks. This was the case with the aforementioned Rollover Fish Pass and will be discussed later in greater detail. In a similar sense, not considering the current magnitudes and littoral drift in an area may easily result in the closure of an artificial inlet. Brown Cedar Cut, on the Texas coast near Freeport, is an example of such a case. No analysis of the surrounding environment was made before channel was opened by dredging. Littoral deposition caused closure to occur within a week (23).

Based on examples such as these, it becomes evident that indiscriminant cutting of inlets must be avoided. Comprehensive studies of the entire environmental system must be undertaken, with special attention given to the possible degradation of the shoreline. While specifically designed inlets may be of value in controlling hypersalinity in bays, the destruction of surrounding shorelines or silting in the bays may reduce their ultimate worth.

INLET HYDRAULICS

To understand the mechanics of inlets and the importance of the factors influencing them, a brief look at the equations involved in predicting their behavior is useful. The approach taken will be to consider only those terms which are dominant and to neglect higher order terms or those of little relative importance.

If the acceleration terms are neglected, writing the energy equation between the ocean and the bay will yield the following:

$$A_0 + \frac{V_0^2}{2g} = A_B + \frac{V_B^2}{2g} + \Sigma H_L \qquad (1)$$

in which

g = acceleration of gravity,

V_0 = water velocity in the ocean,

V_B = water velocity in the bay,

A_0 = water surface elevation above Mean Sea Level in the ocean,

A_B = water sea elevation above Mean Sea Level in the bay, and

ΣH_L = the sum of all head losses resulting from the flow from the ocean to the bay.

If it is assumed that the ocean and bay are relatively deep, then $V_B \doteq V_0 \doteq 0$, and from above,

$$A_0 - A_B = \Sigma H_L \qquad (2)$$

The term ΣH_L involves all resistance encountered in the channel and generally considers two types of losses: "minor" losses and "gradual" losses. The minor losses include the entrance and exit losses, while the gradual losses result from the friction along the perimeter of the channel. The entrance and exit losses are usually expressed as functions of the velocity head in the channel, V_c, and a coefficient, i.e.:

$$\text{Entrance Loss} = K_{en} \frac{V_c^2}{2g} \tag{3}$$

$$\text{Exit Loss} = K_{ex} \frac{V_c^2}{2g} \tag{4}$$

Most approaches consider K_{ex} to be one, while K_{en} is given a value dependent upon the shape of the entrance. The situation is not as simple with the gradual losses. A number of equations are available to approximate this energy dissipation, but each requires using a "friction" or "roughness" coefficient. These factors are difficult to evaluate accurately and are most often based on experimental results or the experience of the writer involved. Often in this type of open-channel problem, the Darcy-Weisbach equation is employed as a suitable expression for determining these approximations (4). The expression is as follows:

$$\text{Gradual Loss} = \frac{fl}{4R} \frac{V_c^2}{2g} \tag{5}$$

in which

f = Darcy-Weisbach coefficient,

R = hydraulic radius of channel, and

l = length of channel

If equations (2), (3), (4), and (5) are combined, it can be shown that

$$A_0 - A_B = (K_{en} + K_{ex} + \frac{fl}{4R}) \frac{V_c^2}{2g} \qquad (6)$$

Equation (6) may be combined with the continuity relationship, restricted to flow into a closed bay, and developed into the form Keulegan analyzed by numerical integration (18). For the purposes of this paper, however, a form of equation (6) could be used to evaluate the losses through Rollover Fish Pass.

It is possible to alter equation (6) to fit certain unique cases. For instance, at Rollover Fish Pass substantial losses are incurred due to the sheet pile weir across the channel. These may be accounted for by adding another loss coefficient, K_W, to equation (6):

$$A_0 - A_B = (K_{en} + K_{ex} + \frac{fl}{4R} + K_W) \frac{V_c^2}{2g} \qquad (7)$$

This equation can now be used to evaluate typical losses through an inlet such as Rollover Fish Pass. If an accepted value for K_{en} and K_{ex} is used, one is left only with the problem of obtaining a value for either $fl/4R$ or K_W and then solving for the one left. These values are the most difficult to obtain, and are usually experimentally determined. The quantity $(A_0 - A_B)$ is, of course, generally known from tidal records.

INLET STABILITY

Inlet stability is generally defined as the tendency of the channel to maintain a permanent position and configuration - i.e., geographic and geometric constancy. The basic requirement for stability is that the tidal and wave energies at the entrance to the inlet must achieve the proper balance to maintain equilibrium (36). Conditions or changes in the environment around the inlet which increase the tidal flow or increase the wave energy may result in excessive scour and/or migration of the channel. Similarly, changes in the cross-sectional shape of the inlet may cause a decrease in current velocities and additional deposition of sediments, thus leading to a possible closure of the pass. Channel migration also leads to energy consumption by frictional losses over the increased inlet length, and closure may again result. Thus it becomes obvious that for a stable channel to exist, the velocities must be such that neither significant scour nor deposition occur during a tidal cycle (20). Bruun and Gerritsen, in fact, picture a stable configuration as a "rolling carpet" of alluvial material moving back and forth over the inlet bottom with the tidal currents (5). The migration and deposition problem can be partially overcome by artificial means-jetties, weirs, and similar devices. Such structures now control Rollover Fish Pass, as will be shown later in this report. Several methods for predicting inlet stability have been proposed, each with varying degrees of usefulness.

Considerable study has been made of the requirements for a stable inlet. O'Brien (24) attempted to establish a constant ratio between the tidal prism and the cross-sectional areas of a stable inlet. Further study by O'Brien resulted in a later paper (25) which gives the following relationships:

$$A = 2 \times 10^{-5} P \quad \text{for non-jettied inlets or}$$

$$A = 4.69 \times 10^{-4} P^{0.85} \quad \text{for inlets with two jetties}$$

where

A = inlet cross-sectional area in square feet

P = the bay tidal prism in cubic feet

The equations do not directly consider wave action or the associated littoral drift brought to the inlet, and their applicability would appear to be somewhat limited. In most cases, however, they do give surprisingly good results and are widely used in preliminary inlet design.

In a study of numerous natural inlets, Bruun and Gerritsen found that a degree of stability can be estimated from the ratios of the tidal prism P, and maximum discharge at spring tide conditions Q, to the annual gross littoral drift rate M, (5). They concluded that for a value of P/2M greater than three-hundred an inlet possesses a high degree of stability, while those with values less than one-hundred tended to be unstable. Those tending toward instability were characterized by the presence of shallow bars and shoals around the entrance and one or more shifting interior channels.

For the ratios of Q/M, it was found that values greater than 0.01 generally indicated more stable conditions than values less than 0.01 (5). The ratio of Q/M is an indication of the inlet's flushing ability in the presence of littoral drift, or more practically, the balance existing between the tidal currents and the littoral drift. Ultimately it is this variable that determines the fate of the inlet.

Another measure of stability may be determined from a knowledge of the flow characteristics involving the movement of the bottom material. This has been proposed by several investigators and is generally taken to be the critical shear stress, τ_c, of the bed (14). The shear stress is a force per unit area on the bottom as applied by the flow of water over it and may be evaluated by measuring velocity profiles with depths. In general, the critical shear stress increases with an increase in grain size of the bed material and with the suspended sediment in the water. It is also affected by channel shape, bottom configuration, and fresh water discharge. Thus it can be a very useful indicator of channel stability, since it takes into account several of the variables involved with this problem (14). A paper by Bruun and Gerritsen (5) gives an average value of τ_c of approximately 0.10 lbs/ft^2 for stable inlets. Carothers (8) has recommended using a median tidal differential to estimate the critical bed shear stress, τ_c. This apparently has been successful in predicting the behavior of certain inlets.

The entire problem of inlet stability is extremely complex, but the three general relations given above are useful in making estimates of inlet size. Their specific application to Rollover Fish Pass will be discussed in a later section of this report.

HISTORICAL BACKGROUND

Rollover Fish Pass (Fig. 2) is an artificial landcut located on Bolivar Peninsula twenty-two miles northeast of Galveston, Texas, at the small town of Gilchrist. Bolivar Peninsula, which separates East Bay from the Gulf of Mexico, is a low "barrier island" about twenty-five miles long, with widths varying from one-fourth to three miles. At its southwest end, the peninsula is separated from Galveston Island by the Galveston entrance channel, an improved natural pass between the Gulf and Galveston Bay (38). At the site of the fish pass, a natural arm of East Bay known as Rollover Bay approaches to within one-quarter mile of the Gulf. This small constriction in the land is breached by an artificial cut, Rollover Fish Pass, made under the direction of the Texas Game and Fish Commission (now Parks and Wildlife Department) in 1954-55. Its purpose is to allow fish migration and to improve marine biological factors in the bay. The cut was made through the lowest part of the area, where surface elevations are less than five feet above Mean Sea Level, with its longitudinal axis along a straight line somewhat west of due north.

The Galveston Bay system, comprising Galveston Bay, West Bay, East Bay, and Rollover Bay as shown in Figure 1, covers an area of about 294,000 acres. East Bay covers about 50,000 acres with water depths tapering from 6-8 feet at its southwest end to 2-3 feet near Rollover Bay. Rollover Bay itself has an area of about sixty acres, with depths of one to two feet of water. The Gulf Intracoastal

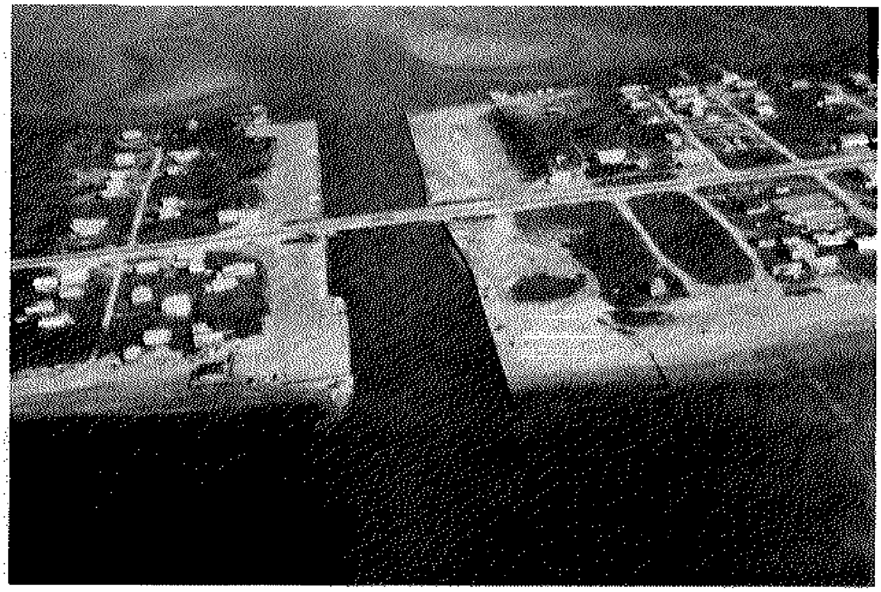


FIGURE 2.--ROLLOVER FISH PASS, NOVEMBER, 1970.
(AUTHOR'S PHOTO)

Waterway is along the bay side of the peninsula and crosses open water at Rollover Bay, about one mile from the Gulf Shoreline.

The Texas Game and Fish Commission first submitted an application to the District Engineer early in 1954 for a permit to dredge a channel from the Gulf to East Bay and make certain other improvements in the area. The Texas Highway Department originally objected to such construction on the basis of possible serious erosion and the probable loss of State Highway 87 during storms. State Highway 87, it should be noted, passes directly over the fish pass on a concrete trestle bridge and provides connection between the mainland and Bolivar Peninsula. The objection was eventually withdrawn, however, and a permit was issued in May, 1954.

Construction work was begun in October, 1954, and completed in February, 1955. The original plans showed a channel across Bolivar Peninsula to be eight feet deep, eighty feet wide, and twelve-hundred feet long at mean low water, with the Gulf end flared and extended into water having a depth of three feet at mean low water. The bay end was to be extended across Rollover Bay to the spoil area of the Intracoastal canal at a depth of four feet and width of one-hundred feet. Furthermore, in an effort to resist the predominant wave action in this area, a steel sheet pile retaining wall was to be constructed along the southwest side of the channel from the bridge into the Gulf (38).

By the time work on the inlet was nearing completion, tidal scour had produced some rather unsuspected effects. The channel was eroded to a depth of thirty feet under the bridge, while the entrance had widened to almost five-hundred feet at the Gulf end. The currents generated through the channel threatened to flank the retaining walls and undermine the bridge abutments. Immediate protective measures were obviously necessary to stop the erosion and protect the remaining structures. These steps included additional pilings to protect the bridge abutments, groins along the northeast side of the pass to halt the growth of the entrance, and a protective cover of shell, broken concrete, stone and other rubble along all exposed banks. The action taken did not, however, completely halt the erosion processes.

Unusually high tides and rough waters during the spring and summer of 1955 continued to cause severe problems both in the pass and along the Gulf shore. There was a recession of the Gulf beach southwest of the pass continuing for about a mile downcoast. Some structures were moved from the northeast side of the inlet to protect them from possible undermining, and the bridge itself showed indications of possible damage resulting from the scour. To protect the bridge structures, a sheet pile bulkhead was installed across the inlet just south of the bridge to completely stop all flow of water through the pass. Figure 3 shows Rollover Fish Pass at this time. A short while later the pass was partially reopened by driving alternate piles across the inlet. All of the piles were eventually driven down to five feet below mean low water to form a weir across the inlet when it was fully reopened.

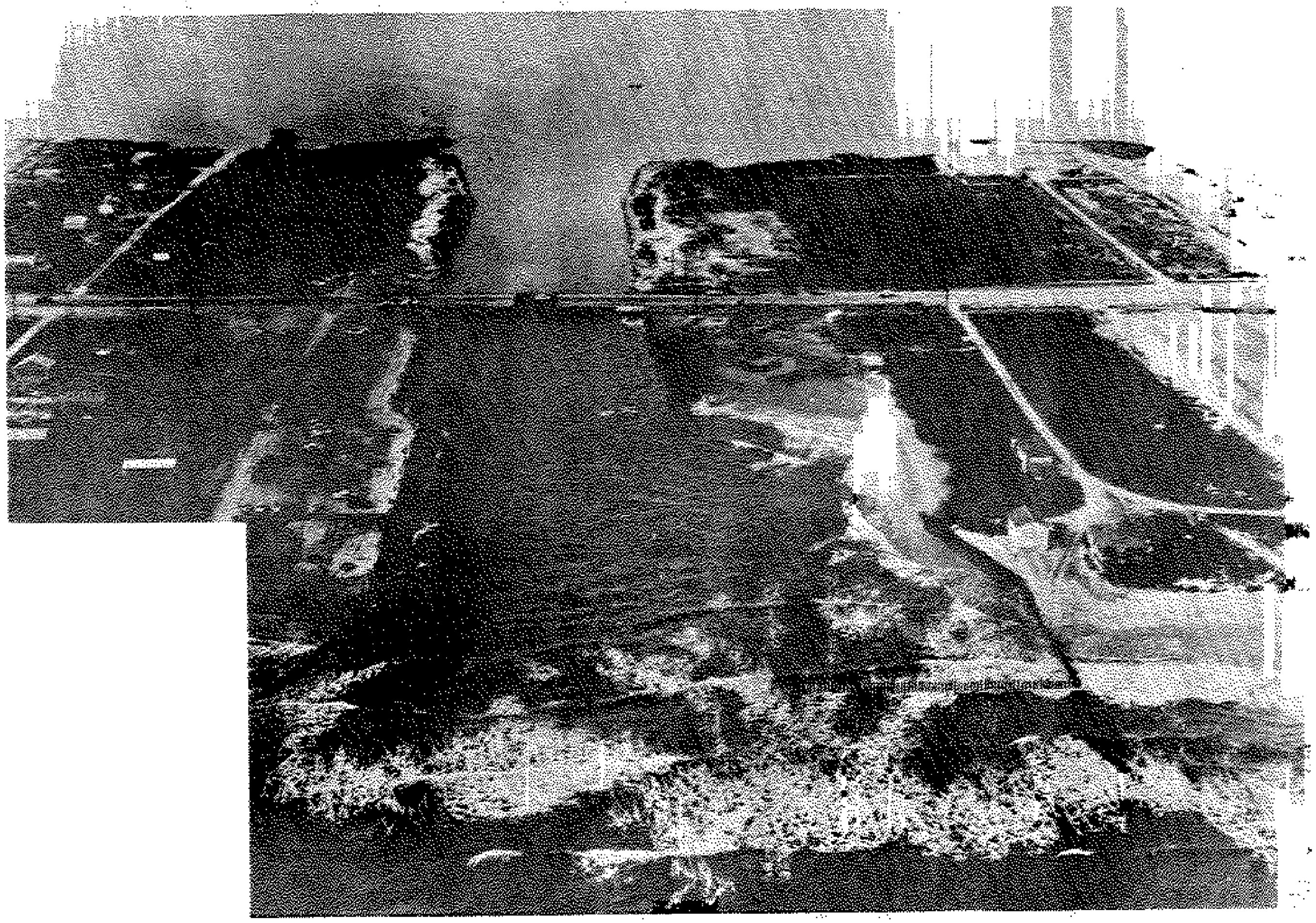


FIGURE 3.--ROLLOVER FISH PASS, FEBRUARY, 1956.
(CORPS OF ENGINEER'S PHOTO)

The pass remained only partially open for some time. Inspection of the site in late 1956 showed some shoaling around the area, and a bar had formed across the mouth of the inlet. The only water exchange was affected through a small channel along the west side retaining wall. At this time, the Corps of Engineers was asked to report on the pass and the surrounding beach erosion and recommend methods of shore recession control and inlet improvement. Their report was published in April, 1958 (38).

The report by the Galveston District, Corps of Engineers suggested several items for putting the inlet into "working order", i.e., providing a stable, predictable inlet capable of producing water exchange and fish migration between the Gulf of Mexico and East Bay. Their recommendations included construction of sills at the bridge and Gulf ends of the channel, bulkheads along both sides of the entire inlet, and periodic nourishment of sand to offset the adjacent shore erosion. Such action was subsequently taken with the exception of continued nourishment to the beach, and the pass has been "stable" since that time. Profiles taken in 1968 by the Texas Parks and Wildlife Commission showed depths along the centerline varying from fifteen to thirty feet with no evidence of scour around the retaining walls. There was still considerable erosion of the beach itself, especially west of the pass, which necessitated artificial sand fill in 1957. This will be examined in more detail later in this study.

Hurricanes have, as discussed earlier, played a major role in the creation and/or maintenance of many tidal inlets along the Texas coast (31). There have been many hurricanes affecting the Texas coast, averaging about one every two years (31). The frequency with which any specific point on the coast is subject to such storms has been estimated at once in every 9.2 years, and in fact, the Rollover Fish Pass area has been attacked twice since its construction (38). Storms previous to 1955 produced high tides and flow over the peninsula, but there is no evidence of an inlet existing in this area prior to 1955. Hurricane "Audrey", which made landfall about eighty miles northeast of the pass, produced seven foot tides at Rollover Fish Pass in late June, 1957, but did not significantly effect the pass itself. The Corps of Engineers estimated one to two foot average scour of the channel on the Gulf side of the bridge, and one to two feet fill on the bay side as a result of the storm. The Gulf beach sustained inshore erosion for an average of fifty to sixty feet for five miles on either side of the pass (38).

Due to the small amount of work done around Rollover Fish Pass, it is very difficult to obtain any records of possible damage from any other storms. Because of the stabilization works now in the inlet, however, it is doubtful whether any significant, or especially any lasting effects could have occured from the passage of storms. Beach erosion would undoubtedly have taken place, and this will be examined later in this study.

Since being reopened, the pass has shown no evidence of the large scale erosion that characterized the first channel. The stabilization works remain in good condition, and no additional steps have been necessary to protect the area. All investigations indicate the adopted Corps of Engineers' recommendations have successfully altered the inlets unstable behavior and transformed it into one that achieves its intended functions.

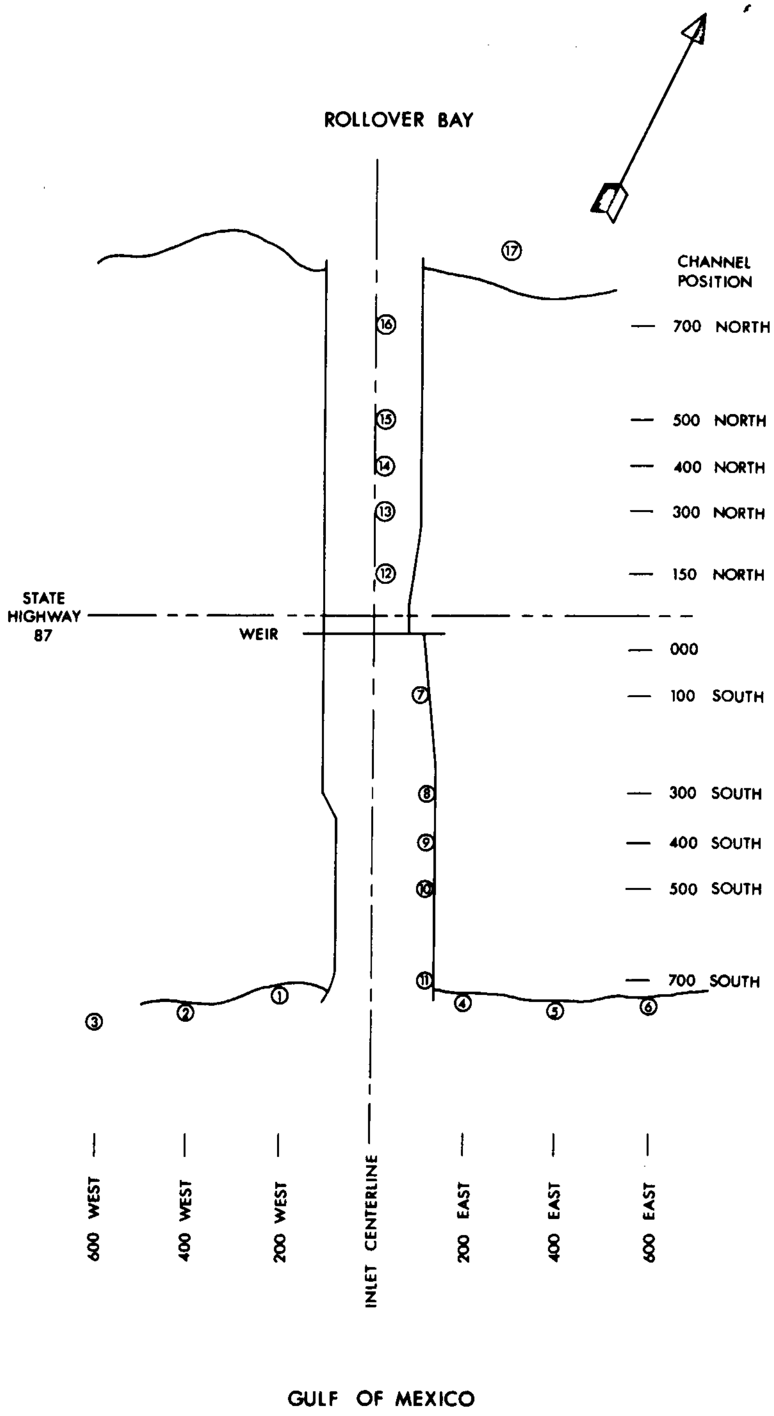
SEDIMENTARY ANALYSIS AND HYDROGRAPHIC SURVEYS

Much information can be determined about an inlet's behavior by studying changes in the appearance, geometry, or geographic location of the channel and surrounding areas. During field investigations at Rollover Fish Pass, several studies were conducted to evaluate any noticeable differences in the inlet or its immediate area. Depth profiles across the inlet and normal to the coastline as well as sediment analyses were conducted, and where possible, compared to data available from previous years. These were then examined for indications of the coastal processes occuring at Rollover Fish Pass.

Sand Sizes and Distribution

To determine the sedimentary characteristics of Rollover Fish Pass, seventeen bottom samples were collected in the channel and adjacent areas shown in Figure 4. In shallow waters and along the beaches, samples were obtained by scooping the upper layers of sand into a baby food jar. In deeper areas, a Birge-Ekman grab sampler dredge was utilized, but heavy shell deposits and several mechanical failures of the sampler made collection difficult. Enough specimens were collected, however, to perform a general sedimentary analysis of the area.

Analysis of the samples was conducted using the visual accumulation tube method (10). Several areas, indicated in Figure



STATION	LOCATION	d_{50} (MM)
200 W	1	.148
400 W	2	.165
600 W	3	.137
200 E	4	.181
400 E	5	.164
600 E	6	.165
100 S	7	⊛
300 S	8	.147
400 S	9	.223 ○
500 S	10	.157
700 S	11	.186 ●
150 N	12	•
300 N	13	.116
400 N	14	.114
500 N	15	.125
700 N	16	.130
SHOAL	17	.116

⊛ NO SAMPLE OBTAINED
○ OVER 50% SHELL
● OVER 50% SHELL
• LARGE SHELLS & PEBBLES

FIGURE 4.--SAMPLE SITES AND MEDIAN GRAIN SIZES.

4, contained large quantities of shell, and shell is not accounted for in the grain size distribution curve using this method. While it may affect the transport characteristics of the material, the shell is removed before analyses because of the inability of the visual accumulation tube to handle particles of such sizes. The central tendencies of the samples are described using the median diameters in millimeters (Figure 4).

Those specimens north of the bridge were mostly gathered with the Ekman dredge used from a small boat. Extremely rough wave conditions south of the bridge precluded use of the boat, however, and the samples were procured from the sides of the inlet close to the east bulkhead.

The median sizes generally tend toward larger values in areas of known high velocities and turbulence. In the south end of the channel, the grains decrease in size from the Gulf toward the bridge. It is important to remember that these samples were obtained from near the sheet pile bulkhead, and not in the higher velocity areas toward the center of the inlet. Also of interest is the development of a small shoal along the east bulkhead, centered around station 550 south and extending about sixty feet north and south along the bulkhead (Figure 5). This was first noticed during an extremely low tide influenced by a strong north wind. This particular area possessed little shell and a smaller median size than other nearby samples. Visual estimates indicated that stations 300 and 700 south both contained on the order of 70% to 80% shell

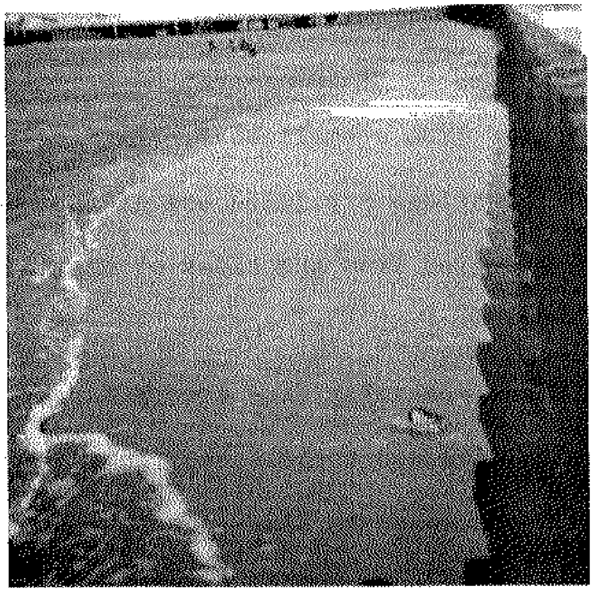


FIGURE 5.--SHOAL ON EAST BULKHEAD, SOUTH SIDE OF ROLLOVER FISH PASS. (AUTHOR'S PHOTO)

and rock, and station 300 south was estimated to contain 40% to 50% shell. Station 100 south yielded no sample, either due to a bottom shell armor or the concrete rip-rap around the bridge.

The north side of the inlet displayed the same general trends as the south end. Station 150 north, owing to high current velocity and turbulence, predictably showed only large shell and pebbles in the samples. The smaller median diameters found at stations 300 and 400 north are apparently the result of the greater channel depths, and therefore, lower current velocities. Stations 500 and 700 north, as well as the shoal behind the inlet, all possessed significantly smaller median diameters than any samples on the south end.

The beach samples gave results as indicated in Figure 4. It should be noted that station 200 west is on the downdrift side of a groin, and is probably not a representative sample because of the "protection" afforded this area from the offshore wave activity. The median diameters of the beach samples were generally larger near the entrance to the pass, and smaller in the lower velocity areas away from the inlet.

Beach Profiles and Stability

To evaluate the stability of the Gulf coastline at Rollover Fish Pass, several profiles were taken in the immediate vicinity of the pass entrance in October, 1971. The profiles begin approximately 500 feet south of State Highway 87 and extend into the water at each station shown in Figure 6. The profiles are plotted in Figures 7 and 8 with data from previous years for comparison.

The profiles show a general recession of the west beach has occurred when compared to the east beach. This is evident in all data west of the inlet with the exception of station 200, but the deposition patterns at that position are probably not indicative of the behavior of the rest of the downdrift beach. The southwest sheet pile bulkhead extends into the Gulf for approximately 100 feet and effects the wave patterns in that area. This in turn affects the erosion rates near the entrance. A comparison of Figure 2, page 20, with Figure 9 shows the accretion occurring at station 200 west in contrast to the general recession of the rest of the west beach.

The beach east of the pass is somewhat more stable than it is on the downdrift side of the inlet. Unfortunately, due to the presence of piles and groins along the beach, it was possible to obtain only two profiles on the updrift side of the beach. Those obtained do indicate a general stability of the shoreline, and are probably representative of the entire beach east of the inlet.

Figure 10 is an overhead photograph of Rollover Fish Pass taken in February, 1972. The stability of the updrift beach is fully evident, and the recession of the west beach is graphically shown in comparison. Offshore bars are also present just south of the beaches. Once again the abnormal appearance of station 200 west is apparent.

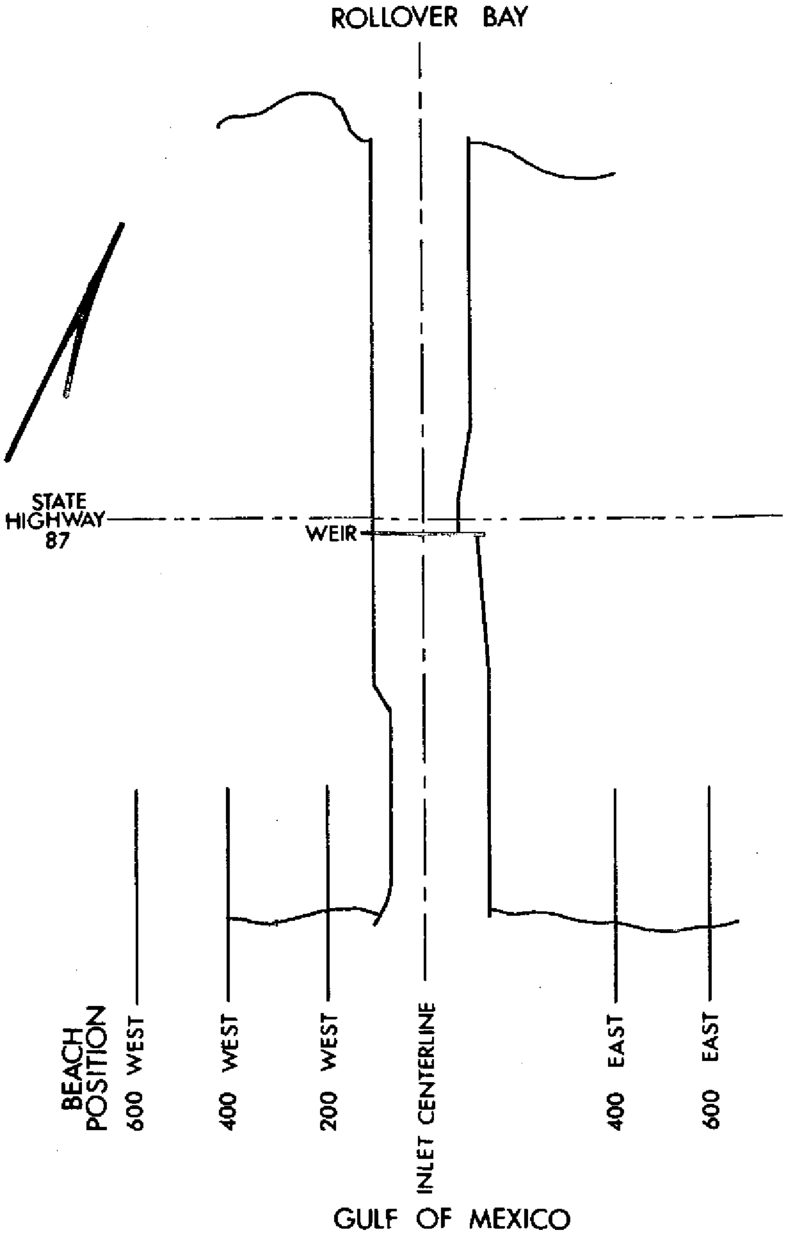


FIGURE 6.--LOCATION OF BEACH PROFILES.

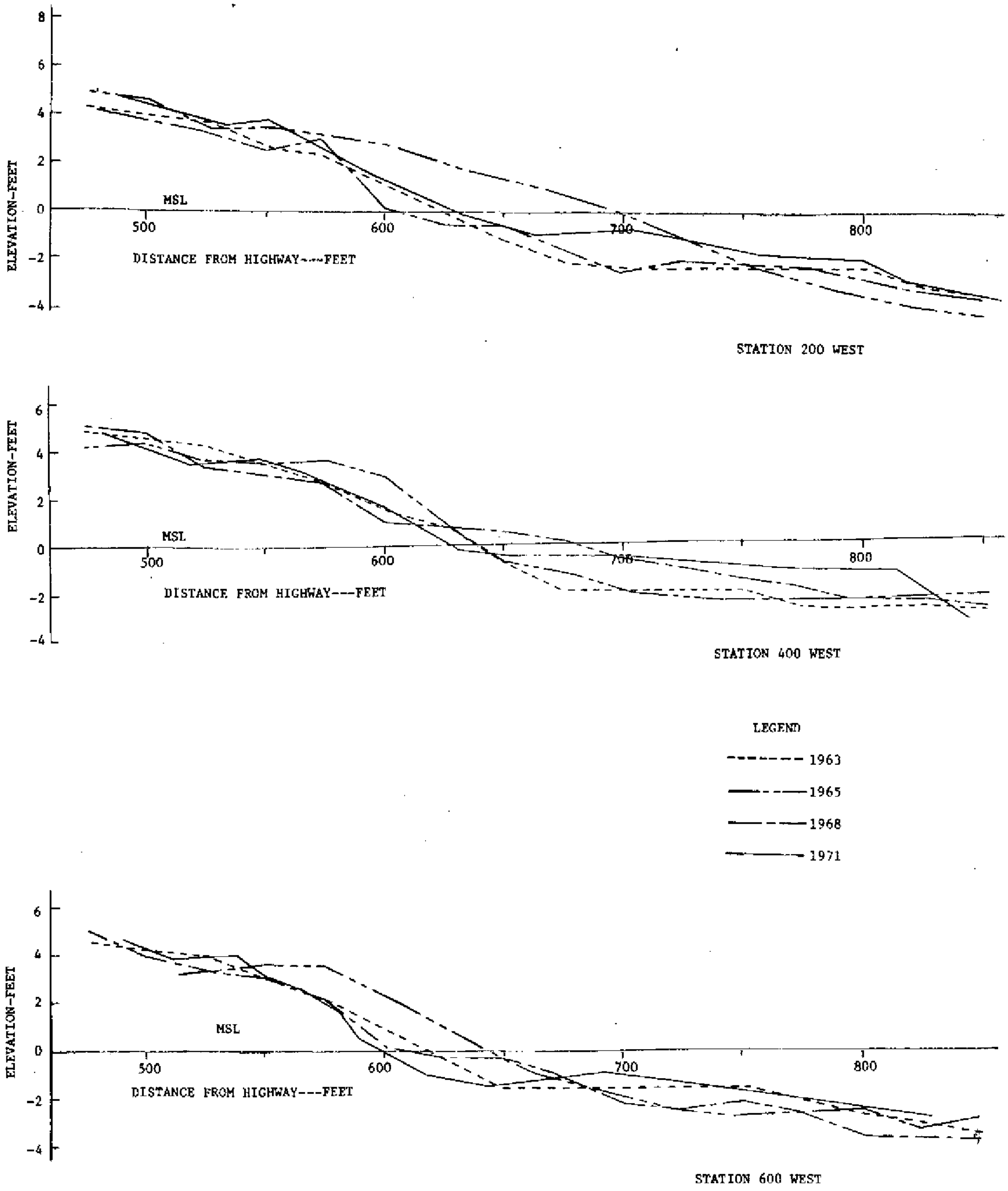


FIGURE 7.--BEACH PROFILES, ROLLOVER FISH PASS, WEST SIDE.

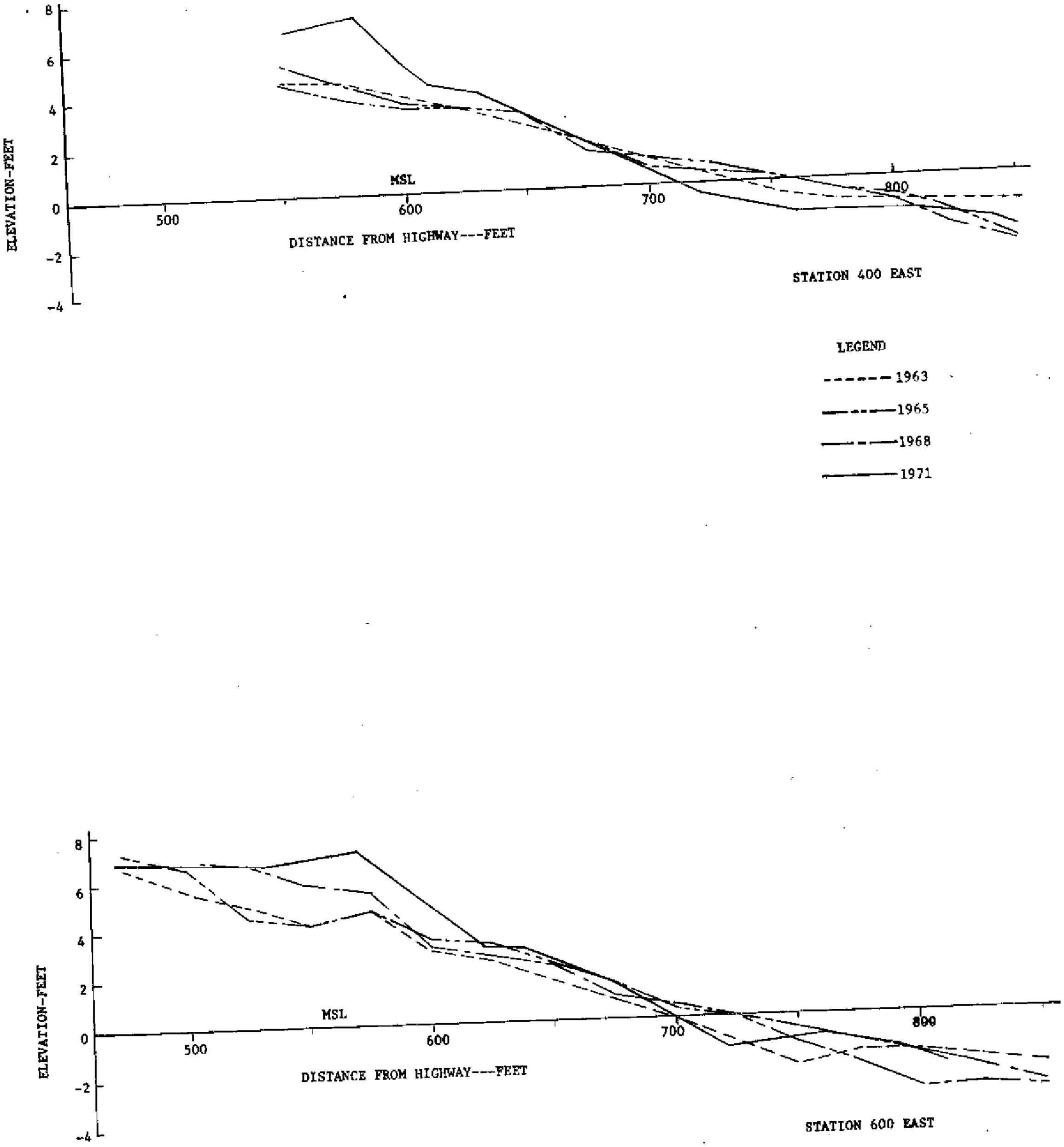


FIGURE 8.--BEACH PROFILES, ROLLOVER FISH PASS, EAST SIDE.

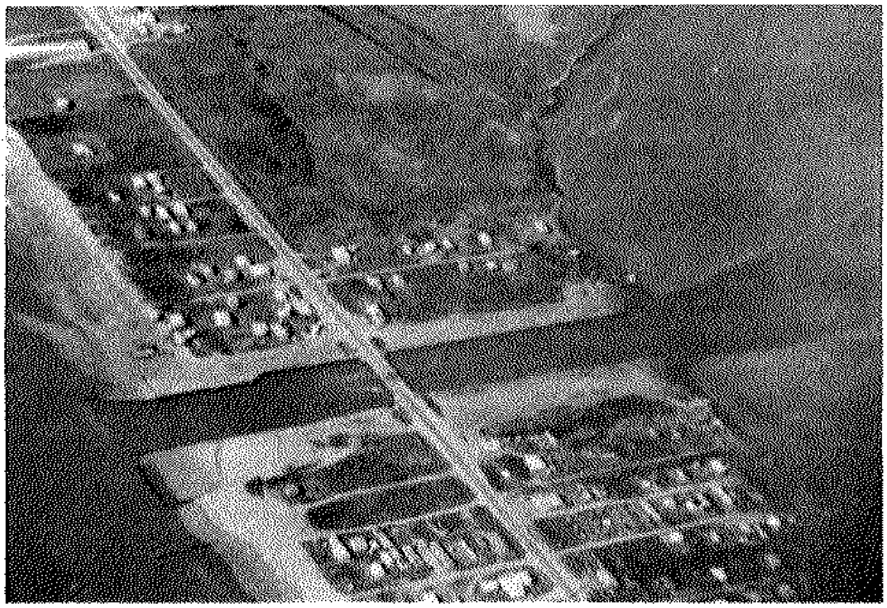


FIGURE 9.--ROLLOVER FISH PASS, FEBRUARY, 1972.
(AUTHOR'S PHOTO)

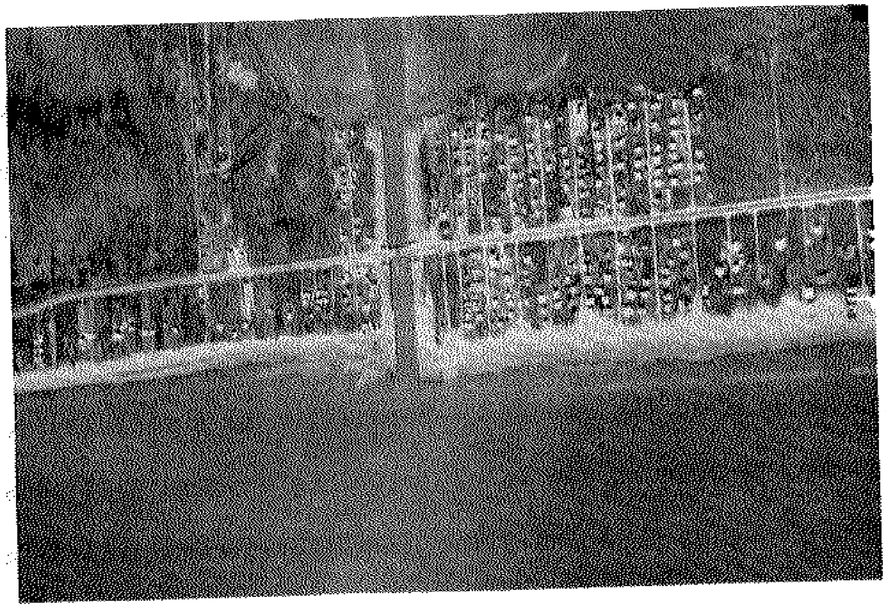


FIGURE 10.--BEACHES AT ROLLOVER FISH PASS, FEBRUARY, 1972.
(AUTHOR'S PHOTO)

Section Profiles and Stability,

Cross-sectional profiles of the pass were measured at several stations along its length, as shown in Figure 11. The north end of the channel was sounded in late October, 1971, and the south end in January, 1972. Depth measurements were made at twelve and one-half foot intervals across the inlet using a hemp sounding line marked in one-half foot increments. Results are shown in Figures 12 through 15. Plotted for comparison are profiles taken in previous years by the Texas Parks and Wildlife Department (previously Texas Game and Fish Commission). Figures 16 and 17 show the bottom contours of the channel as compiled from 1968 and 1971-72 data.

The data show a general tendency toward sedimentation rather than erosion in the channel. Deposition is especially evident in the eastern side of the inlet, with the western half remaining fairly constant in depth. The deep hole present near station 150 south in 1968 has shifted northward, and is centered near station 100 north in 1971. The only erosion of any significance has occurred at station 900 north, or approximately 100 feet north of the end of the bulkheads. This section appears to be stabilizing at about three feet below Mean Sea Level.

As a whole, the channel appears to be dynamically stable and well behaved. The overall change in depths the last eight years has been moderate, and no tendency toward gross instability is apparent.

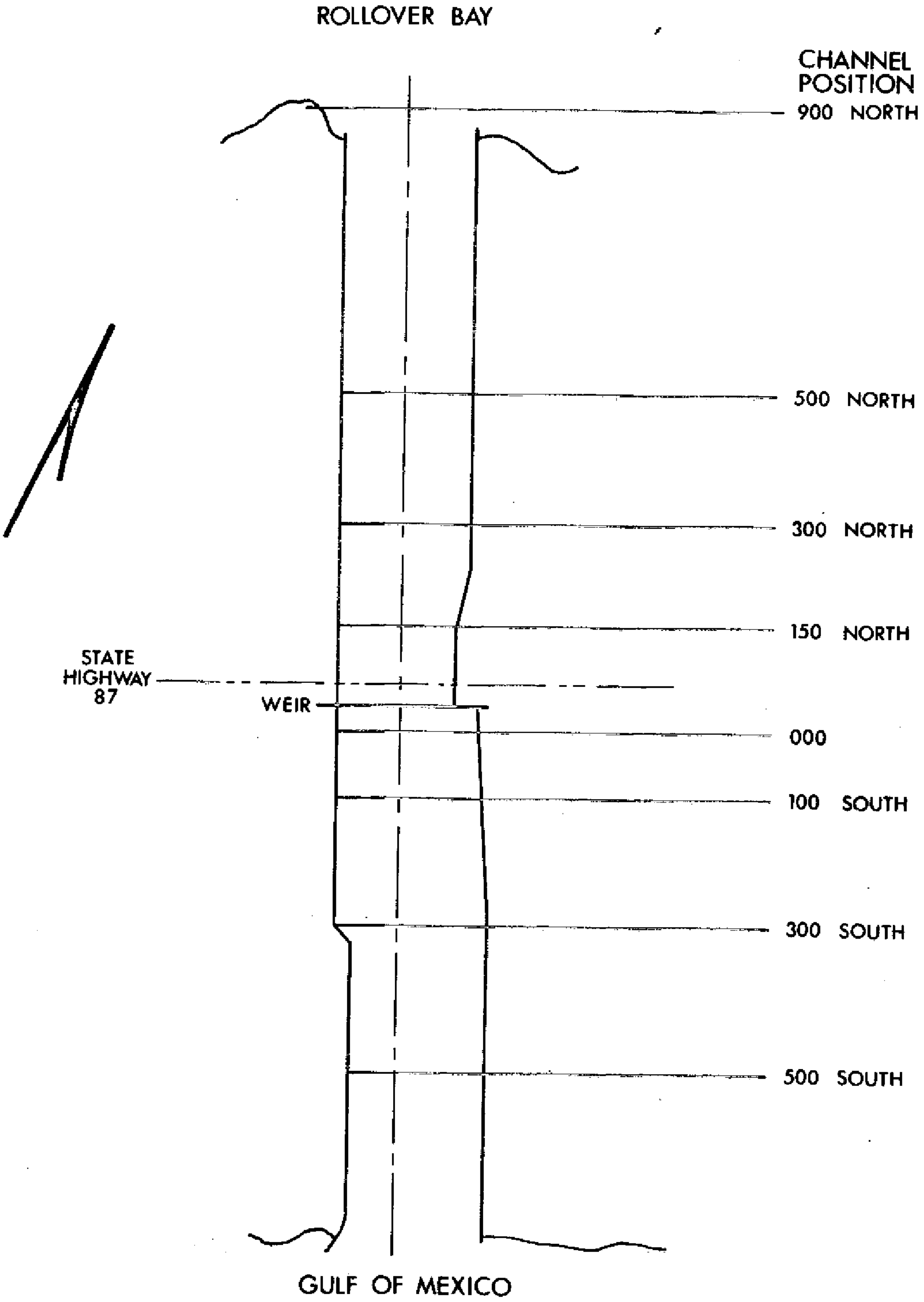


FIGURE 11.--LOCATION OF CHANNEL SECTIONS.

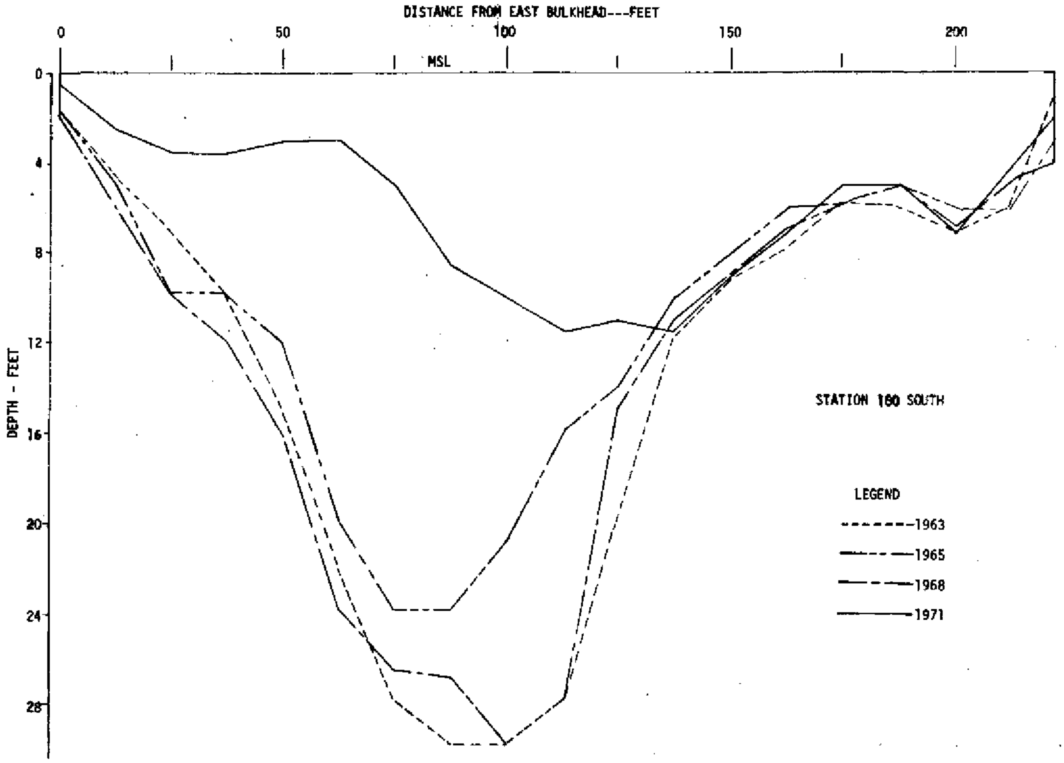


FIGURE 12.--CHANNEL PROFILE, ROLLOVER FISH PASS, SOUTH SIDE.

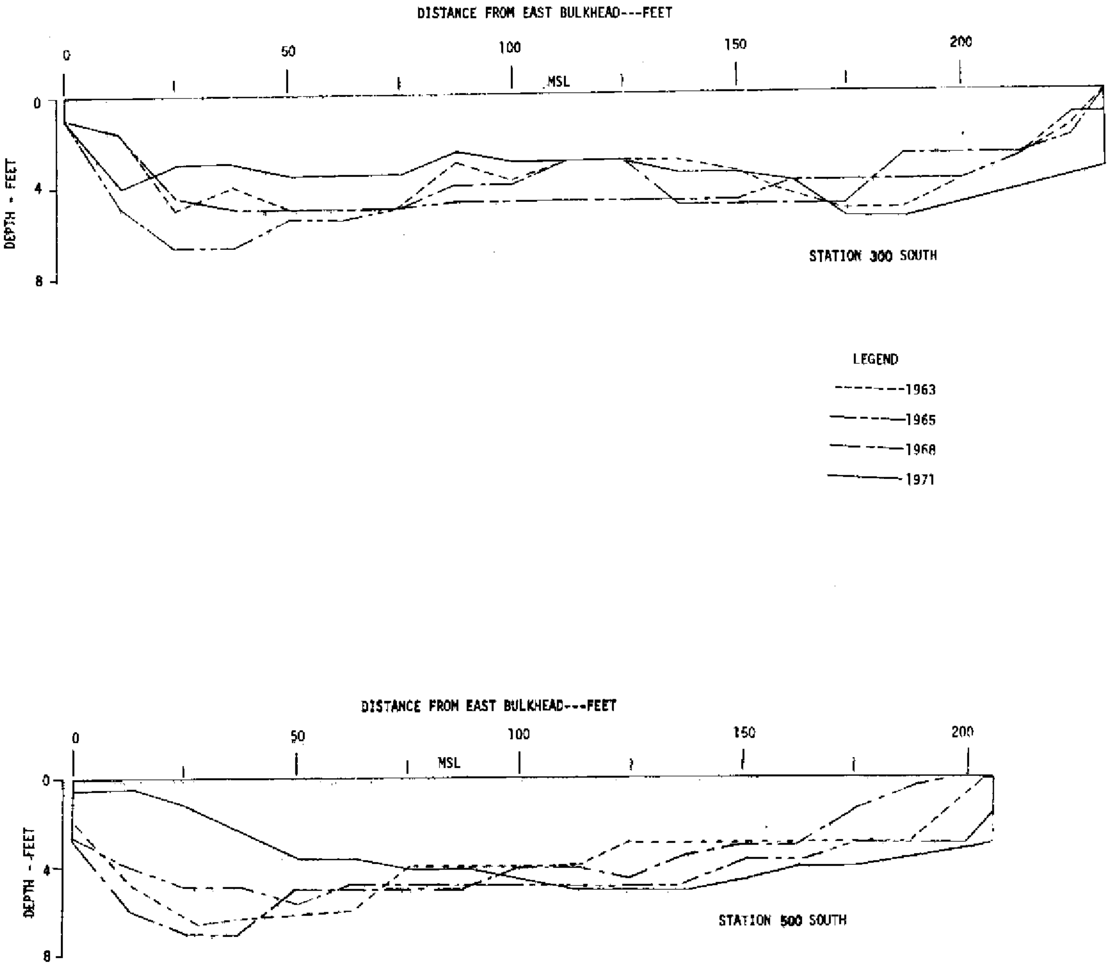


FIGURE 13.--CHANNEL PROFILES, ROLLOVER FISH PASS, SOUTH SIDE.

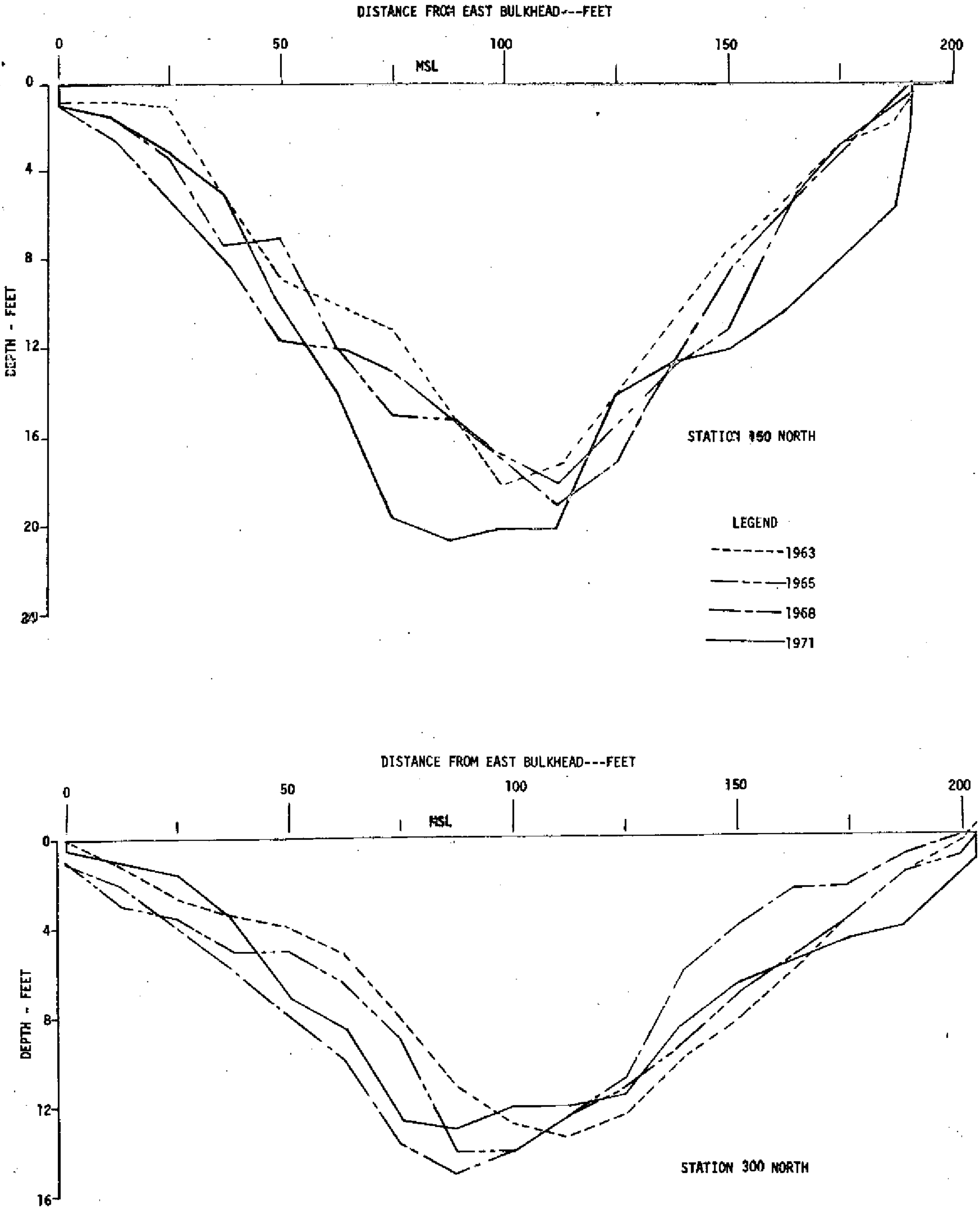


FIGURE 14.--CHANNEL PROFILES, ROLLOVER FISH PASS, NORTH SIDE (I).

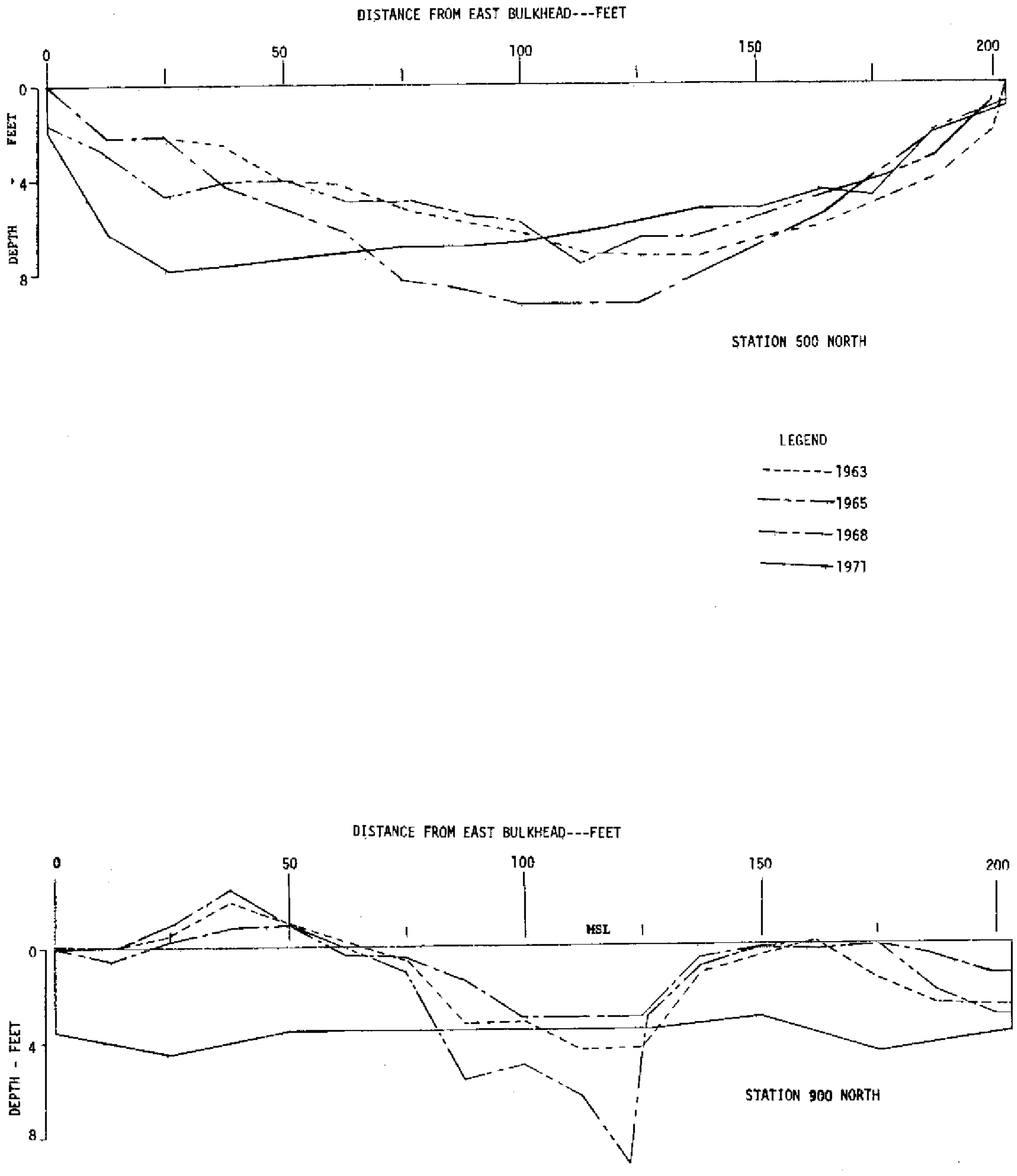


FIGURE 15.--CHANNEL PROFILES, ROLLOVER FISH PASS, NORTH SIDE (II).

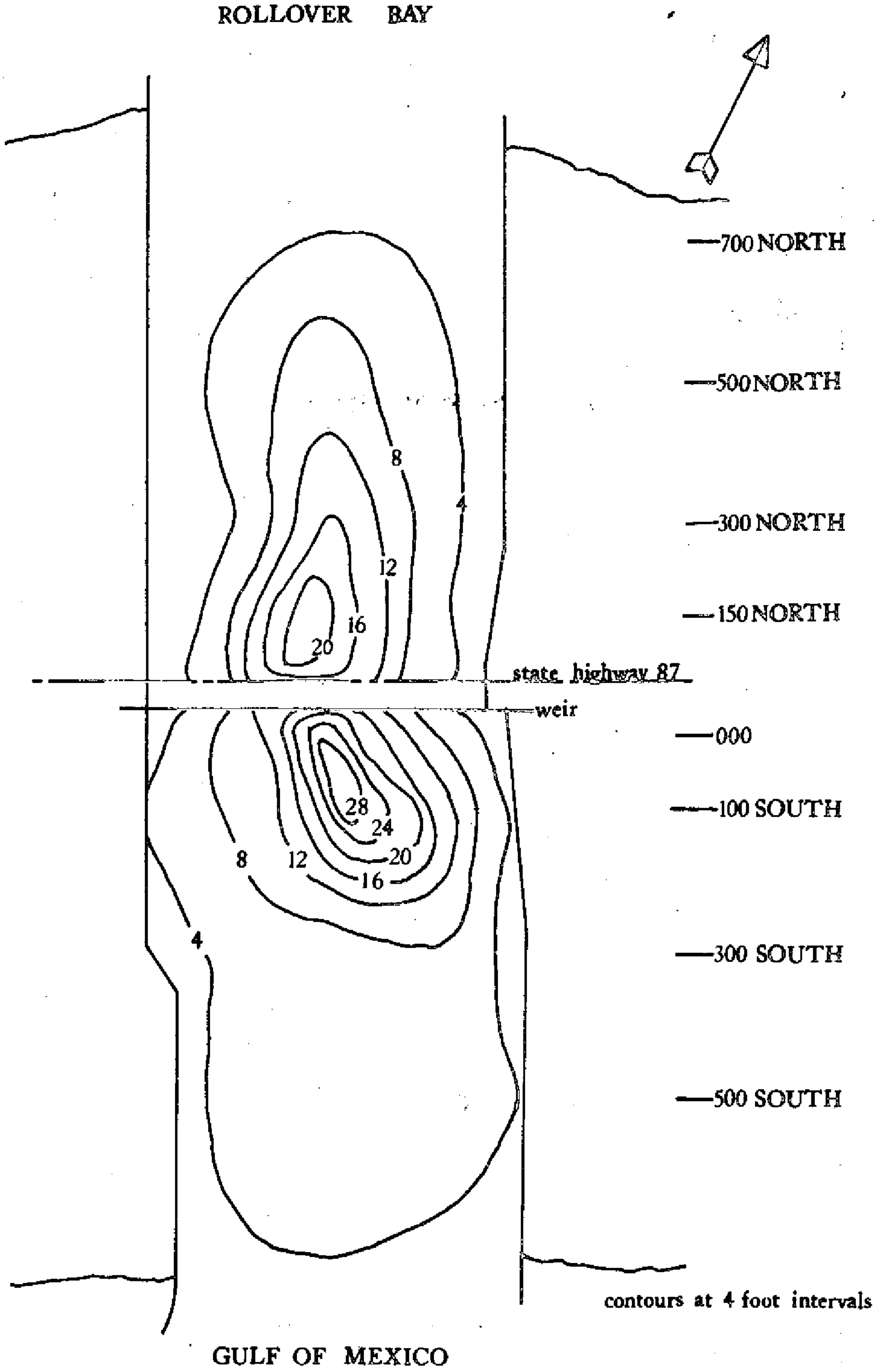


FIGURE 16.--INLET BOTTOM CONTOURS, JULY, 1968.

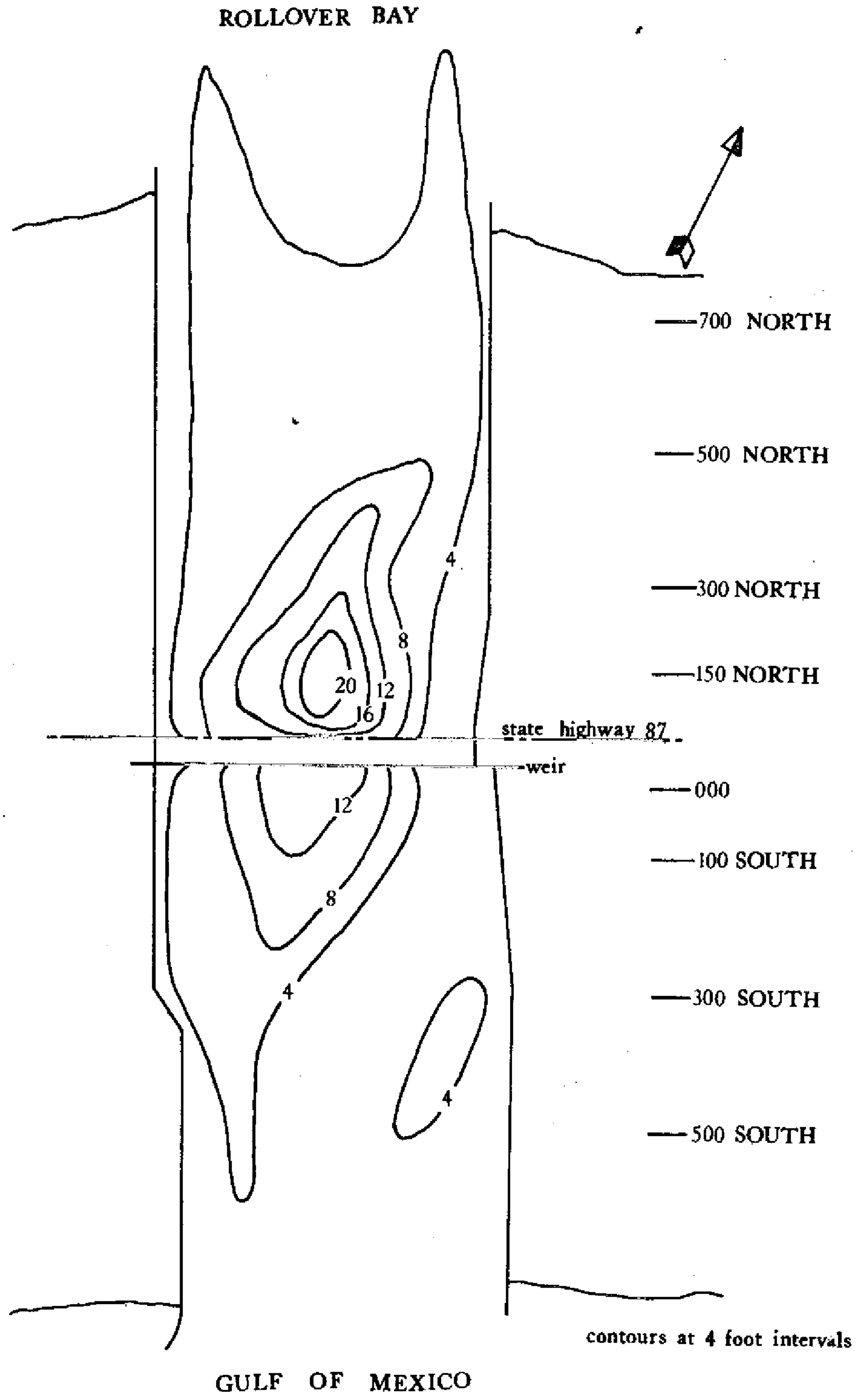


FIGURE 17.--INLET BOTTOM CONTOURS, 1971-1972.

Discussion and Conclusions

As described earlier in this report, erosion of the Gulf shoreline had been a major problem since shortly after the pass was opened in 1955. In 1956, approximately one year after the flow through the pass had been restricted, erosion was still continuing at an objectionable rate along the coastline west of the inlet. Estimates made before the opening of Rollover Fish Pass had indicated a shore recession of about five feet a year near Gilchrist, tapering to zero about seven miles east of the Galveston north jetty. The presence of the channel had apparently increased this erosion rate along the shore for about one mile west of the pass (38). In early 1957, the Game and Fish Commission placed 6000 cubic yards of fill sand along the beach for about 1300 feet west of the inlet in an effort to halt the scour. The fill eroded quickly for approximately 30 days, but stabilized about four months later as the bankline approached its former position (38). The loss of 6,000 cubic yards of sand in four months indicates an additional deficiency of approximately 18,000 cubic yards annually superimposed on the regular "pre-channel" downcoast erosion rate. This assumes that natural erosion will remain active, and that the pass will cause an additional removal of 18,000 cubic yards of material downcoast from the channel. To control the beach recession west of the inlet, the Corps of Engineers recommended periodic nourishment with sand fills in that area (38), but such action has apparently not yet been taken. A beach recession in excess of five feet a year west of the inlet is therefore expected to be continuing.

The profiles presented earlier indicate a general recession of the downdrift beach has occurred when compared to the updrift beach. The picture is clouded somewhat by the seasonal variations in the beach development at the times the various profiles were taken. The studies in 1965 and 1971 were conducted in October, while the others were made in December, 1963, and July, 1968. Shepard (36) has shown beaches to "build up" during summer periods of gentle on-shore breezes, and recede during winter months of strong winds and waves, or during summer hurricanes. His observations seem to account for the somewhat flatter beach present in 1968 since it is the only summer profile shown (Figures 7 and 8). Attaching a specific number to the recession rate is difficult because of these variations, but it is clear that a general recession has occurred near the inlet. The estimated erosion rate of five feet per year (38) appears to be somewhat questionable, however. This figure would result in a gross beach recession of approximately forty feet since 1963, and the profiles do not indicate any erosion of this magnitude. It does appear the beach has stabilized and is oscillating seasonally, or due to periodic storm action in the area. Additional data are necessary before a more meaningful conclusion can be reached.

As was the case along the beach, erosion also presented a major problem in the channel itself after opening the pass. Since the installation of the side bulkheads and the weir, the channel erosion has been controlled. The profiles discussed earlier in this report indicated a general tendency toward accretion, although some scour was apparent in certain areas. The overall appearance was that of a dynamically stable inlet.

In addition to discussion concerning the profiles, mention should be made of two large dredge spoils and shoals that are present at the bay entrance to Rollover Fish Pass. These are shown in Figure 18. The spoils "normally" extend from just north of the bulkheads to just south of the intracoastal canal. These areas may be completely above water, and at high tide are less than a foot deep. These are almost certainly the principal areas of deposition for the finer sediments that pass through the inlet and are not returned on the ebb tide.

The intracoastal canal itself, which lies about one mile from the Gulf, also shows signs of silting. Several times while conducting field studies, barges and tug boats were seen grounded in the intracoastal canal at a point directly in line with the inlet channel.

Some of the depositional patterns can be explained by the mechanics of the flow in Rollover Fish Pass. High velocities and turbulence are created near the bridge because of the geometry of the weir and channel at that point. The channel widens to over 230 feet for 200 to 300 feet south of the weir, but narrows to about 190 feet just north of the weir. In addition, the weir is not everywhere the same depth, but slopes from both sides toward the

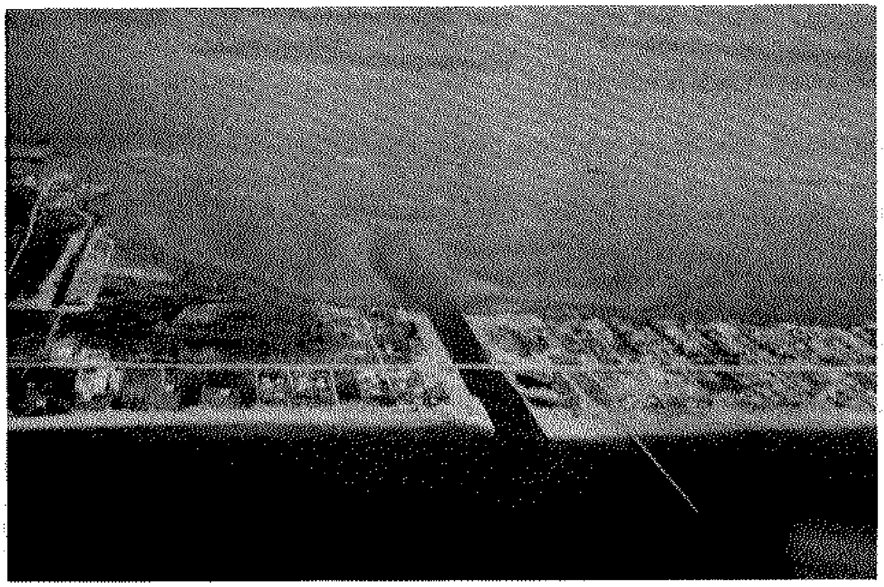


FIGURE 18.--SHOAL DEVELOPMENT, ROLLOVER FISH PASS.
(DATE UNKNOWN, PHOTOGRAPHER UNKNOWN)

middle before leveling off at five feet below Mean Low Water. It protrudes well above Mean Sea Level for several feet at either end. During the flood tide, this geometry causes the water to "back up" along the bulkheads and funnel in toward the center, creating large water velocity increases and strong turbulence. These combine to scour the deeper holes present in the vicinity of the bridge. Wave action in the Gulf side of the channel keeps most of the finer sediment in suspension, allowing them to be carried over the weir and on into the channel. The reverse is true on the ebb cycle, but lower ebb current velocities and sediment loads decrease the relative importance of this flow. The flood cycle dominates over the ebb cycle in this pass, typical for Gulf Coast inlets (37).

The possibility exists that the accretion - scour patterns in the channel are a seasonal phenomenon (36). The profile from 1968 was taken in July; the others were taken in winter months. Some variations are undoubtedly due to the seasonal changes, but just how much is difficult to estimate. However, some evidence supporting this premise is shown in Figure 19. Note the striking difference in the shoals development between Figures 18 and 19. The exact date Figure 18 was photographed is unknown but from certain identifying landmarks it is apparently around 1963. While no evidence of additional dredging in Rollover Bay was found, it is possible some did occur in the time period between the two photographs. A more likely explanation is either seasonal or long term

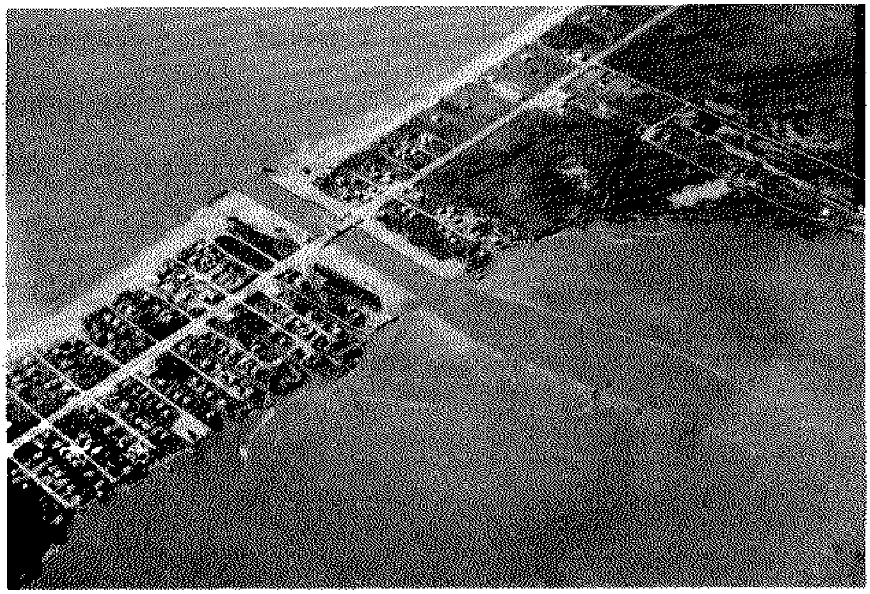


FIGURE 19.--SHOAL DEVELOPMENT, ROLLOVER FISH PASS, FEBRUARY, 1972.
(AUTHOR'S PHOTO)

variations in the shoal development behind the pass. Careful examination of more complete data would be necessary to fully evaluate this contingency.

Sedimentary analysis generally supports the conclusions reached with the beach and section profiles. When all the studies are grouped and analyzed as a whole, there is no doubt Rollover Fish Pass is dynamically stable and well behaved. The evidence all points to a general shifting of the channel bed. The bottom is no doubt in a constant state of flux, seasonal variations, and general shifting, but overall it is stable in the sense that there is no runaway erosion, migration, or siltation. It has existed for 14 years in a more or less constant configuration and should continue to do so.

HYDRAULIC PROPERTIES

The behavior of a tidal inlet is partially determined by the water exchange brought about by water level differences between the channel ends. This flow is influenced by winds, coastal structures, the cross-sectional area of the channel, channel roughness, and the general shape of the inlet. To define the hydraulic properties at Rollover Fish Pass it was necessary to evaluate the channel section properties, the tide levels in the Gulf and in Rollover Bay, and the other features affecting the flow. Continuous recordings of the tidal fluctuations and numerous field investigations supplied the information necessary to accomplish these goals. The results of these studies are in the following sections of this report.

Section Properties

It is necessary to determine the section properties of a channel before evaluating the velocities, discharges, or stability of the inlet. As discussed earlier, depth profiles were taken at seven stations along the channel. At each of these locations an area and hydraulic radius were calculated for the channel. The values are shown in Table 1.

Due to the difficulty involved in working with changing values of area or hydraulic radius, an average value of each quantity was

TABLE 1.--SECTION PROPERTIES OF ROLLOVER FISH PASS

STATION	HYDRAULIC RADIUS (FEET)	AREA (SQUARE FEET)
900 north	3.57	753
500 north	5.30	1098
300 north	6.83	1414
150 north	10.67	2161
100 south	6.09	1370
300 south	3.60	853
500 south	4.00	840
AVERAGE	6.08	1289.

found. These values are also indicated in Table 1. Station 900 north was deleted from the average because it does not lie in the channel itself, but approximately 100 feet north of the bay entrance. It is realized the figures obtained may not depict flow at every particular point in the channel, but it is believed they are representative of a typical cross-section of Rollover Fish Pass.

Tidal Differentials

The water level differentials across Rollover Fish Pass were computed from continuous recordings of the water levels in the Gulf of Mexico and Rollover Bay. A Leopold and Stevens Water Level Recorder, Type F, Model 68, was installed next to a retaining wall approximately 100 yards northeast of the bay entrance to the pass. This gage provided records of the water levels in Rollover Bay at the inlet site. Gulf water levels were obtained from recordings provided by the Galveston District, U.S. Army Corps of Engineers. The only records available of Gulf tides were from gages at Galveston South Jetty and Sabine Pass Southwest Jetty, approximately forty miles up the coast from Gilchrist. The Gulf tide elevation at Rollover Fish Pass was obtained by interpolating between the two records. Because the shoreline is essentially straight along Bolivar Peninsula, and the tidal wave approaches almost parallel to the coast, the estimated tidal record is considered to be satisfactory. The differentials were recorded from November 13, 1971, through February 10, 1972, and are presented in the appendix of this report, Figures 25 through 34.

To reduce the data to a more useable form, a cumulative frequency diagram, Figure 20, was plotted for the tidal differentials (Δ A total) across Rollover Fish Pass. The curve showed a predominance of flood over ebb tides, and a median tidal differential of 0.53 feet. The value of 0.53 feet is approximately the same as the value of 0.58 feet calculated from Corps of Engineers' data taken in 1956-57 while the inlet was closed (38).

Because channel erosion had presented a major obstacle to the reopening of Rollover Fish Pass, some means of restricting the flow velocities through the inlet had to be incorporated into the redesign. Some losses were present from the bridge, but these were insufficient to reduce the velocities to acceptable values. The desired results were achieved by driving the sheet pile wall that had been placed across the inlet south of the bridge, down below the Mean Low Water level to form a weir. The bridge-weir combination causes losses in the flow, and in effect lowers the surface elevations of the water flowing over it. If differences in the water levels across the weir were recorded and considered over the range of total tidal differentials, then a resultant differential in water surface elevation could be computed. The hydraulic characteristics and bed stability of the inlet are in fact a result of these revised differentials rather than the total differentials across the pass. With these distinctions in mind, a system was set up to read the

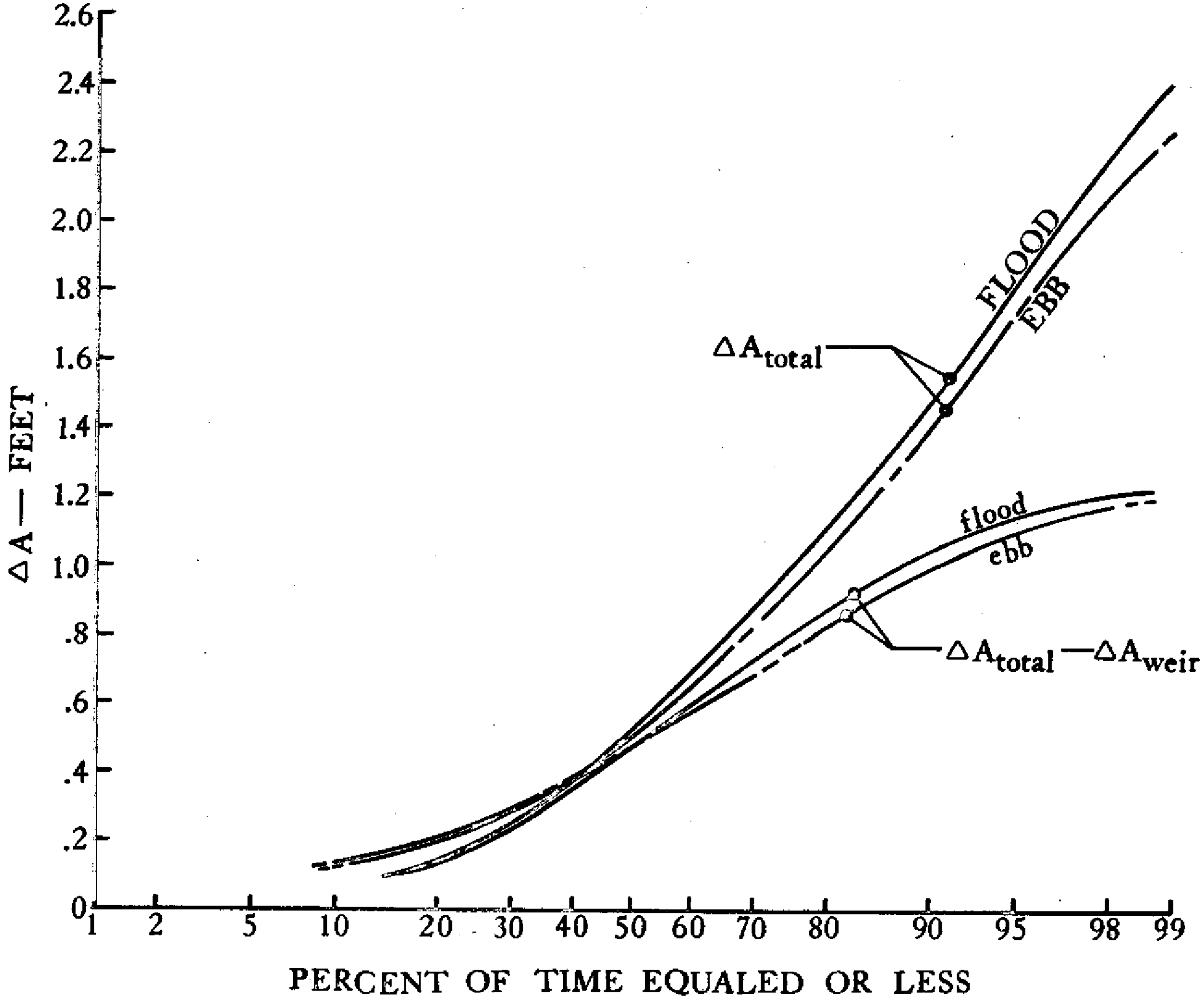


FIGURE 20.--CUMULATIVE FREQUENCY DIAGRAM OF TIDAL DIFFERENTIALS.

water levels on each side of the weir.

Two stilling wells were attached to the east bulkhead on either side of the weir and bridge to record the water levels at points approximately 140 feet north of the weir, and about seventy feet south of the weir. Resultant readings and knowledge of the differentials across the inlet at that time, enabled a graph of the differential across the weir (ΔA_{weir}) to be plotted for any total differential (ΔA_{total}) across the inlet, (Figure 21). The results can be used to evaluate an adjusted figure for the inlet differential. An adjusted curve was found by subtracting the elevation loss over the weir from the total elevation - i.e. the quantity $\Delta A_{total} - \Delta A_{weir}$. The lower curves on Figure 20 show these values, and will be used in stability calculations shown later in this report. The revised median differential is 0.46 feet.

Certain design procedures use average estimates of differential and velocity rather than median values. Rollover Fish Pass possesses an average total differential of 0.67 feet, and an adjusted average value ($\Delta A_{total} - \Delta A_{weir}$) of 0.57 feet. These numbers were derived from averaging the total differentials across the inlet as shown on the tidal records, then adjusting them by using Figure 20.

Discharge Measurements

The total discharge into and out of a bay over a tidal cycle is usually referred to as the tidal prism. This quantity is widely

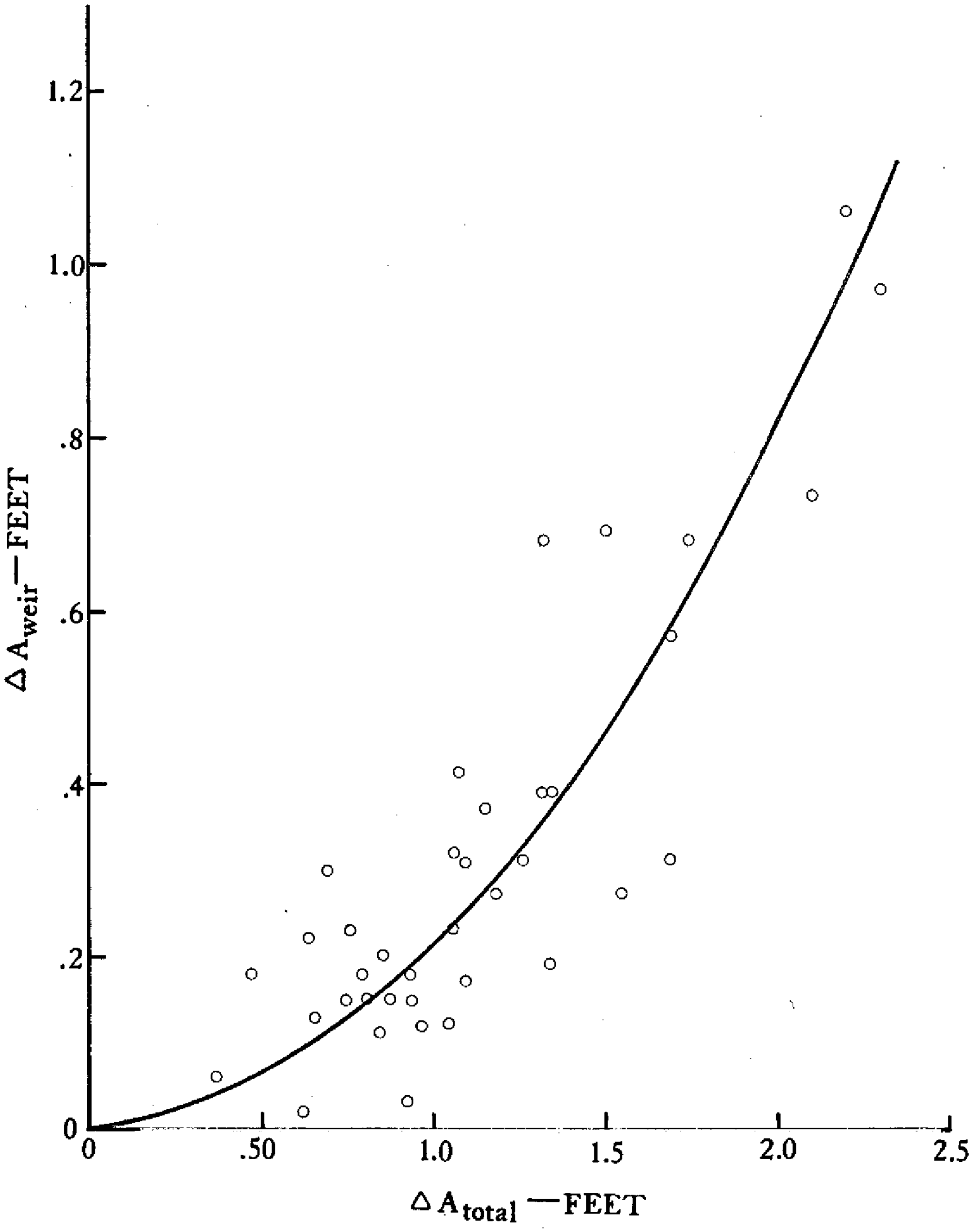


FIGURE 21.--CHANGE IN WATER SURFACE ELEVATION ACROSS THE WEIR, ROLLOVER FISH PASS.

used in stability estimates, and is an important inlet design parameter. An original objective of this report was to estimate the flushing capability and stability of Rollover Fish Pass, each of which partly depends on use of the tidal prism. In order to determine this quantity, a plan was implemented to measure the discharge through the inlet at any tidal differential.

Current measurements were conducted at Rollover Fish Pass at various times during a tidal cycle using a Gurley-Price current meter. These included one set of measurements taken at two hour intervals over a twenty-five hour period, or one full tidal cycle. The period was purposefully selected to be one of maximum tidal differentials across the inlet. The studies were conducted at station 500 north where a known bottom profile and cross-sectional area existed. The section was divided into eight equal segments, each twenty-five feet in width, and current measurements were made at two depths in each segment. These values were then averaged to give a representative velocity in that particular segment, and by using the continuity relationship, a total discharge over the channel was calculated. The time was recorded at each current measurement, thus allowing a tidal differential to be found for each discharge. Figure 22 is a plot of these data, and shows the discharge through the inlet, Q, existing at any tidal differential, Δ A.

A median and average discharge through the inlet can be estimated from Fig. 22. The tidal prism may then be evaluated at each

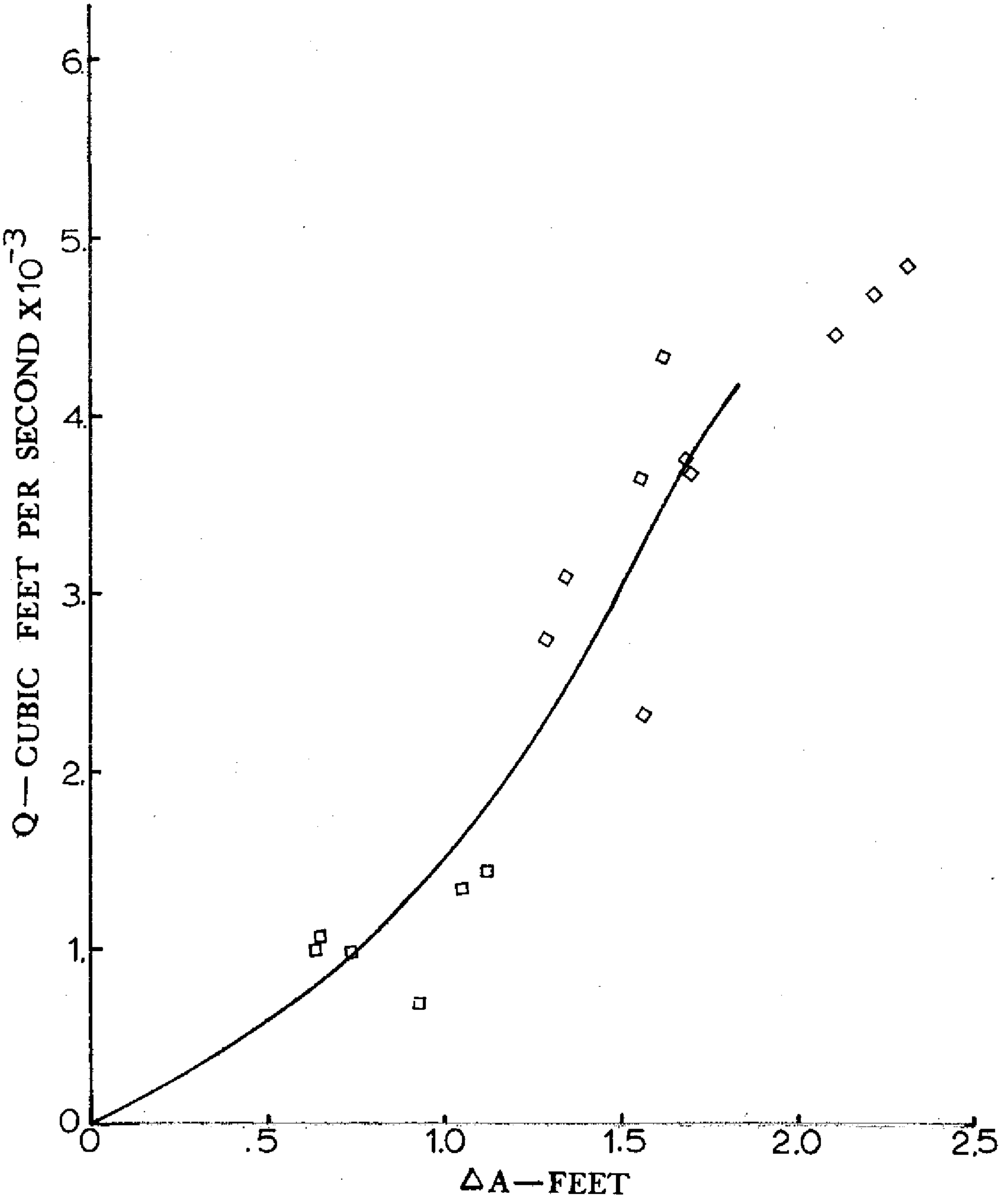


FIGURE 22.--INLET DISCHARGE AT ANY DIFFERENTIAL.

of these values. Using the values of 0.53 feet and 0.67 feet obtained for median and average differentials, discharge values of 670 and 850 cubic feet per second, respectively, are found. These lead to a tidal prism over a 12.25 hour diurnal flood tidal cycle of 2.96×10^7 and 3.75×10^7 cubic feet. The adjusted tidal prism is close to these values, and will be considered to be the same.

Velocity Data

As discussed earlier, many inlet design procedures employ median or average velocities as an important design parameter. These values at Rollover Fish Pass can be easily determined by employing the continuity relationship, $Q = V_{avg}A$, the discharges already computed, 670 and 850 cubic feet per second, and the average channel area of 1289 square feet. The median and average velocities computed in this manner are 0.52 and 0.66 feet per second, respectively.

It is interesting to note that during the twenty-five hour discharge measurement, an average velocity of 2.71 feet per second was found. The highest velocity recorded during this period was 4.23 feet per second. It is believed that these are not representative figures because of the weather conditions existing at Rollover Fish Pass at the time of this study. North winds of up to thirty-eight miles per hour were recorded, and the precipitation was 1.17 inches over that period. These factors combined with the large differentials of the selected tide, and a number of unusually high velocities were measured.

Table 2 summarizes the hydraulic properties of Rollover Fish Pass.

TABLE 2.--HYDRAULIC PROPERTIES OF ROLLOVER FISH PASS

	ACTUAL DIFFERENTIAL	ADJUSTED DIFFERENTIAL	VELOCITY	DISCHARGE	TIDAL PRISM
MEDIAN	0.53 ft	0.46 ft	0.52 fps	670 cfs	29.6×10^6 ft^3
AVERAGE	0.67 ft	0.57 ft	0.66 fps	850 cfs	37.5×10^6 ft^3

STABILITY

The application of various stability criteria to the inlet should predict the original erosion that occurred in the channel, and the stable conditions now existing, providing the correct stability parameters are used. The following sections will apply the most widely accepted inlet design procedures to the pass and evaluate their accuracy in predicting its stability.

Original Inlet Stability

Rollover Fish Pass was unstable when it was first opened, and rapid erosion took place throughout the channel, especially on the Gulf side of the bridge. After the flow was severely restricted and retaining walls were erected along the sides of the channel, the pass became "stable". The instability may have been anticipated if a careful study of the area had been made before the pass was dredged.

Predictions of inlet stability usually employ either inlet velocities, tidal prisms, or the critical bed shear stress as stability guidelines. Continuous measurements of water surface elevations in both the bay and the Gulf are available at Rollover from November, 1956, to February, 1957 (38). The highest differential across Bolivar Peninsula was 3.3 feet, and a median differential of 0.58 feet was recorded for those three months. From these figures, maximum and median velocities through the proposed inlet could have been calculated.

Average velocities can be estimated by applying the Manning equation to the channel (9). The equation, for steady, uniform flow is as follows:

$$V_{avg} = \frac{1.49}{n} R^{2/3} S^{1/2}$$

in which

n = roughness coefficient (estimated as 0.02),

R = hydraulic radius of the channel at Mean Sea Level, and

S = slope of the water surface.

From this equation and the proposed channel dimensions of 8 feet deep, 80 feet wide, and 1200 feet long, it can be shown that the maximum and median average velocities are 14.1 and 5.9 feet per second, respectively. These values are unusually high for open channel flow, and scour can be suspected based on their magnitudes alone. Using the proposed cross-sectional area of 640 square feet and the median velocity calculated from Mannings equation, a projected tidal prism of 16.7×10^7 cubic feet was calculated for a normal tidal cycle. With the above figures in mind, forecasts of the inlet's behavior were made using the numbers obtained by the methods described above.

O'Brien (26) proposed an inlet cross-sectional area ($A_{c/s}$)

based on the tidal prism (P) as follows:

$$A_{c/s} = 2 \times 10^{-5} (P)$$

Using the proposed inlet area of 640 ft^2, the above equation indicates a required tidal prism of 3.20×10^7 cubic feet for stable conditions. Since the projected tidal prism of 16.7×10^7 cubic feet was greater than the one calculated, a tendency for the inlet to scour is indicated.

Carothers also developed a method for determining the design velocity in channels (8). The velocity is established at the beginning of saltation of median size particles. This establishes the geometry so that the inlet tends equally toward erosion and accretion. He recommended a median velocity of 1.3 to 1.8 feet per second for channels with R equal three to twenty-five feet in fine sands with $d_{50} = 0.15$ mm, indicating that the velocities in Rollover Fish Pass were probably too high for stable conditions. Erosion could have been predicted for the channel on the basis of this relationship.

Escoffier (13) suggested a value of about three feet per second to be a fair approximation of the channel velocity required to maintain stable conditions. This value is also less than the velocities computed in the original inlet, and erosion is again predicted in the channel.

Bottom shear stress can be approximated from the following relationship (9):

$$\tau_b = \gamma RS$$

in which γ is the specific weight of sea water. The equation gives bottom shear stress values of 0.21 and 1.172 pounds per square foot for median and maximum velocities in the channel. Bruun and Gerritsen found that inlets should possess a shear stress of approximately 0.10 pounds per square foot to remain stable. Once again, vigorous erosion is predicted in the original inlet.

A brief view of the stability criteria applied to the conditions present in 1956 at Rollover Pass has been presented. The next step will be to determine the inlet's probable appearance if the methods described above had been adopted as the design philosophy.

If the available inlet design criteria are applied to the conditions present at Rollover Pass in 1956, typical values for channel cross-sectional areas, and velocities can be calculated. Each approach will yield a slightly different answer, and some value judgments must be made to determine an acceptable design approach.

Carothers' recommended design velocity of 1.6 feet per second, the existing channel length and the median tidal differential can be substituted into Manning's equation to determine a stable channel shape. This approach shows an approximate depth of one-half foot required for an eighty foot width.

In a similar manner, Escoffier's recommended channel velocity of three feet per second can be used in Manning's equation. This shows a depth of 2.60 feet required for an eighty foot width.

Bruun and Gerritsen's work (5) can also be applied to the original inlet. Their findings of a shear stress value around

0.10 pounds per square foot for stable channels may be used to find either a cross-sectional shape or an inlet length. For stable conditions, and the same length channel as now exists (1,200 feet), this relationship requires a depth of approximately 3.5 feet for a channel width of eighty feet. Conversely, the length would have to be almost twice its value, or 2,500 feet, for the same cross-section of eight feet by eighty feet to prevent scour.

Present Inlet Stability

The stability of Rollover Fish Pass has been established earlier in this report. Comparisons of periodic bottom profiles taken over nine years confirmed the basic constancy of the inlet's cross-section, and no runaway erosion has taken place in the general area. It is of interest to apply the most popular stability criteria to Rollover Fish Pass and ascertain their predictions for this inlet.

O'Brien's relationship (26) indicates a tidal prism of 6.45×10^7 cubic feet to be required for stable conditions in Rollover Fish Pass, if the average cross-sectional channel area of 1289 square feet is used. This figure is roughly seventy percent greater than the actual tidal prism of 3.75×10^7 cubic feet. An adjusted tidal prism will be near the actual value, thus indicating a tendency for accretion to occur in the inlet.

Carothers recommends using a design velocity based on median differentials of 1.6 feet per second. The computed median velocity of 0.52 feet per second is significantly lower than this, and predicts a tendency for the inlet to close. Escoffier's estimate of a 3 foot per second velocity in stable channels is larger than Carother's recommendation. This value then appears to be somewhat in error based on the findings in this report.

Perhaps the most accurate stability prediction is from bottom shear stress criteria. Bruun and Gerritsen, as discussed earlier, recommend a number of 0.10 pounds per square foot be used as a design value for the bottom shear stress. Using the adjusted average differential across Rollover Fish Pass and the equation $\tau_b = \gamma RS$, a shear stress of 0.185 pounds per square foot is found to exist in the channel. Use of the adjusted median differential gives a value of 0.152 pounds per square foot. Although slightly higher than the 0.10 pounds per suggested, either 0.185 or 0.152 is close to the desired value. This particular procedure shows Rollover Pass to be relatively stable, but tending slightly toward erosion.

It is of interest to examine the littoral drift quantities in the inlet area. The question of an actual littoral transport rate past the inlet can be partially answered by applying Bruun and Gerritsen's relationships (5) to Rollover Fish Pass. Using the average discharge and tidal prism calculated earlier, and assuming that $P/2M = 300$, and $Q/M = 0.01$, values of 62,500 cubic yards and 85,000 cubic yards, respectively, are found for the gross littoral transports past the inlet. These values represent the maximum possible amount of littoral material that can be passing the inlet in its present stable configuration. The actual values are probably much less.

The Corps of Engineers has estimated the deficiency in the supply of littoral material to the entire Gulf shore west of the pass to be on the order of 200,000 cubic yards annually (38). This figure was apparently increased by an approximate 18,000 cubic yards annually due to the pressure of the inlet, as determined by the removal of fill material immediately west of the pass in February, 1957 (see page 46). The beach area near the inlet has stabilized since 1963, (see page 47), indicating either a change in the wave activity near the site, or some other phenomena not yet recognized changing the littoral transport quantities in the area. In any event, the transport rate past the inlet is around a maximum value of 75,000 cubic yards annually. Further study is necessary to estimate any transport rate downcoast of the inlet.

It is difficult to evaluate the applicability of these stability criteria in the case of Rollover Fish Pass. Both O'Brien's and Carothers' parameters show a tendency toward siltation in the inlet. Bruun and Gerritsen's relationship revealed a slight tendency toward erosion. The shifting of the channel bed discussed earlier may be accounted for by these differences. It is obvious engineering judgment must still be used to evaluate the best method for predicting bed stability.

TIDAL PROPAGATION IN THE BAY,

Another primary purpose of this report was to study the propagation of the tidal wave in East Bay. To accomplish this, records were obtained from tide gages located at the four points shown in Figure 23. Gages number 1 and 2 were installed by Texas A&M University for the study period, while gages 3 and 4 were permanent installations operated by the U.S. Army Corps of Engineers. The instruments installed by Texas A&M University were Leopold and Stevens Water Level Recorders, Type F, Model 68. Tide gage number 1, shown in Figure 24, was also used earlier in computing the differentials across the inlet. Records were taken from November 13, 1971, through February 28, 1972, and are shown plotted on the same graphs for comparison in Figures 35 through 45 of the appendix to this report. Occasional malfunctions were experienced in the various gages, and these records are missing on the figures. Sufficient data are available, however, for the objective outlined.

Tide tables compiled by the National Oceanic and Atmospheric Administration indicate the tides at Gilchrist lag behind those at Galveston by 3.2 hours at high tide and 4.3 hours at low tide. It has also been predicted that eighty-five percent of the flow into the Galveston Bay system passes through Bolivar Pass, i.e. the Galveston Entrance Jetties, while only one percent is exchanged at Rollover Fish Pass. The additional fourteen percent is accounted for at San Luis Pass at the southwest end of West Bay (33). These figures seem

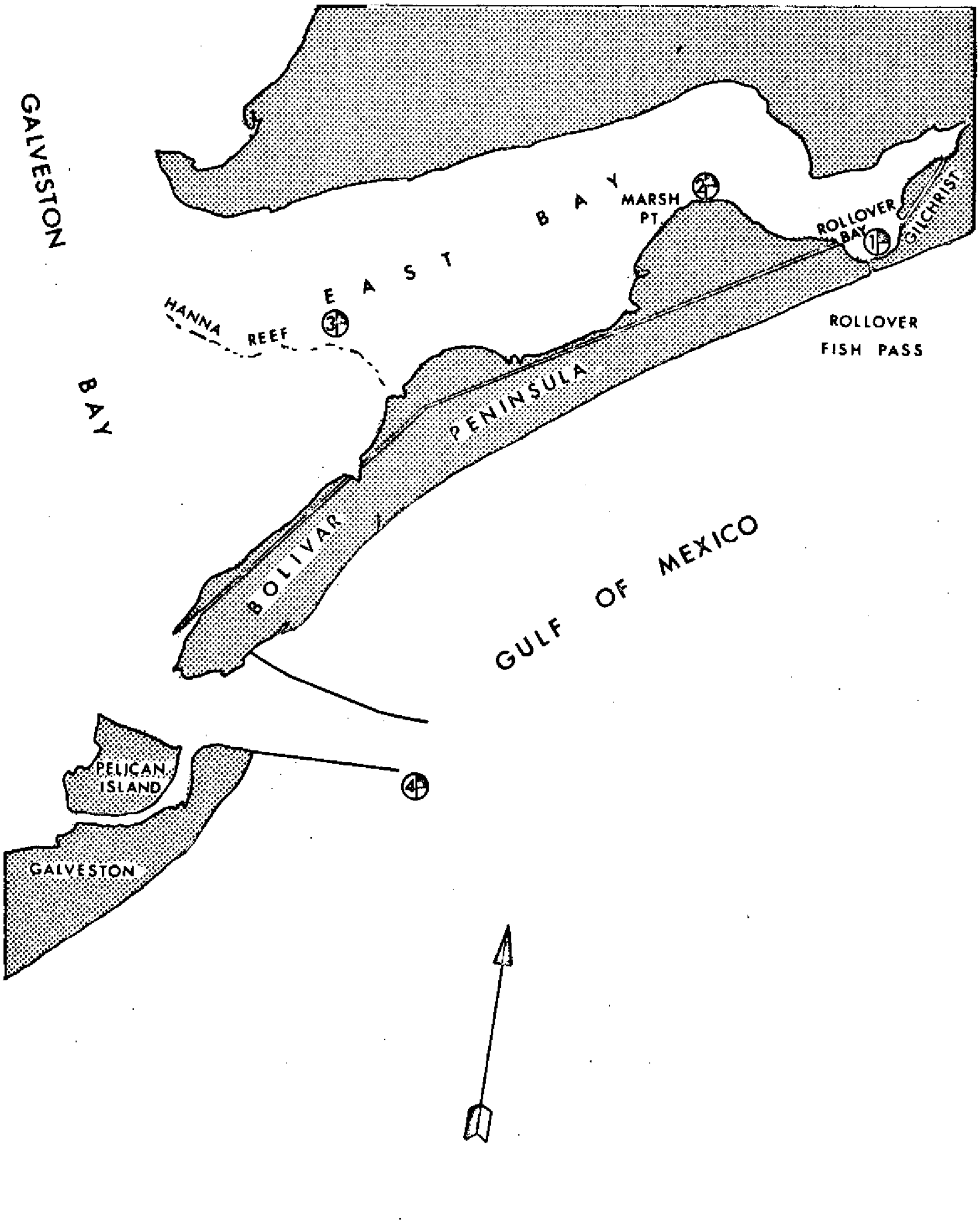


FIGURE 23.--TIDE GAGE LOCATIONS

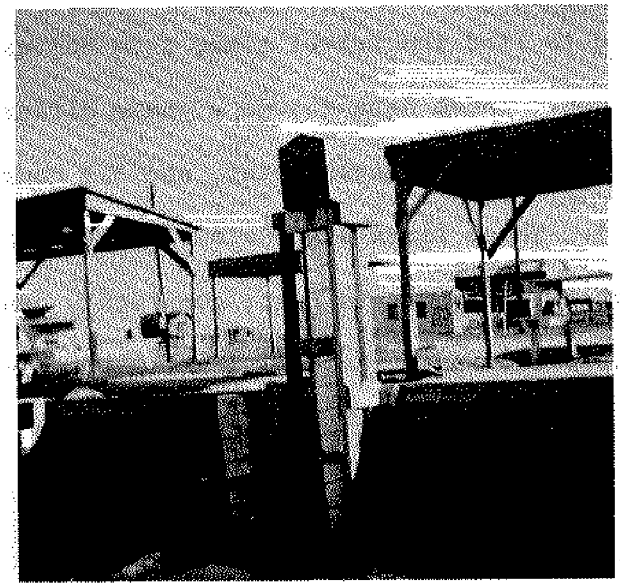


FIGURE 24.--TIDE GAGE 1, TYPICAL INSTALLATION
(AUTHOR'S PHOTO)

to suggest the passage of the tides from the Galveston Entrance Channel through East Bay to Rollover Bay. Beginning at tide gage 4, the tide wave should first reach Hanna Reef (tide gage 3), then Marsh Point (tide gage 2), and finally Rollover Bay, or tide gage 1. The travel times should also correspond to the location of the gages, i.e., instruments, 4, 3, 2, 1 for incoming tides. Such was not the case. The records shown in Figures 35 through 45 in the appendix were averaged to find the travel times from Galveston to each of the other gages. These data showed a phase difference of 5.2 hours to Hanna Reef, 4.3 hours to Marsh Point, and 3.5 hours to Rollover Pass (see Table 3). These times are obviously not in agreement with expected results, and are, in fact, completely opposite from the order of propagation anticipated. In view of this, explanations were sought for the conflicting times. Three possible reasons were investigated to explain the inconsistent time lags. These were (1) erroneous data, (2) delay of the tidal wave due to bottom hydrography and obstructions, and (3) propagation of the tidal wave from Rollover Fish Pass through East Bay.

The most obvious answer to the time dissimilarities lie in the data itself. The amplitude ranges are within reasonable limits, and are consistent throughout the records. The time scales on the recorders were checked and corrected each time the instruments were serviced. An average loss of approximately one hour per month was noted on the records; this was considered negligible when compared to the tidal cycles. A third tide gage was installed by Texas A&M

TABLE 3.--TIDE PROPAGATION DATA, EAST BAY

	GALVESTON	HANNA REEF	MARSH POINT	ROLLOVER FISH PASS
Time, recorded	0 hours	5.2 hours	4.3 hours	3.5 hours
Time, recorded	-3.4 hours	1.7 hours	.8 hours	0
Time, tide tables	0	-	-	3.8 hours
Time, calculated	0	1.4 hours	2.8 hours	3.7 hours
Time, calculated	-	2.3 hours	.9 hours	0
Tidal Range, recorded	1.8 feet	1.2 feet	1.6 feet	1.7 feet

University for the study period about one mile north of tide gage 1. The records from this gage are not plotted because the data almost perfectly matches that of tide gage 1. The similarity of the two records does add confidence to the data gathered in Rollover Bay. A Corp of Engineers gage is also located at Marsh Point, about 300 yards northwest of tide gage 3. This instrument was not working for the majority of the study period, but tidal data for the month of February are available. These data agreed closely with those obtained from tide gage 2, and supports the results obtained at that station. Thus it appears the tidal data is correct and no errors are present of sufficient size to cause the discrepancies noted.

Since the tide records must be assumed accurate, the delay of the tidal wave due to the bottom hydrography in the bay was next investigated. Only Hanna Reef is of sufficient length to "block off" East Bay, but such a condition does not seem possible. The water depths around the reef are two to four feet, and much of the reef itself is submerged. A wave of tidal proportions would simply engulf such a structure and continue into the bay. The entire idea of tidal delay of the magnitudes involved was rejected as being highly improbable, if not impossible.

The concept of East Bay not being influenced by the tides entering at Galveston, but rather by water exchanged at Rollover Fish Pass, was the third possible explanation sought for the questionable time tables. A computation was made to estimate the travel time of the wave through the bay based on the celerity of the wave itself. The tidal celerity, C, is related to the water depths, d, and the acceleration of gravity, g, by the equation, (16):

$$C = \sqrt{gd}$$

Using average depths, times were calculated for the wave to reach each successive tide gage location. These times are shown in Table 3. It is interesting to note that the time required for the tides to reach Rollover Fish Pass is almost exactly the time predicted by the tide tables, and is very close to the lag computed from the tidal records. The explanation for the similar times may possibly be very simple. Since there are no permanent tide gage installations at Rollover Bay, it is probable the time lag given in the tide tables was simply calculated in the same manner as the computed values shown. The recorded lag, on the other hand, is close enough to either of these values to be considered the same when errors are accounted for. As expected, Hanna Reef and Marsh Point were calculated to be affected in correspondingly less times, but these are less than the time lags shown by the gages. It is also of interest to note in Table 3 the similarity of the calculated travel times from Rollover Fish Pass to Marsh Point and Hanna Reef when compared to thos recorded by the gages. This raises the possibility of water from Rollover Fish Pass "filling" East Bay rather than Galveston water doing so.

Two approaches were taken to analyze the ability of Rollover Fish Pass to exchange a volume of water large enough to affect

East Bay in the amounts indicated by the tidal records. The amplitude ranges of the tides were averaged from the instrument records as a preliminary check, and are shown in Table 3. Tide gage 1 reveals a 1.7 foot amplitude occuring in Rollover Bay. This compares to an amplitude of less than one foot recorded by the Corps of Engineers in 1956-1957 in the same area (38). There is some question as to the accuracy of the Corps' records, however. Numerous "flat spots", suggesting a non-functioning gage, are present which contribute to the small amplitudes noted. Nevertheless, the amplitude differences indicate the pass is having an effect on the tides in Rollover Bay, and possibly on into East Bay. Unfortunately, no other data are available in East Bay at that time, and additional comparisons cannot be made. As seen in the table, Hanna Reef recorded a 1.2 foot amplitude, while Marsh Point possessed a 1.6 foot value. The geometry of East Bay is such that these values could be due to either convergence acting on the wave from Galveston, or divergence if the wave came through Rollover. These numbers did nothing to reveal the propagation direction of the tides.

A second, more exact method of analyzing the ability of East Bay to be affected by Rollover Fish Pass is to calculate the volume of water exchanged through the pass during a tidal cycle - i.e., its tidal prism. The average value of the tidal prism was found to be 3.75×10^7 cubic feet earlier in this report. If an average tidal amplitude of 1.6 feet is assumed to be the response to this influx, the affected bay area will be 22.1 x 10^6 square feet. These figures indicate an area only slightly larger than Rollover Bay is responding to the water exchanged through the Pass. It is obvious that Rollover Fish Pass is simply not capable of filling East Bay, and in fact, does not significantly affect the tides at Marsh Point. The only inlet of sufficient size to cause the tide levels recorded at the locations indicated is the Galveston-Bolivar Pass.

On the basis of the studies conducted, it is impossible to present a reasonable explanation for the seemingly inconsistent time lags from the gages. The travel times calculated and shown in Table 3 are dependent upon the assumed route of the tidal wave through Bolivar Pass and into East Bay. The errors introduced in this way may account for the differences in times recorded at Marsh Point to those calculated. If better agreement were achieved at this location, only the question of the lag-times at Hanna Reef would remain. These differences are of such magnitude that the accuracy of the gage must be questioned. It does not appear possible for a tidal wave propagating through Bolivar Pass to experience a 5.2 hour delay in route to Hanna Reef. The solution must come from either additional field studies, or laboratory and/or mathematical models. Any of these were beyond the scope of this report. In any event, additional work must be carried out before the problem is resolved.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this report, as stated in the introduction, were the following: 1) to determine the flow and stability characteristics of the inlet, 2) to investigate the propagation of the tidal wave through the connected bay system, and 3) to study the associated environmental impact of the inlet on its surroundings. The conducted research showed the original instability of the inlet was predictable, and the controlled stability now present can be forecast (page 65). The data collected for analysis of the tidal wave propagation left many questions unanswered as to the actual phenomena occuring in the bay. Further discussion concerning this may be found beginning on page 71. Initially, the environmental impact of the inlet on the surrounding area was large, but its effect is now limited to a small area. Discussion beginning on pages 19, 31, 46, 71, and below covers this subject in more detail.

An important question concerning Rollover Fish Pass is whether or not it accomplishes its intended functions of fish migration and water exchange between the bay and the Gulf of Mexico. It apparently does allow fish migration, although this was not specifically investigated for this report. The exchange of water through the pass is being affected, but to what degree is uncertain. It was calculated that the amount of water exchanged through Rollover Fish Pass is small in comparison to Galveston Pass. What the pass does achieve is perhaps not a large volume exchange of water, but rather a continued exchange which, over a long period, completely changes the waters in the upper end of East Bay.

Model studies of the Galveston Bay System conducted by the U.S. Army Corps of Engineers have indicated the circulation in East Bay to be extremely poor due to the Galveston Entrance Channel (39). It has also been shown that East Bay is sometimes hyposaline, and Gulf waters are needed to aid in controlling this condition (38). Rollover Fish Pass is in an excellent location to change either of these characteristics in East Bay. The water exchange through the pass is undoubtedly of sufficient magnitude to "flush" or circulate the waters in the upper end of East Bay, when considered over a long time period. This exchange is probably the greatest contribution the pass makes to the bay system and, by itself, makes the inlet valuable to the area concerned.

Rollover Fish Pass is constructed at the optimum location on Bolivar Peninsula for its expressed purposes. The site is at the upper end of East Bay, where it is most needed, and is at the narrowest point of land on the peninsula. This placement allowed expenditure of a minimum of time and expense during construction. Had the pass not experienced the runaway erosion it did, the project probably would have been satisfactory. The ultimate value of this report may not be its analysis of the channel, but rather its showing the necessity of applying engineering knowledge to the design of coastal inlets in order to avoid costly errors such as those incurred at Rollover Fish Pass.

There is much work yet to be done in the field of coastal inlets. More research and field studies are necessary before agreement can be reached among the methods of predicting inlet stability. It is apparent from this study, however, that even a minimum of preliminary computations may point out an undesirable behavior pattern of a tidal inlet. Such predictions may ultimately prove to be invaluable in terms of time, expense, property losses, and general public acceptance of such coastal projects.

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APPENDIX.--TIDAL DIFFERENTIALS

Figures 25 through 34 present the data used to compile the tidal differentials across Rollover Fish Pass. Tide gage 1 data and the elevations in the Gulf at the inlet site are plotted in feet above or below Mean Sea Level (0 feet elevation) in all cases. The legend for the records is shown below.

———————— Tide Gage 1 (Rollover Bay)

- - ———— - - ———— Gulf of Mexico (Gilchrist)

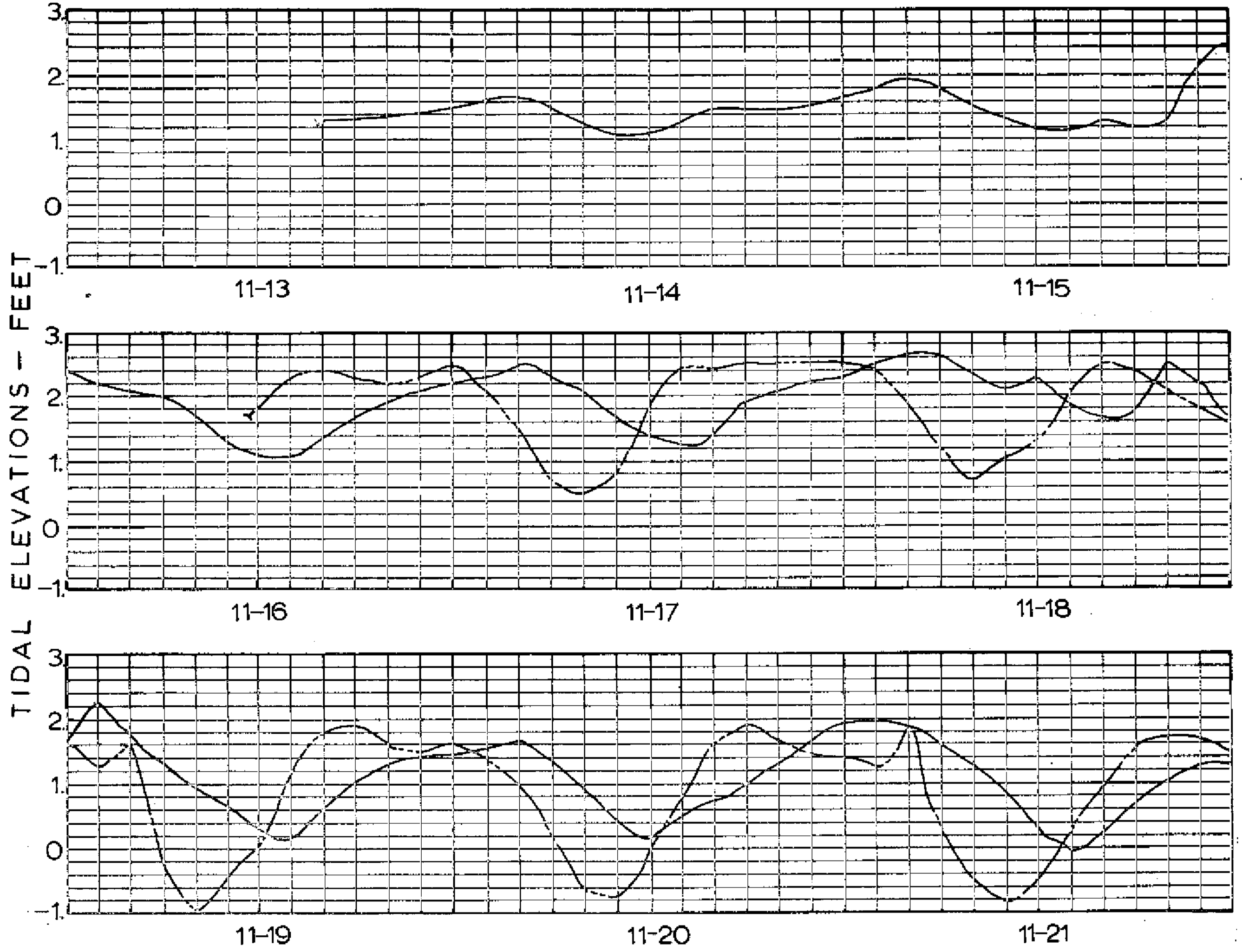


FIGURE 25.—TIDAL DIFFERENTIALS, NOVEMBER 13, 1971 TO NOVEMBER 21, 1971.

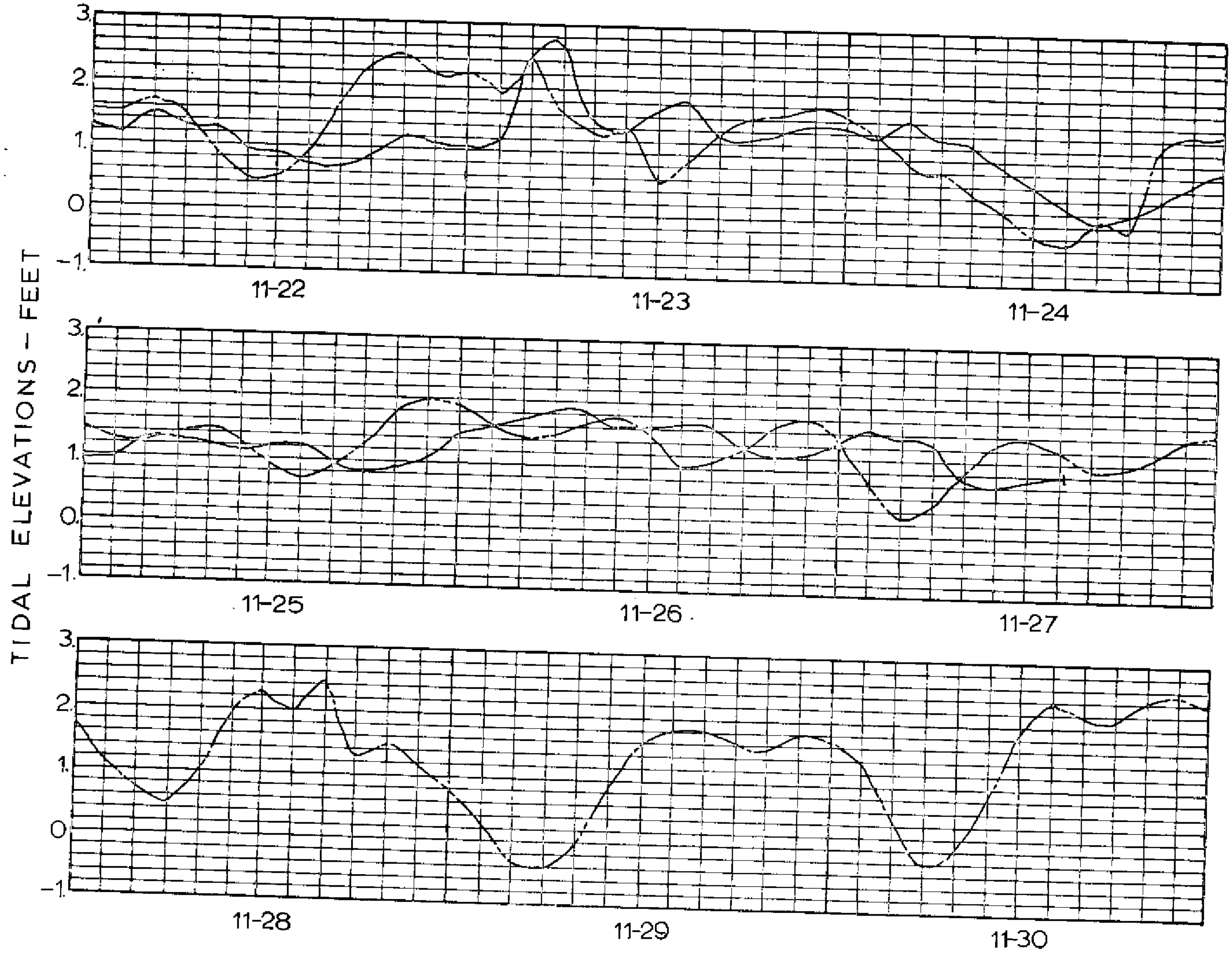


FIGURE 26.--TIDAL DIFFERENTIALS, NOVEMBER 22, 1971 TO NOVEMBER 30, 1971.

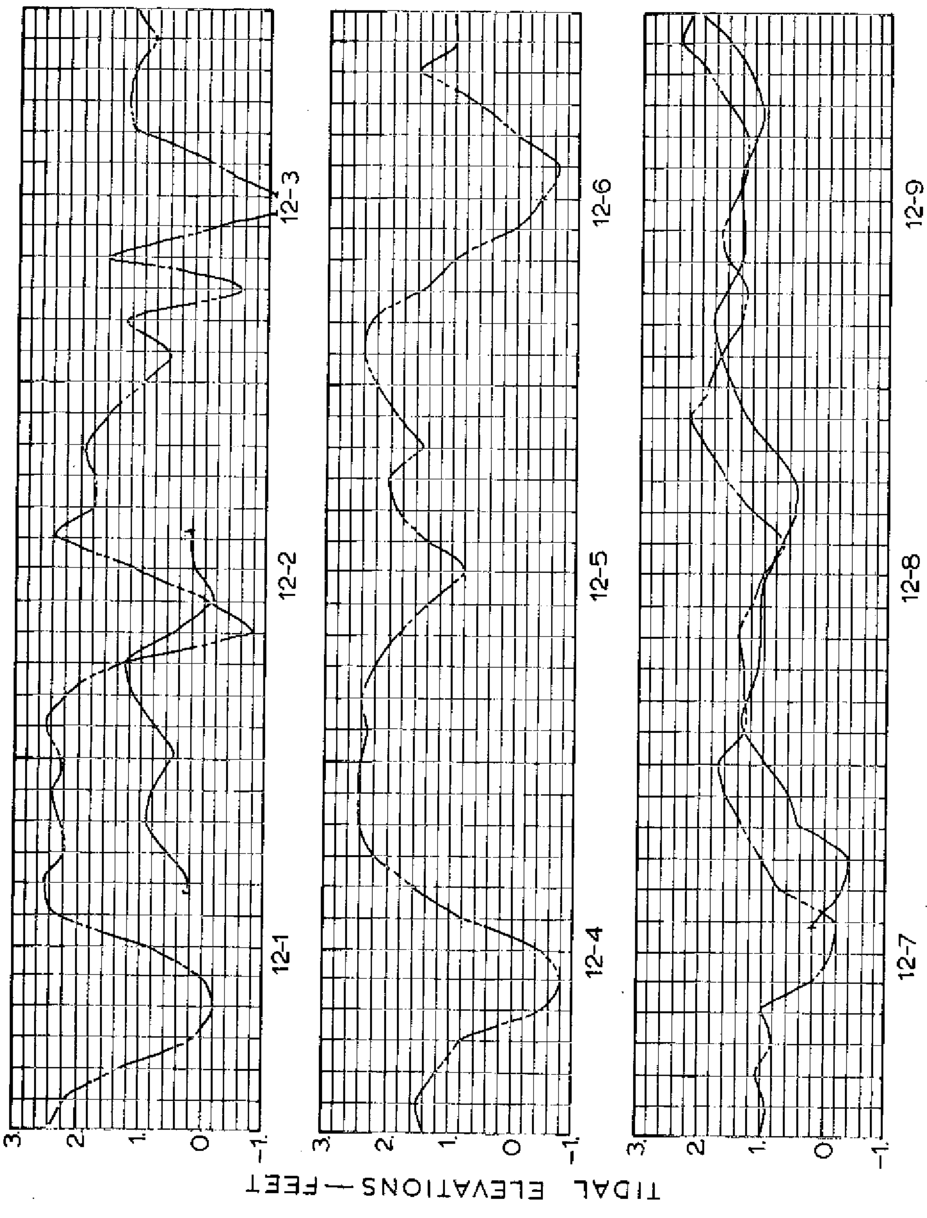


FIGURE 27.--TIDAL DIFFERENTIALS, DECEMBER 1, 1971 TO DECEMBER 2, 1971.

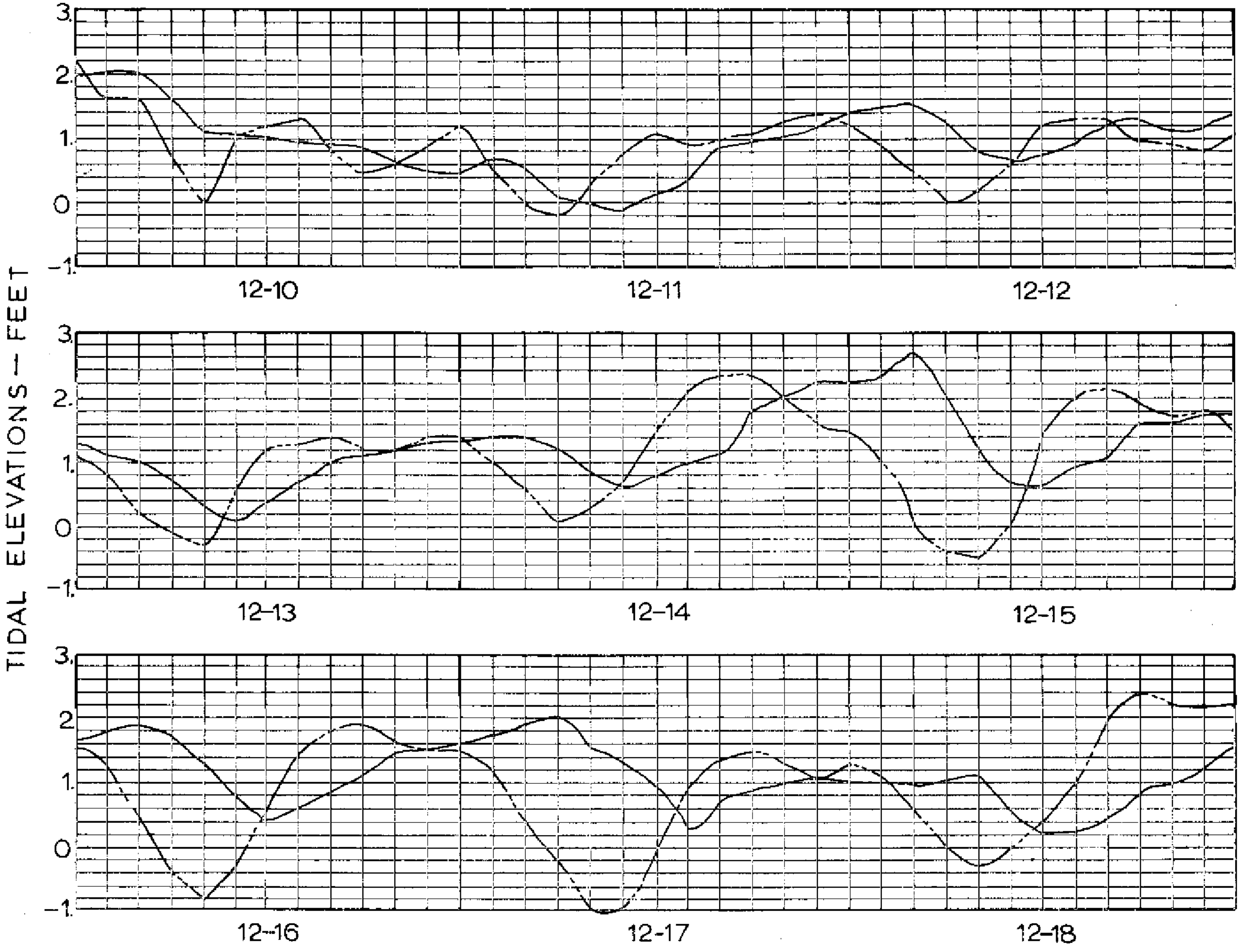


FIGURE 28.--TIDAL DIFFERENTIALS, DECEMBER 10, 1971 TO DECEMBER 18, 1971.

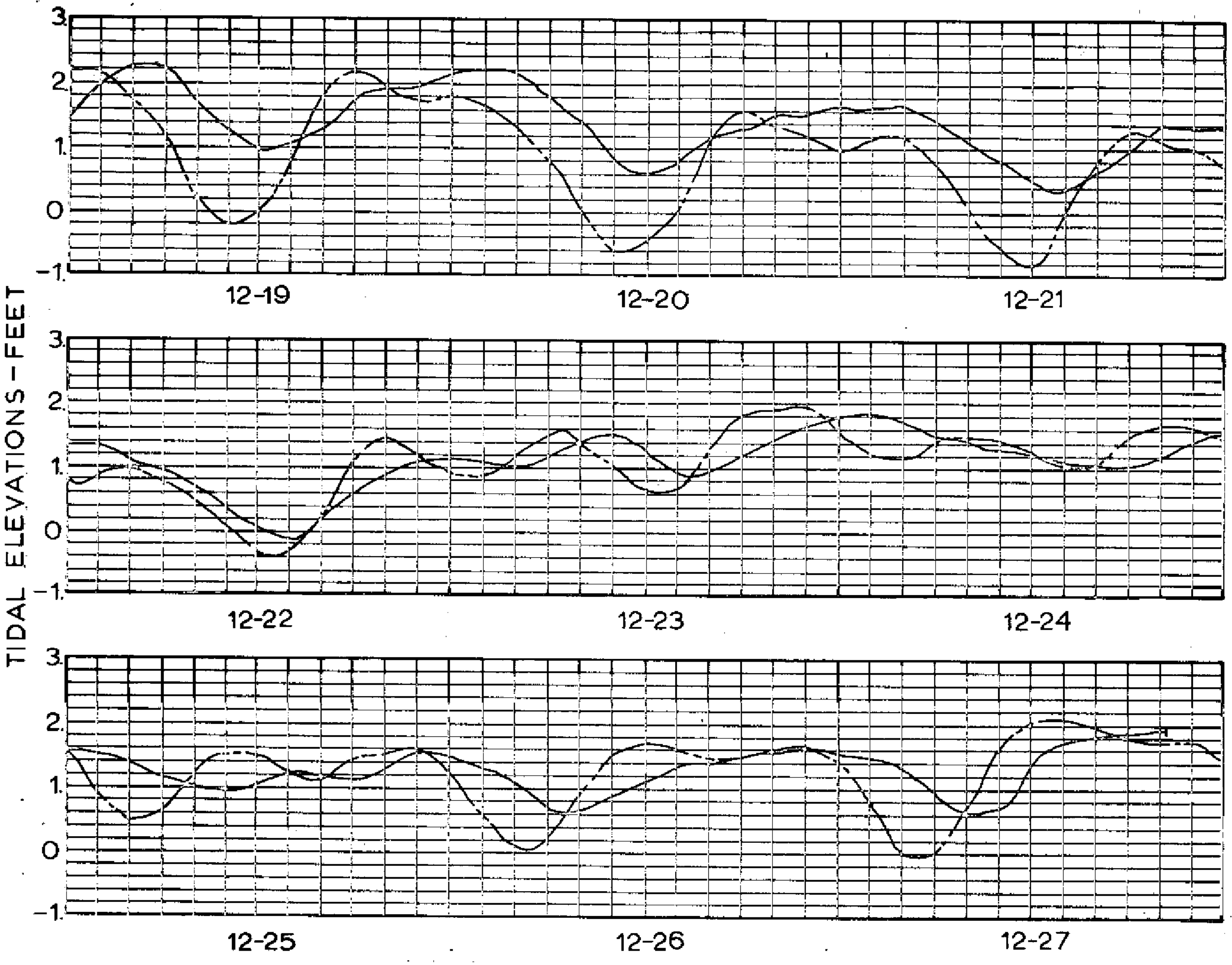
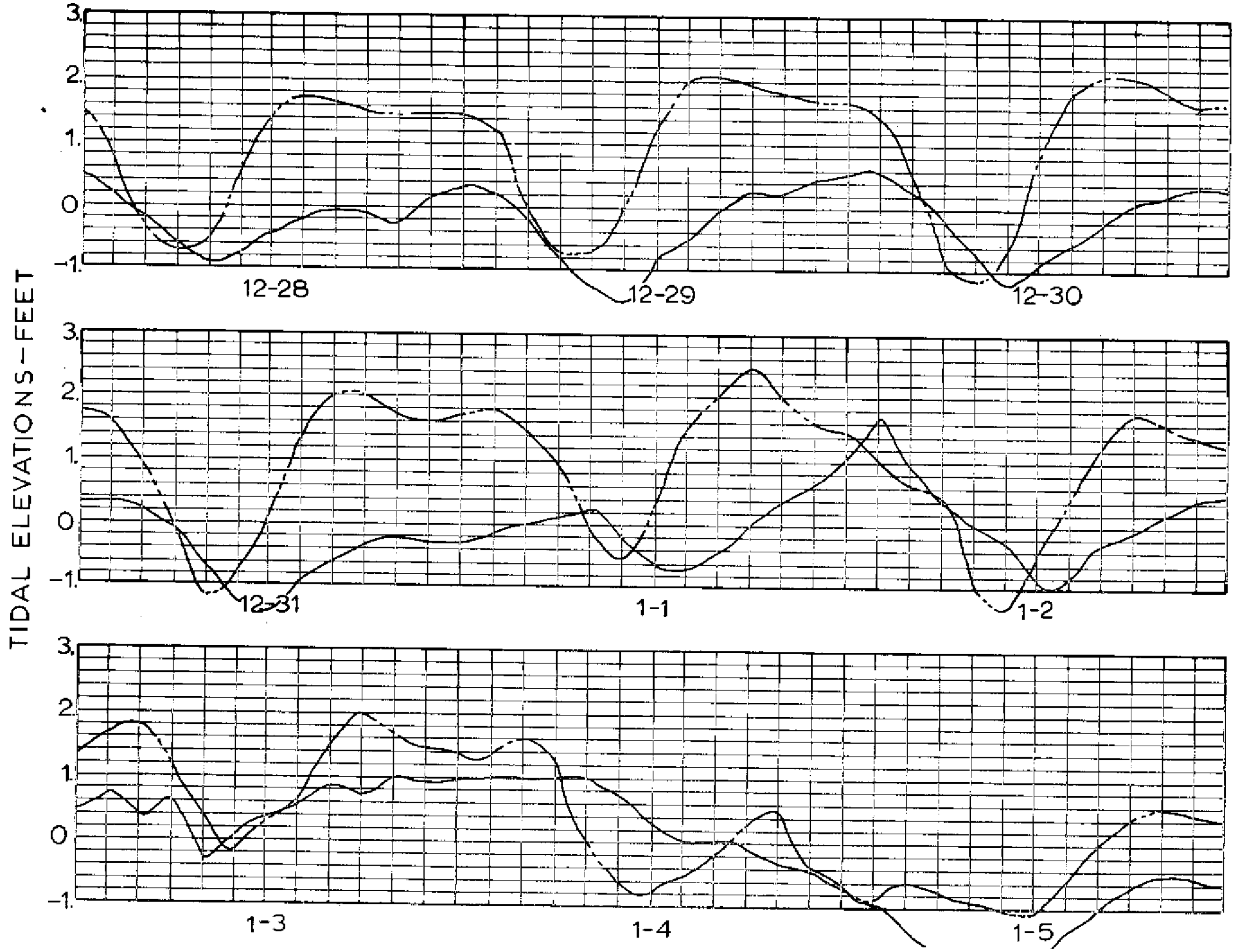


FIGURE 29.--TIDAL DIFFERENTIALS, DECEMBER 19 TO DECEMBER 27, 1971.



FUGURE 30.--TIDAL DIFFERENTIALS, DECEMBER 28, 1971 TO JANUARY 5, 1972.

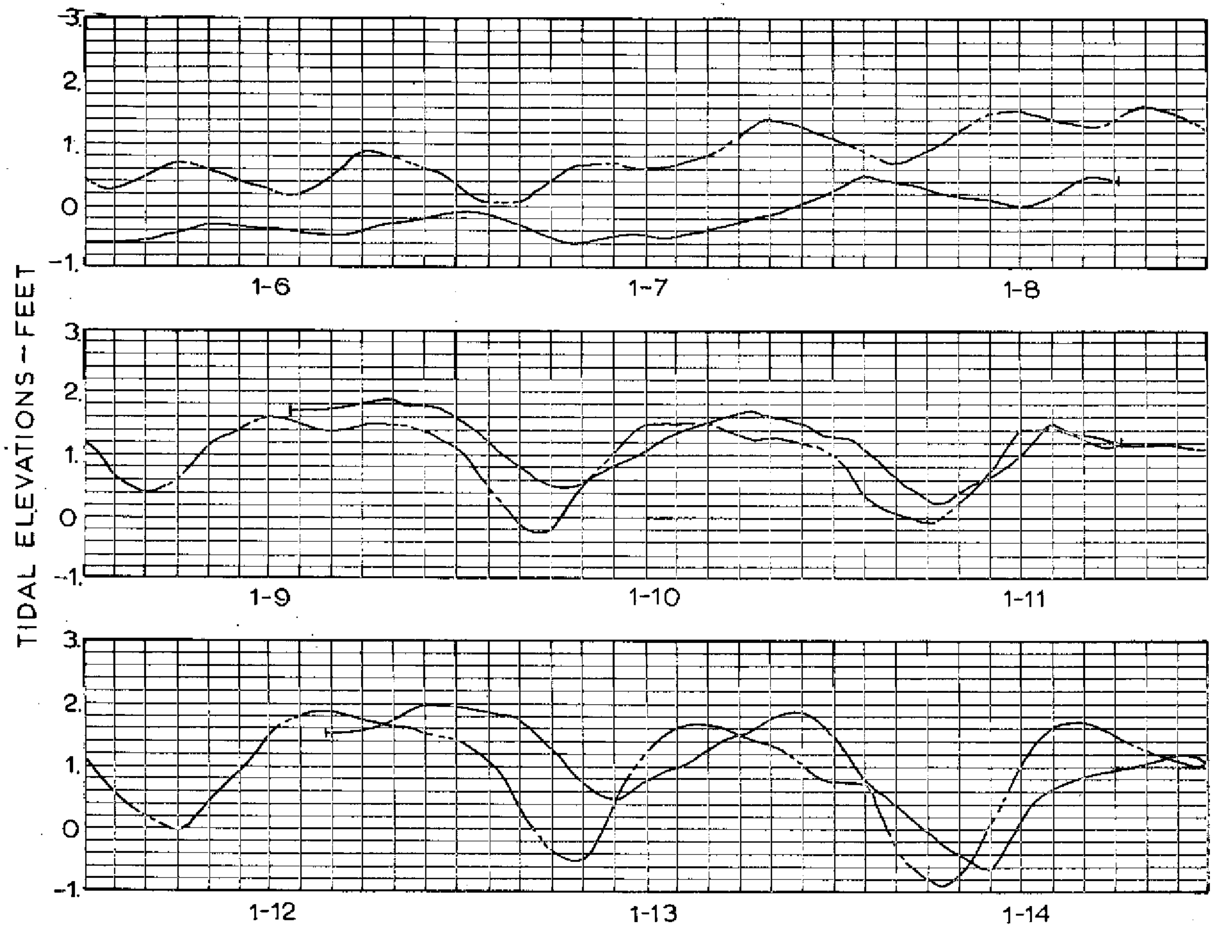


FIGURE 31.--TIDAL DIFFERENTIALS, JANUARY 6, 1972 TO JANUARY 14, 1972.

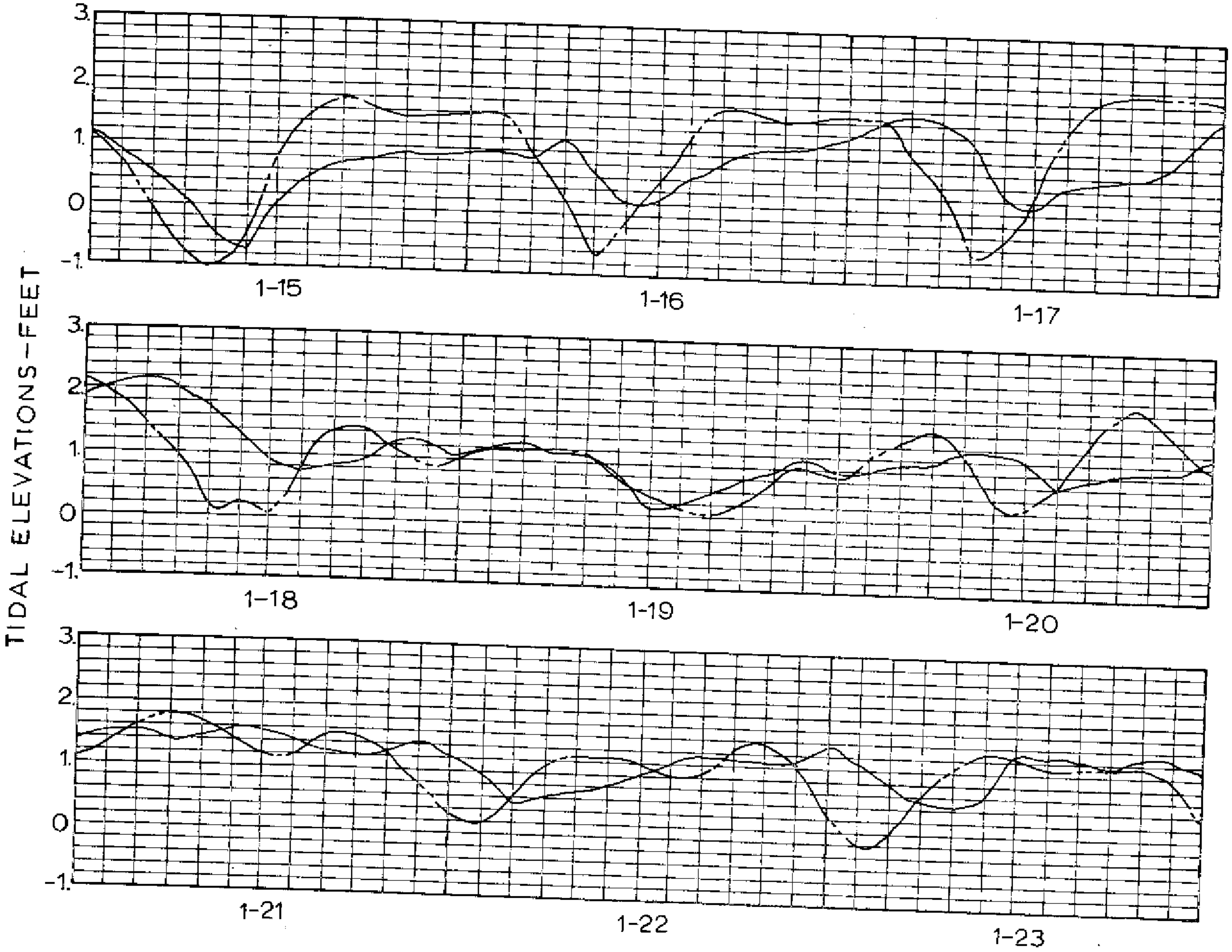


FIGURE 32.--TIDAL DIFFERENTIALS, JANUARY 15, 1972 TO JANUARY 23, 1972.

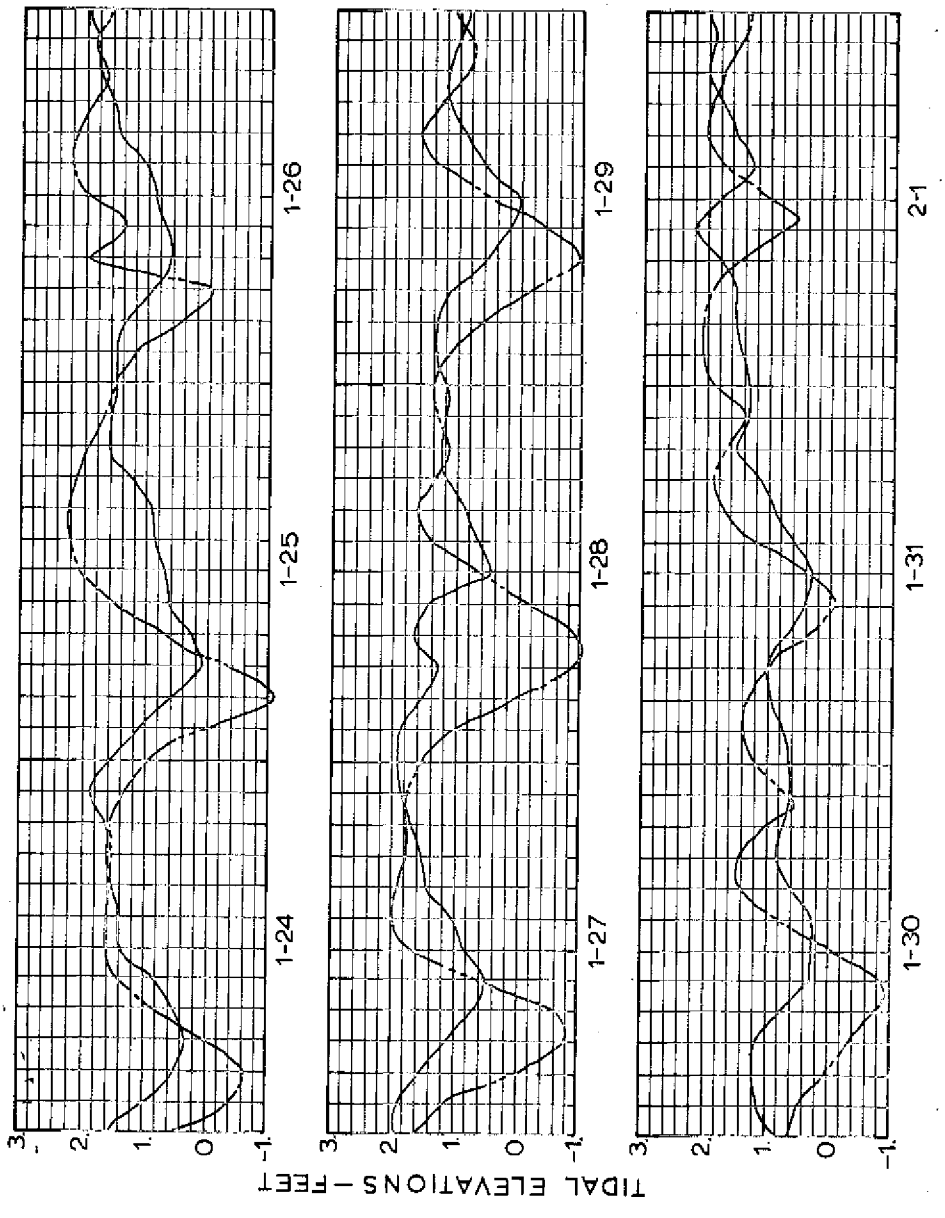


FIGURE 33.—TIDAL DIFFERENTIALS, JANUARY 24, 1972 TO FEBRUARY 1, 1972.

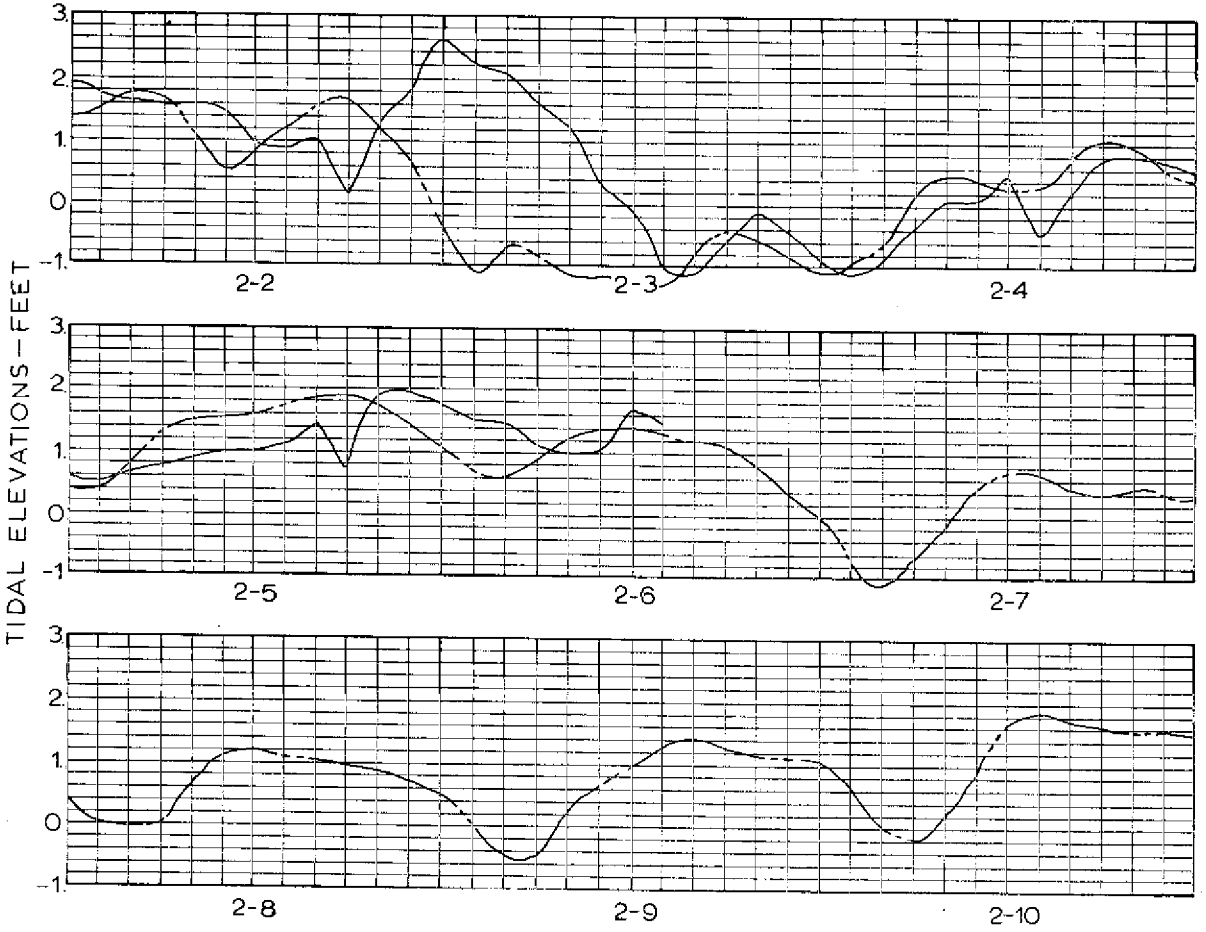


FIGURE 34.--TIDAL DIFFERENTIALS, FEBRUARY 2, 1972 TO FEBRUARY 10, 1972.

APPENDIX.--TIDAL RECORDS

Figures 35 through 45 present the tidal records taken at gages 1, 2, 3, 4 as discussed earlier in this report (page 71). In all cases Mean Sea Level is at 0 feet elevation, and tides are given above or below Mean Sea Level. Daily wind data, where available, is shown in direction by small arrows, and magnitude (Miles Per Hour) by the numbers next to the arrow. The legend for the gages is shown below.

———————— Tide Gage 1 (Rollover Bay)
- ——— - - ——— - Tide Gage 2 (Marsh Point)
— — — — — — — — Tide Gage 3 (Hanna Reef)
- - ——— - - ——— - - Tide Gage 4 (Galveston South Jetty)

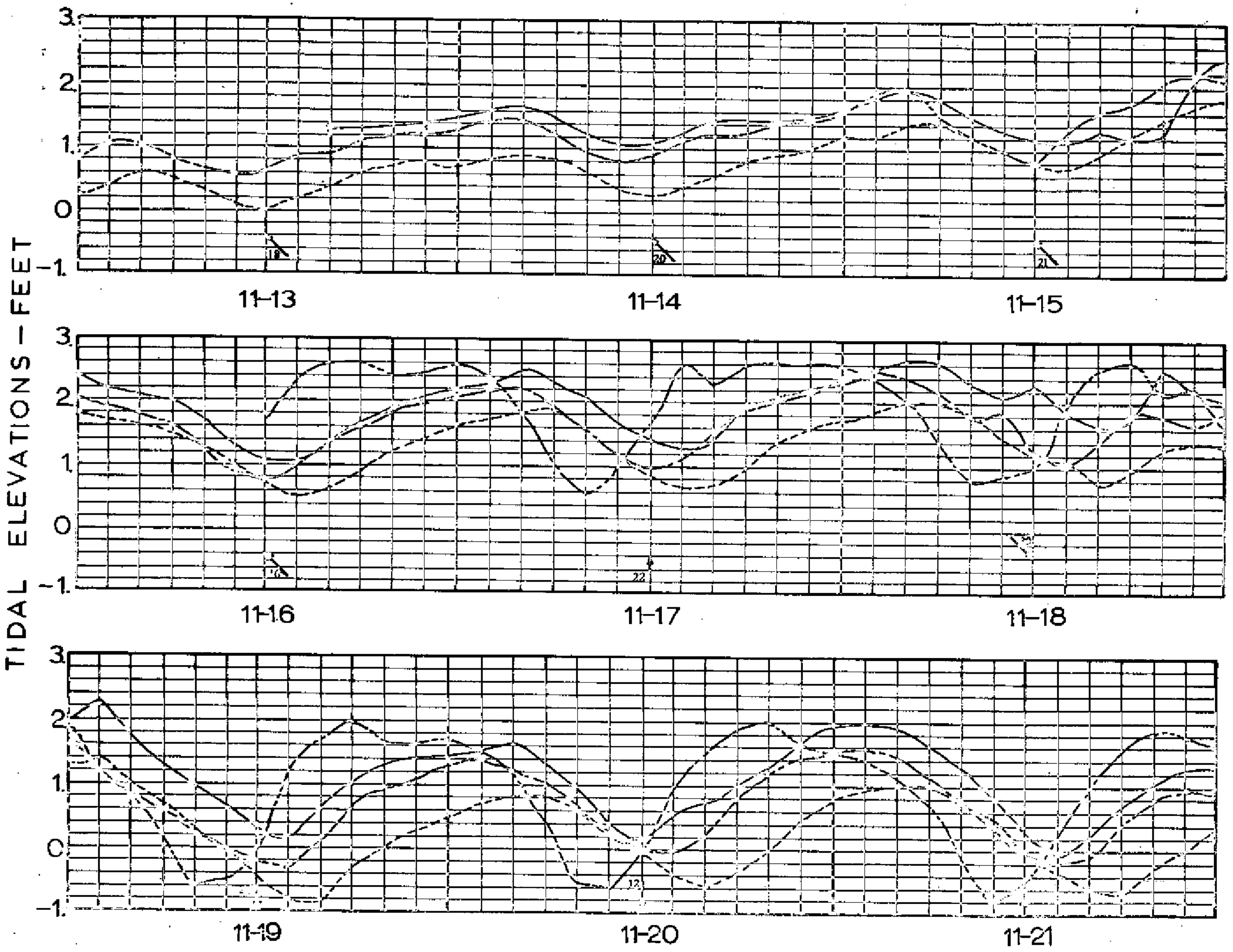


FIGURE 35.--TIDAL RECORDS, NOVEMBER 13, 1971 TO NOVEMBER 21, 1971.

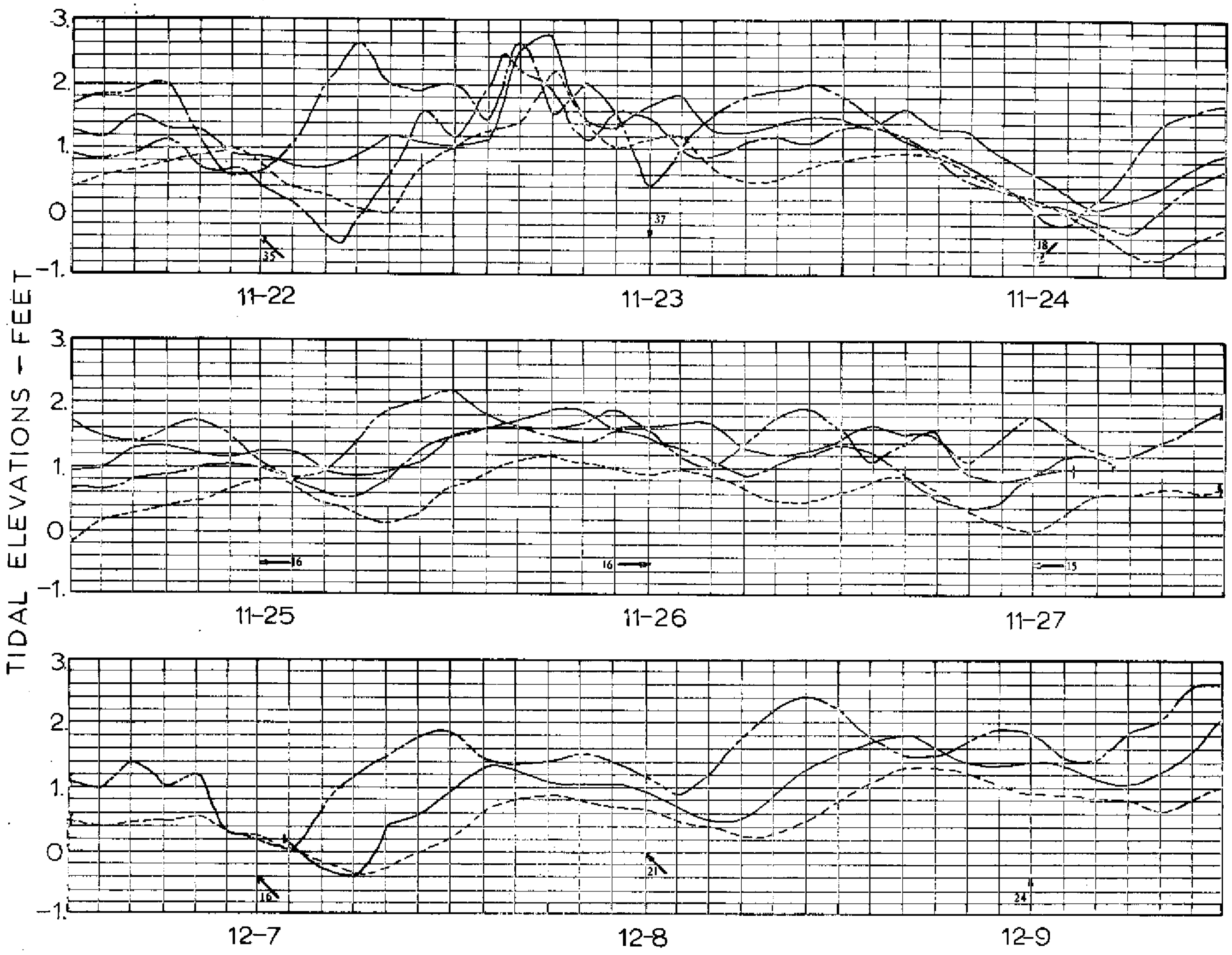


FIGURE 36.--TIDAL RECORDS, NOVEMBER 22, 1971 TO DECEMBER 9, 1971.

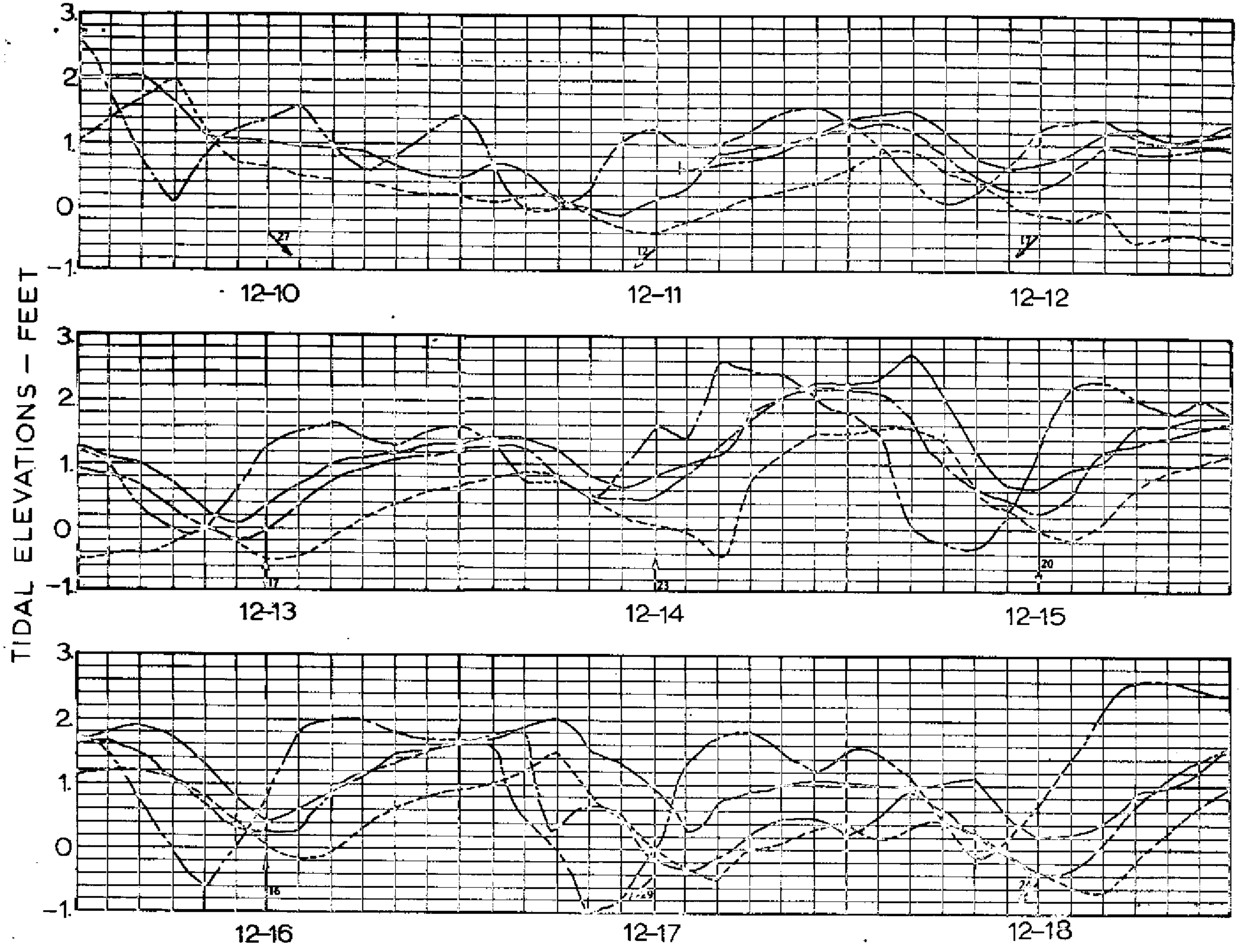


FIGURE 37.--TIDAL RECORDS, DECEMBER 10, 1971 TO DECEMBER 18, 1971.

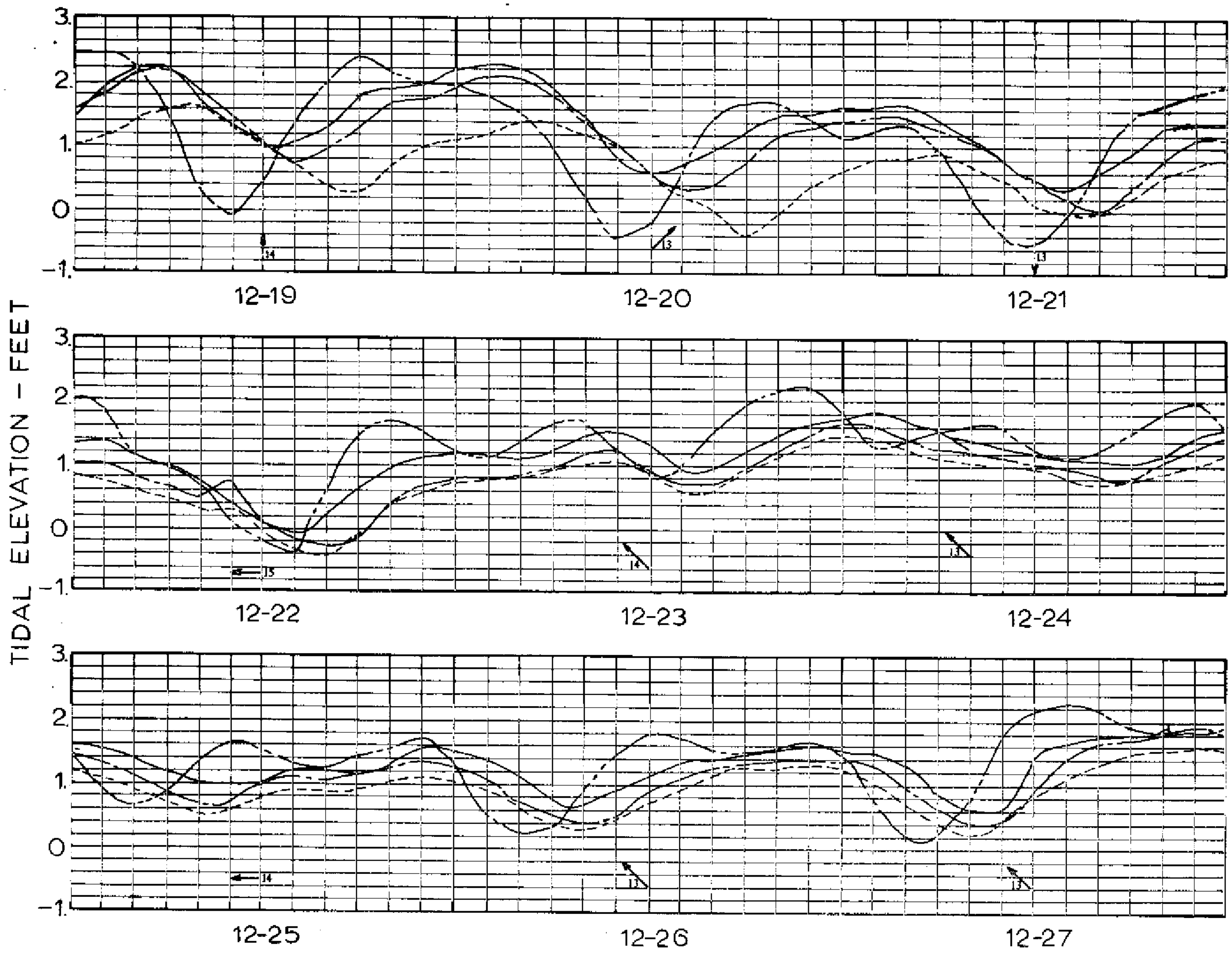


FIGURE 38.--TIDAL RECORDS, DECEMBER 19, 1971 TO DECEMBER 27, 1971.

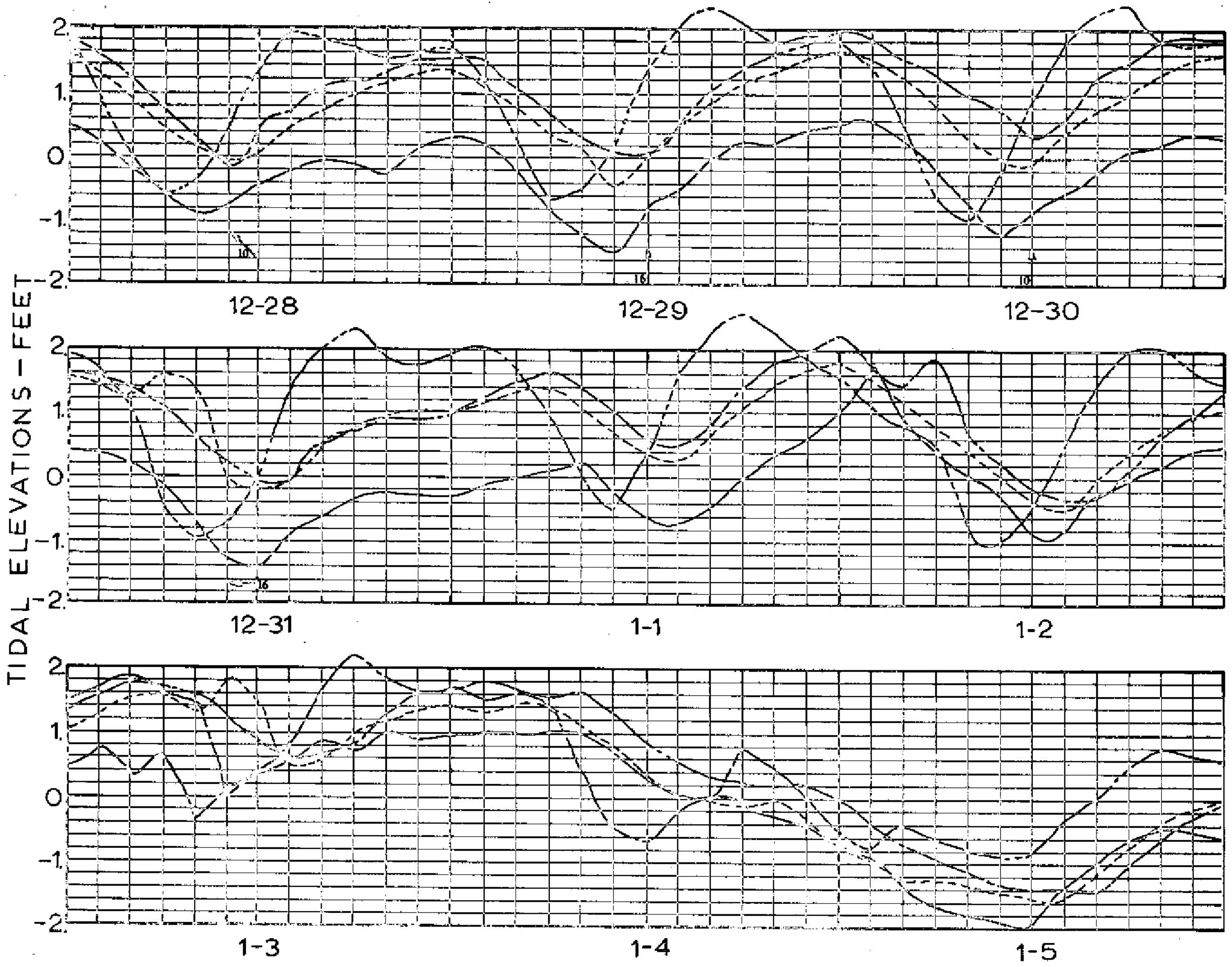


FIGURE 39.--TIDAL RECORDS, DECEMBER 28, 1971 TO JANUARY 5, 1972.

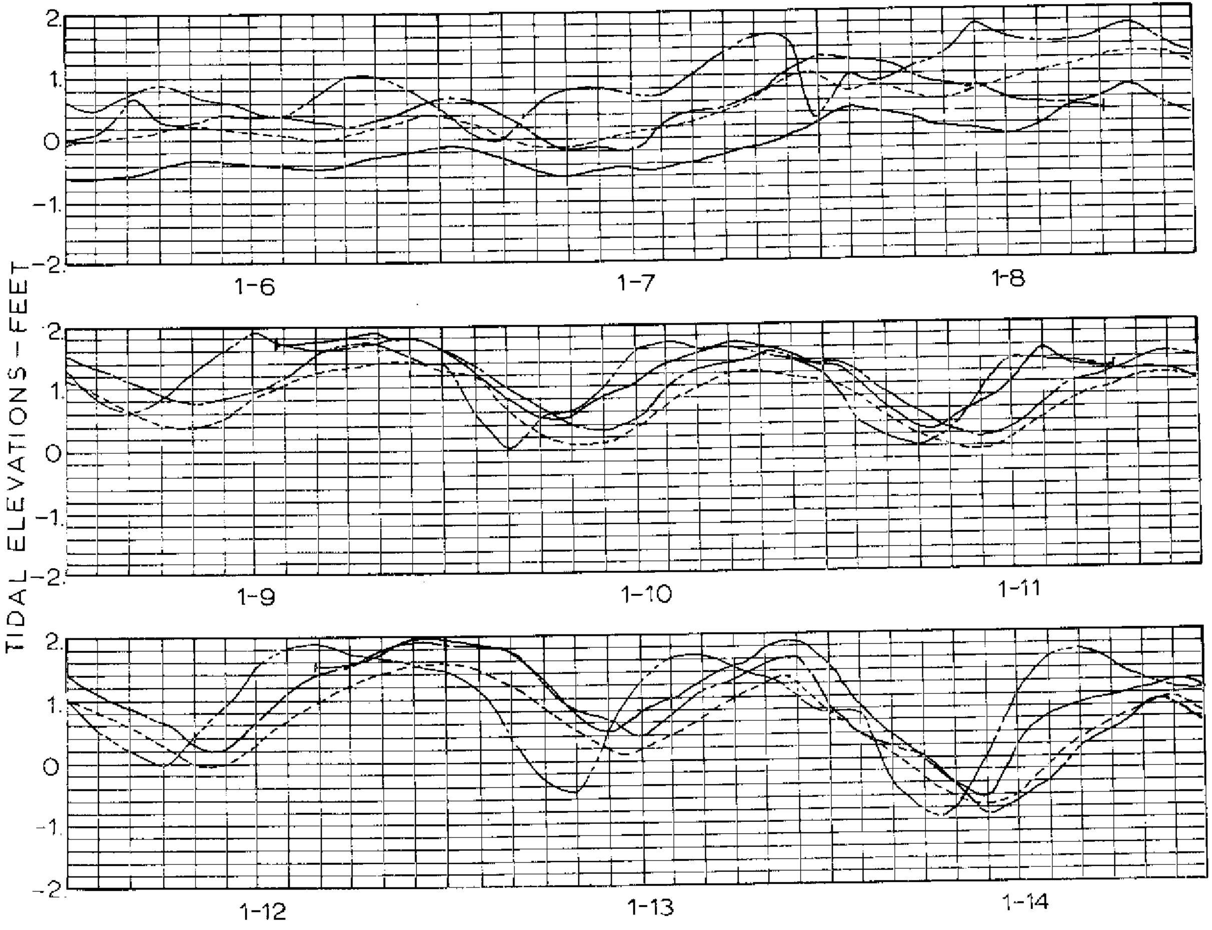


FIGURE 40.--TIDAL RECORDS, JANUARY 6, 1972 TO JANUARY 14, 1972.

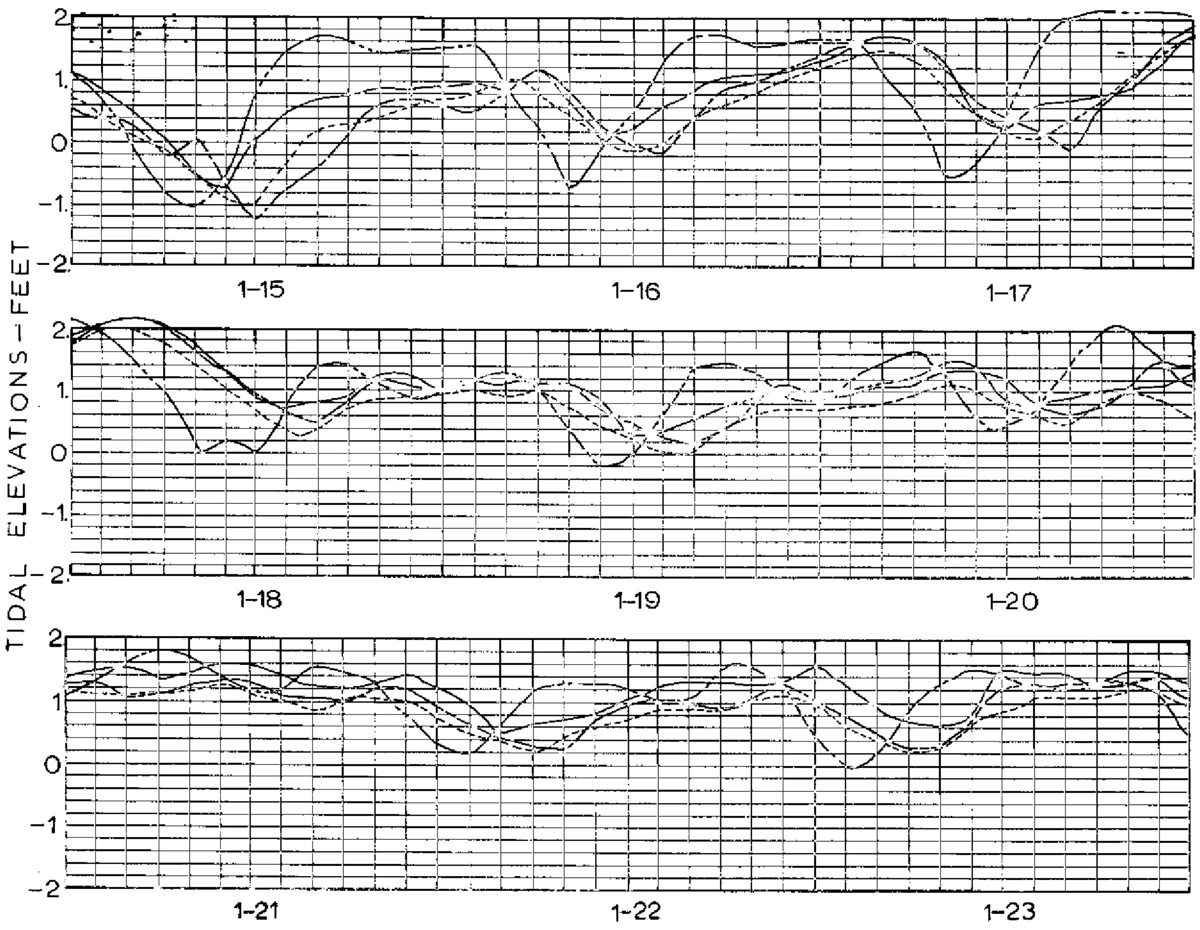


FIGURE 41.--TIDAL RECORDS, JANUARY 15, 1972 TO JANUARY 23, 1972.

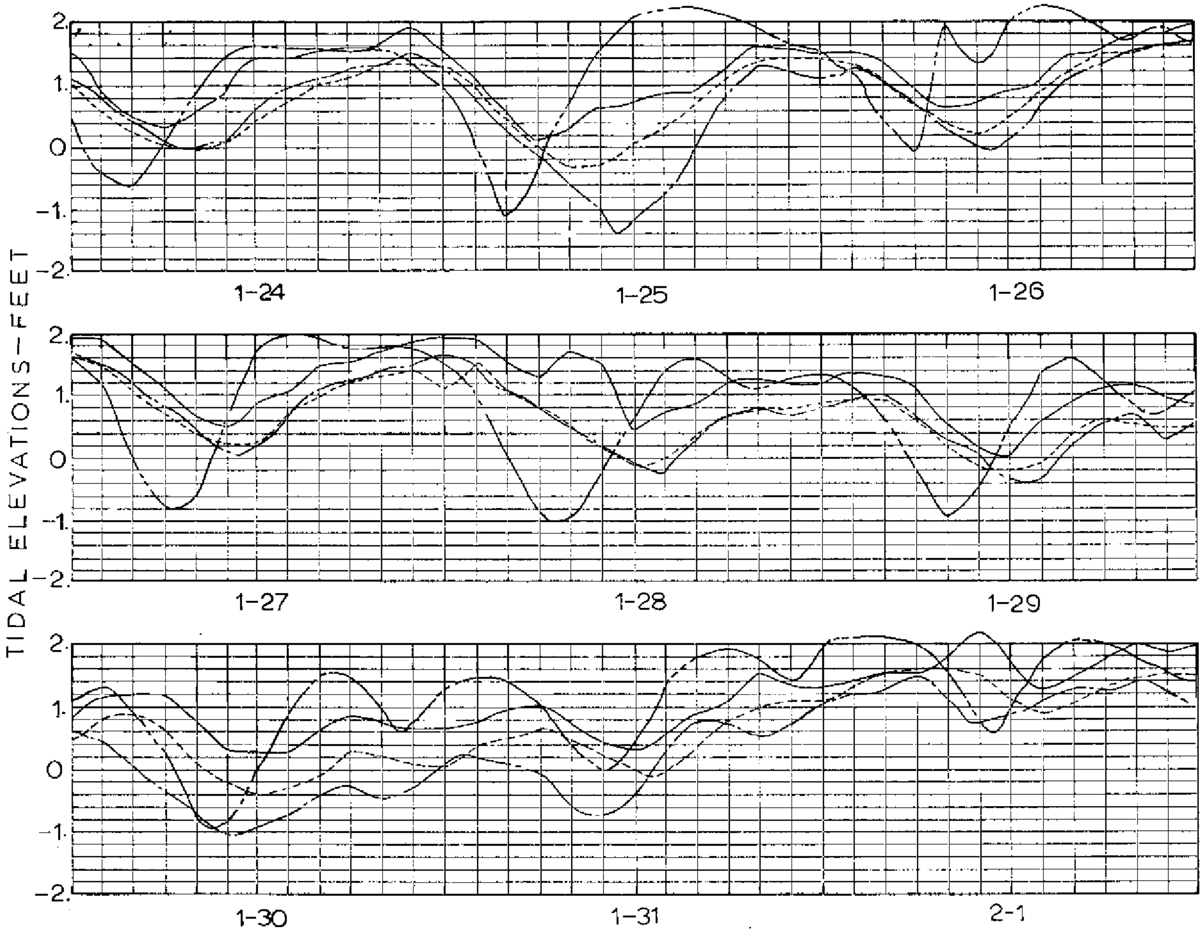


FIGURE 42.--TIDAL RECORDS, JANUARY 24, 1972 TO FEBRUARY 1, 1972.

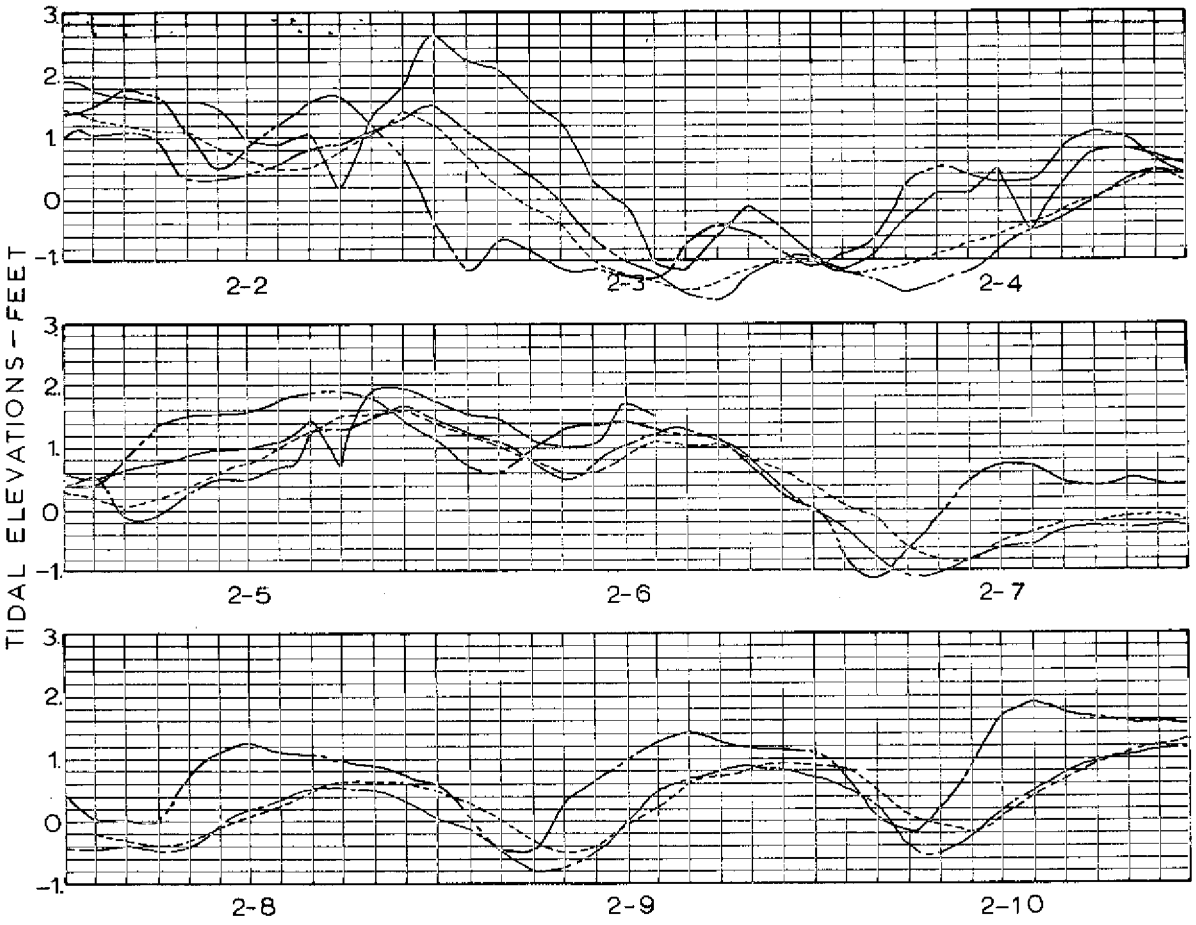


FIGURE 43.--TIDAL RECORDS, FEBRUARY 2, 1972 TO FEBRUARY 10, 1972.

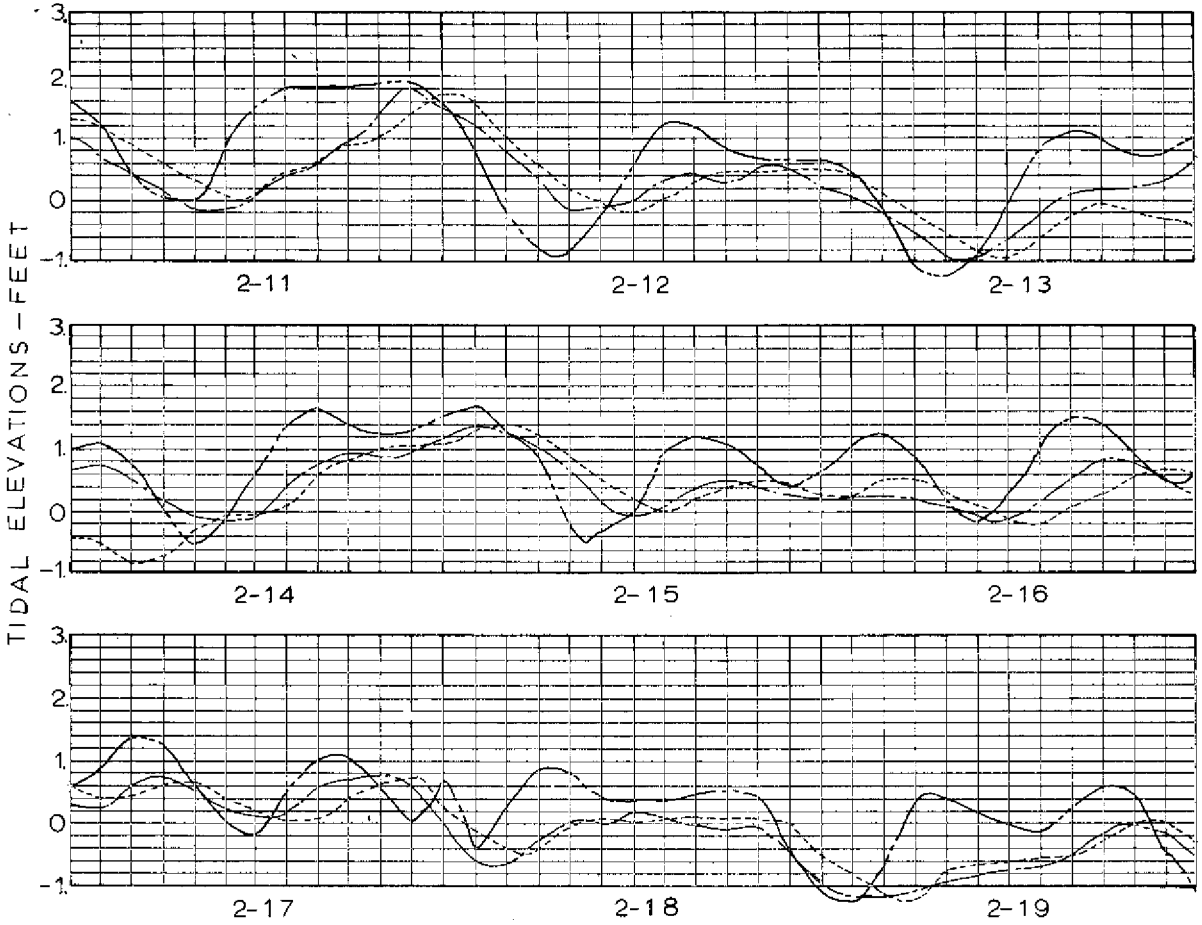


FIGURE 44.--TIDAL RECORDS, FEBRUARY 11, 1972 TO FEBRUARY 19, 1972.

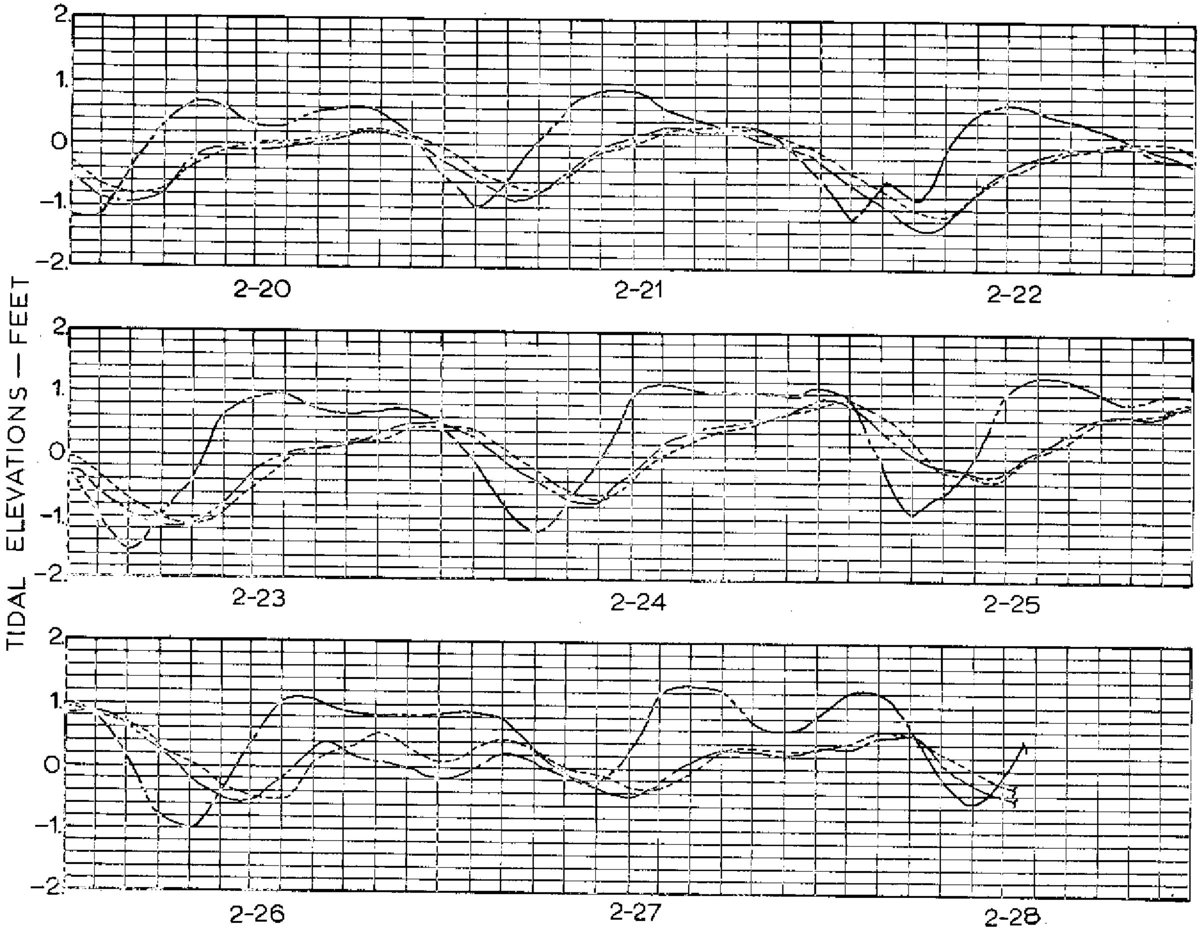


FIGURE 45.--TIDAL RECORDS, FEBRUARY 20, 1972 TO FEBRUARY 28, 1972.