STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

REPORTS OF THE
DIVISION OF WATER RESOURCES
EDWARD HYATT, State Engineer

BULLETIN No. 22

Volume I
of Two Volume

REPORT ON

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers, California

By WALKER R. YOUNG, Engineer,
U. S. Bureau of Reclamation

Prepared under contracts executed jointly by the U. S. Bureau of Reclamation, the California Department of Public Works, and the Sacramento Valley Development Association

1929

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FOREWORD

This bulletin, printed by the State Division of Water Resources, is the report in full of the investigations for a Salt Water Barrier below the confluence of Sacramento and San Joaquin rivers, carried on from April, 1924, to March, 1926.

On January 26, 1924, a contract was executed jointly by the U. S. Bureau of Reclamation, the then California State Division of Engineering and Irrigation, and the Sacramento Valley Development Association, providing for contribution of funds and carrying out of the investigations. Three supplemental contracts were subsequently executed, providing additional funds. The work was performed in accordance with an agreement covering the general plan of procedure. Field investigations and preparation of the report were under the direct charge of Walker R. Young, Engineer of the U. S. Bureau of Reclamation, in consultation with a state engineering advisory committee. Texts of the contracts and agreement are given in Part Two of this volume.

The release of the report was authorized to the U. S. Bureau of Reclamation by Edward Hyatt, State Engineer of California, on June 21, 1928, and its final release approved by Elwood Mead, Commissioner of Reclamation, on June 22, 1928. Since the latter date the report has been publicly accessible in manuscript form, but no funds were available for printing from federal, state or other sources.

On June 18, 1929, the U. S. Bureau of Reclamation approved publication of the report in full but solely at state expense. The cost of printing the report, therefore, has been defrayed entirely from state funds, which became available for this purpose in August, 1929.

The original typewritten report was prepared in four volumes, but in printing it was found advisable to assemble all material except the drawings under one cover as Volume I, and to bind the plates separately as Volume II.

LETTER OF TRANSMITTAL

Ellensburg, Wash., August 27, 1927.

From Walker R. Young, *Construction Engineer,*
To Chief Engineer, Denver, Colorado.

Subject.—Report upon the proposed Salt Water Barrier below the confluence of the Sacramento and San Joaquin rivers in California.

1. Transmitted herewith is a report upon the investigation made of the above proposed control works as provided for in the Cooperative Contract of January 26, 1924, to which the United States Department of the Interior; the Department of Public Works, Division of Engineering and Irrigation of the State of California; and the Sacramento Valley Development Association are parties. The execution of supplementary contracts made possible the extension of the investigation to include development of foundation conditions in detail at three locations, and to make studies of subjects which are inseparable from those of the structure itself. These studies have not only delayed the completion of the report but have added materially to its volume.

2. In the report, sixteen preliminary designs and estimates with three alternatives, are presented according to the suggestion of your Board of Engineers that all designs and estimates completed be included in the report in order that they may be readily available in the economic study which is considered necessary in the final determination of the feasibility of the barrier. No attempt was made to study the economic aspects of the problem other than to enumerate the advantages and disadvantages, as such a study was not considered within the scope of this report.

3. The report is submitted in the following four volumes:*

Volume I—Text.
Volume II—Exhibits, Tables, and Estimates.
Volume III—Logs of Holes Drilled.
Volume IV—Drawings.

Realizing that many of the details will be of no particular interest except to those who may be assigned to the further study of the problem, an effort has been made, in Chapter I of the report, to give a brief history of the investigation and to summarize the results obtained. It is not believed that it will be necessary for you to do more than review the first chapter to obtain the essential information.

4. The writer wishes to express his appreciation of the many courtesies extended by those with whom he and his associates have come in contact in the course of the investigation. Valuable assistance was rendered by the Navy Department. I wish to acknowledge especially

* In the printed report all material except the drawings is assembled under one cover as Volume I. The drawings are bound separately as Volume II.

the courtesy of Commander C. A. Carlson, Public Works Officer, Mare Island Navy Yard, through whom drill equipment was secured. The War Department cooperated through the District Engineers at San Francisco, Seattle and Detroit. We are indebted to Colonel W. J. Barden, District Engineer at Seattle, who furnished very complete data on the design and operation of Lake Washington Ship Locks. The United States Coast and Geodetic and Geological Surveys cooperated, as did the Southern Pacific and San Francisco and Sacramento railroads. Data were furnished by the State Flood Control Engineer, Highway Engineer and Water Supervisor. The Association of Industrial Water Users of Contra Costa and Solano counties furnished data relative to shipping, use of water and salinity. The American Toll Bridge Company made available their record of borings in Carquinez Strait. Space does not permit of naming the many individuals who cooperated. I can not, however, refrain from mentioning the courtesy and material assistance rendered by Mr. Geo. A. Atherton, general manager for California Delta Farms, Inc., by Mr. William Pierce of Suisun, California, and by Mr. C. H. Schedler, general manager, Great Western Electro-Chemical Company.

5. In the preparation of the materials for the report, credit is due Mr. W. A. Perkins, associate hydraulic engineer, Division of Engineering and Irrigation, State Department of Public Works, who made the principal studies of tides, floods and water required for operation; to Mr. Nelson B. Hunt, associate engineer, Bureau of Reclamation, who had direct charge of the preparation of all designs and estimates of cost; to Mr. Paul A. Jones, assistant engineer, Bureau of Reclamation, who made the field surveys and the study of storage in the bays and delta channels; and to Mr. Ray C. Gossett, diamond drill foreman, Bureau of Reclamation, who was in direct charge of all drill operations. I wish here to express my appreciation of the loyalty and earnest effort of these men and of their assistants.

(Signed) WALKER R. YOUNG.

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PART ONE

TEXT OF REPORT ON SALT WATER BARRIER

CHAPTER I

HISTORY OF INVESTIGATION AND SUMMARY OF RESULTS

HISTORY

The Problem.

In the delta of the Sacramento and San Joaquin rivers, in California, there are nearly one-half million acres of highly productive land which are wholly dependent upon the lower river and delta channels as a source of fresh water necessary in the irrigation of crops variously estimated to be worth from 50 to 90 million dollars annually. Along the shores of the upper San Francisco Bay system are many industrial plants requiring large quantities of fresh water in their operation.

As shown on Plate 1-1, Sacramento and San Joaquin rivers discharge into Suisun Bay through what is practically a common mouth and find their way to the Pacific Ocean through the "Golden Gate" after passing through Suisun Bay, San Pablo Bay and the northerly portion of San Francisco Bay proper. If it were not for the rivers the water in the bays would be practically as salty as the ocean, wholly unsuitable for irrigation and for many industrial uses.

In years of normal run-off from the two great valleys of the Sacramento and San Joaquin, the discharge of fresh water during the flood season is sufficient to flush out the lower river and delta channels, and, in fact, Suisun Bay and Carquinez Strait. With decreasing river discharge during the summer months the salinity of Suisun Bay increases, but in normal years the summer discharge of the rivers is sufficient to keep their common mouth flushed clear of injurious quantities of salt. However, in recent years of deficient rainfall the run-off from the area draining into Suisun Bay has decreased to the extent that it has, in years like 1920 and 1924, not been sufficient to supply irrigation demands of the two great valleys and of the delta, and leave enough fresh water to act as a natural barrier against encroachment of salt water into the lower river and delta channels.

Salinity in the lower reaches of the rivers is not a new experience, as is evident from the following quotations from page 54, House Document No. 123, 59th Congress, first session:

> It is of interest to note that in August, 1841, Commander Ringgold's party entered the mouth of the San Joaquin "and proceeded upstream for a distance of 3 miles, where they encamped, without water, that of the river being still brackish" (this camp was evidently opposite or in the immediate vicinity of the site of the present city of Antioch). It is also said that there was trouble from salt water in this vicinity in 1871.

In years of extreme drouth, salt water invades the San Joaquin to points opposite Stockton. If it had not been for the water conservation measures adopted in 1924, it is probable that Sacramento's domestic water supply would have been contaminated by salt from the ocean. The encroachment of salt water into the upper bays and lower rivers, therefore, constitutes a serious menace to irrigation, industries and municipalities, which promises to become more acute as the demand for water increases with the natural development of the two great valleys.

Purpose of Investigation.

The investigation was made at the request of the Sacramento Valley Development Association and of the Delta Land Syndicate for the purpose of determining the feasibility, probable effectiveness and the approximate cost of a "Salt Water Barrier" constructed at some point below the confluence of the Sacramento and San Joaquin rivers to prevent incursions of salt water into the region of the delta. It was hoped that in addition to eliminating the salt menace in the delta, the construction of a barrier would make possible the reclamation of what are now salt marshes around the bays, and would create a body of fresh water which would be of great economic value to the rapidly growing communities and industries. If incursions of salt water can be prevented through construction of a barrier, not only could the fresh water now required to act as a natural barrier be largely conserved, but the delta channels could be utilized as canals for the transfer of water from the Sacramento Valley to San Joaquin Valley, which transfer is contemplated in the development of the state's water resources. The request for the investigation, dated January 4, 1923, is attached as Exhibit 1.

Authority for Investigation.

Authority for the investigation is contained in a cooperative contract of January 26, 1924, entered into by the United States of America, Department of the Interior; the Department of Public Works, Division of Engineering and Irrigation of the State of California, and the Sacramento Valley Development Association, and three supplementary contracts dated June 26, 1924, March 3, 1925, and March 16, 1926. The contracts accompany this report as Exhibits 2, 3, 4 and 5, respectively.

A contract dated September 19, 1924, attached as Exhibit 6, is the authority for performing certain drilling for the East Bay Municipal Utility District.

Plan of Procedure.

A controlling board, created under the provisions of the original contract, included the Chief Engineer, Bureau of Reclamation, the State Engineer of California and the president and general manager of the Sacramento Valley Development Association. In practice, Mr. Paul Bailey acted for the state, Mr. W. A. Beard for the Development Association, while the writer was authorized to act for the Bureau of Reclamation.

According to the terms of the first contract, the investigation followed a general plan agreed to by all parties to the contract. The agreement covering the general plan of procedure is attached as Exhibit 7.

Valued advice and suggestions have been obtained through the frequent visits of Mr. W. A. Beard, Mr. Paul Bailey and Mr. J. L. Savage, Chief Designing Engineer, Bureau of Reclamation.

A plan was adopted of holding meetings in cities and towns in the bay and delta regions for the purpose of discussing the Salt Water Barrier as it might affect various interests. Meetings were held in Berkeley, Richmond, Crockett, Martinez, Pittsburg, Sacramento, McNear's, San Rafael, Napa, Vallejo and Suisun.

The work accomplished in the investigation was made the subject of monthly reports to the Chief Engineer, Bureau of Reclamation, for the period April, 1924, to the date of this report.

Engineering Board Meeting.

On June 9, 1924, the state's advisory committee met in the Berkeley office of the Bureau of Reclamation in an advisory capacity to assist in the formulation of the general plan of procedure. The committee met again in the Berkeley office on December 13, 1924, and on February 17, 1926. Members of the committee were Consulting Engineers F. C. Herrmann, W. L. Huber, A. J. Cleary, G. A. Elliott, A. Kempkey and B. A. Etcheverry.

Mr. R. G. E. Weber, superintendent of the Orland Project, was called in to confer with the state's committee in the formulation of the plan of procedure. On January 4, 1926, a Board of Engineers, appointed by the Chief Engineer, Bureau of Reclamation, convened in Berkeley for the purpose of considering the designs and estimates which had been prepared. Members of the board were Consulting Engineer A. J. Wiley and Chief Designing Engineer J. L. Savage. Their report was transmitted to the Chief Engineer on January 11, 1926.

General Conference.

On January 8, 1926, a general conference was held in the Berkeley office to discuss the broader aspects of the barrier problems. Those present were Mr. C. E. Grunsky, Mr. W. A. Beard, Commander C. A. Carlson of the Navy Department, Lieut. Col. G. R. Lukesh, and Majors John W. N. Schultz and C. S. Ridley of the War Department; Messrs. Paul Bailey and W. A. Perkins, representing the state, and Messrs. A. J. Wiley, J. L. Savage, N. B. Hunt and the writer for the Bureau of Reclamation. Unfortunately, members of the state's advisory committee could not attend.

Field Office.

Headquarters for the joint investigation of the Iron Canyon Project in Sacramento Valley, and of the proposed Salt Water Barrier, were established in Berkeley, California, on April 19, 1924, the writer being in direct charge. Mr. W. A. Perkins, Associate Hydraulic Engineer, representing the State of California, Department of Public Works, Division of Engineering and Irrigation, was assigned to the Berkeley office on July 21, 1924.

The Berkeley office was discontinued on March 31, 1926, after which work on designs and estimates were continued in the offices of the Bureau of Reclamation at Ellensburg, Washington, to which the writer had been assigned. The state's representative returned to his regular duties in Sacramento upon discontinuation of the Berkeley office.

Studies Made.

The principal studies made, aside from design of the barrier, included those of tides, floods, navigation, storage, salinity, silt and water required for operatiton.

Field Work.

Of a number of sites which have been proposed for construction of a barrier, three were selected for investigation as being typical. The Dillon Point site is located in Carquinez Strait at Dillon Point, where the distance between shores is about one-half mile—less than at any other point below the mouth of the rivers. As would be expected, the depth of water is the greatest. The Point San Pablo site, between Point San Pablo and Point San Pedro, represents a wide side, the distance between shores being nearly two miles. At the Army Point site what may be considered average conditions are found, the distance between shore lines being about one mile.

Each of the three sites was drilled to determine the cross-section between shores and to develop foundation conditions under the ship locks and flood gates. Drilling was started on August 16, 1924, and completed on August 7, 1925, after drilling a total of 322 holes, aggregating 24,640 linear feet.

Topographic surveys and geological examinations were made at each of the sites investigated, the latter by Kirk Bryan, Geologist of the United States Geological Survey.

Measurements of tidal fluctuations and velocities were made at each site as a part of the study to determine the gate area required to pass floods from the rivers.

Samples of bay water were taken at the Army Point and Point San Pablo sites over a period of one year in connection with the study of salinity.

A count was made of vessels of various sizes passing each of the sites for use in the determination of the number and size of ship locks required.

Funds.

The original contract of January 26, 1924, made $30,000 available for the investigation. As the work progressed it became evident that additional funds would be required to complete the investigation of the three typical sites selected. To meet the situation other contracts were executed which, with the original sum, made available a total of $77,407.82, of which the United States contributed $37,736.92, the State of California $27,110.10 and local interests $12,560.80. A more detailed statement of funds contributed appears as Exhibit 8.

It should be stated that funds contributed by local interests were raised, principally, by subscription through the efforts of a contributors' committee of the Lower Sacramento River Control Water Project, of which Mr. Dan Hadsell was chairman.

Cost of Investigation.

All money made available for the work has been expended with the exception of a small amount reserved by the state for reviewing the report. Of the total, approximately 57 per cent ($43,600), including a proportional part of the overhead expense, was used in drilling operations, the balance being used in the various studies made and in the preparation of the preliminary designs and estimates recommended for inclusion in the report by the Board of Engineers. A detailed statement of the cost of the investigation is included as Exhibit 9.

The great increase in cost over that contemplated in the original contract is explained by the fact that three sites for the barrier were fully developed by extensive drilling, whereas it was first believed that development drilling could be limited to one site, selected upon the results of a comparatively small amount of preliminary drilling. Moreover, alternative designs and estimates have been made for all three sites drilled, and for one site which was not developed by drilling, rather than for one site only, as was originally contemplated.

Data Filed.

Original computations and drill logs, field note books, maps, reports and correspondence relative to the investigation are filed in the office of the Chief Engineer, U. S. Bureau of Reclamation at Denver, Colorado. In most cass copies of computations, drill logs, and othr essential data used in the preparation of the report, as well as all of the drill core and samples obtained in the drilling operations, were forwarded to the State Department of Public Works, Division of Engineering and Irrigation, at Sacramento, California.

Visitors.

During the course of the investigation a number of prominent persons inspected the sites for the proposed barrier, among them the following:

Commissioner Elwood Mead was in Berkeley at the time the investigation was inaugurated in April, 1924. He was a visitor again in June, 1924, and in April, 1925.

Chief Engineer F. E. Weymouth and Director of Reclamation Economics Geo. C. Kreutzer visited the work in June, 1924. The Chief Engineer was in Berkeley again in October of the same year.

State Engineer W. F. McClure (now deceased) called at the Berkeley office in July, 1924.

In October, 1924, Congressman Clarence F. Lee of California and party inspected the work.

Secretary Hubert Work and party went over the work in April, 1925.

In June, 1925, a party of about thirty guests of Congressmen Chas. F. Curry of California made an inspection of the barrier sites. The principal guest was Secretary Herbert Hoover. Other guests included State Engineer McClure, engineers of the Army and Navy, and representatives of various chambers of commerce and industries.

Superintendent of Construction, S. O. Harper of the Bureau of Reclamation, inspected the work in August, 1925.

In October, 1925, the Rivers and Harbors Committee of Congress inspected the various sites under investigation while on a trip through the bay and delta regions. The committee members were Congressmen S. Wallace Dempsey of New York, chairman; Walter Lineberger of California, John McDuffie of Alabama, and Nathan L. Strong of Pennsylvania. Other congressmen who made the trip were Chas. F. Curry and Clarence F. Lee of California and A. J. Sabath of Illinois. Engineers of the Army, Navy, state and government accompanied the party.

SUMMARY OF RESULTS

General.

The studies made lead to the conclusion that it is physically feasible to construct a Salt Water Barrier at any one of the sites investigated, but at great expense; and that it will be effective in controlling the salinity of the reservoir impounded above it. Not only will it protect the delta and industrial plants along the shores of the bays, but its construction will result in the conservation of a large part of the fresh water required to act as a natural barrier against invasions of salt water under present conditions.

Without the barrier, salinity conditions will become more acute unless mountain storage is provided to be released during periods of low river discharge to act as a natural barrier against invasions of salt water. The amount estimated as necessary to act as a natural barrier was in excess of the flow in the Sacramento River above Red Bluff in 1924. Below Red Bluff diversions of water for irrigation in the Sacramento Valley exceeded inflow.

The sites selected for development by drilling are considered geologically satisfactory for the type of structure proposed. Although preliminary designs and estimates are presented for four sites, there are only two general plans involved. A barrier, if constructed at the Army Point, Benicia, or Dillon Point site, would creat a body of fresh water in Suisun Bay and in the delta channels, while a barrier at the Point San Pablo site would include San Pablo Bay as well.

Type of Dam Proposed.

The type of structure to which principal consideration is given is one in which the ship locks and flood gates are located at one side upon rock foundations, the closure of the present waterway being effected by means of an earth and rock fill dam to be brought up to its designed height after completion of the ship locks and flood gate structure. In another type studied the flood gates form the closure between concrete piers sunk to bedrock foundations in the present waterway by the open caisson method. Both types have been designed with and without provision for carrying a railroad and highway.

The passage of floods is probably the most important problem since it involves the safety of the delta levee system. It would be desirable, if practicable, to provide gate area equivalent to, or slightly in excess of, the present waterway area in order that conditions of flow might remain unchanged, but the accomplishment of this plan would be very costly if not altogther infeasible.

In the design of the structure, advantage is taken of the difference in the elevation of water surface which it is possible to create above and below the barrier to discharge flood water. On account of the fluctuating head, resulting from tides on the downstream side, the discharge thorugh the flood gates will vary from a maximum at low tide to a minimum at high tide. The reservoir above the barrier, therefore, will function as a basin in which the river discharge in excess of the flow through the flood gates at high tide is stored to be discharged at a rate in excess of the river discharge during low tide.

The flood gates are of the Stoney roller type with sills depressed to 50 or 70 feet below sea level in order better to control the salinity of the water behind the barrier as explained in Chapter IX. In operation, the gates woud be raised clear of the water surface as required to allow free passage of the floods. As the flood receded the gates would be lowered, one at a time, as necessary to maintain the water surface above the barrier at any predetermined elevation.

The requirements for passing vessels through the barrier is an important consideration irrespective of where it might be located, but particularly, if located below Mare Island Navy Yard. In the designs proposed, ship locks have been provided in number to care for considerable growth in water borne commerce and in size to pass the largest ships likely to navigate the waters above the barrier.

In some of the design for the Army Point site, the ship locks would be constructed away from the flood gates, which, of course, would be advantageous for shipping during the passage of great floods from the rivers but these are rare and considerable study would be required before it could be determined whether the advantage thus gained would offset the advantage of having the large salt water sump adjacent to the ship locks where the salt water entering the fresh water reservoir through the locks could be caught and returned to the salt water side. It is possible that the design with the ship locks and flood gates separated would be even more efficient in controlling salinity, but this is doubtful. The plan at the Army Point site in which the structures are separated interferes least with the plant of the Mountain Copper Company and results in economy otherwise.

In the designs including a railroad and highway bridge across the locks these have been placed at an elevation to permit a large portion of vessels using the locks to pass underneath without opening or lifting the bridges. In one design at the Dillon Point site, the clearance is made sufficient to pass large ships without the necessity of moving bridges. Adequate clearance will be more important 25 years hence than at present on account of the increase to be expected in commerce.

A fish ladder is provided in one of the ship lock walls and provision is made for relieving salinity above the barrier by pumping salt water from that side in an emergency. The design of the structure is discussed in Chapter IV.

Estimated Cost.

Following is a table showing the estimated cost of the barrier at each of the sites investigated. It should be noted, particularly, that the estimates for the Benicia site are based upon assumed foundation conditions since the site was not developed by drilling as were the other three sites. No attempt will be made to analyze the costs as such an analysis would be quite involved and of no particular value. Conclusions as to the desirable plan can be arrived at best by balancing the estimated costs against the features of the design as shown on the general plans referred to in the table, and to other drawings contained in Volume II. Estimate No. 13 is unique in that Carquinez Strait, for its full width, is taken advantage of in providing an extra large flood gate area, and the railroad and highway bridges are placed at the elevation required to avoid the necessity of lifting bridges to allow the passage of vessels.

SALT WATER BARRIER—SUMMARY OF PRELIMINARY ESTIMATES

Totals only

(Refer to Table of Contents, Page 12, Section III, for reference to detailed description of each structure estimated.)

Estimate No.	*Plate No.*	*Location*	*Estimated total cost*
1	4- 1	Army Point-Suisun Point	$58,500,000
2	4-14	Army Point-Suisun Point	55,900,000
3	4-18	Army Point-Suisun Point	54,100,000
4	4-20	Army Point-Suisun Point	49,800,000
5	4-22	Army Point-Suisun Point	46,300,000
6	4-25	Army Point-Martinez	77,300,000
7	4-27	Benicia	*46,200,000
8	4-31	Benicia	*40,200,000
9	4-33	Dillon Point	97,100,000
10	4-35	Dillon Point	38,900,000
11	4-37	Dillon Point	50,400,000
11-A	4-37	Dillon Point	44,700,000
12	4-37	Dillon Point	50,600,000
12-A	4-37	Dillon Point	44,900,000
13	4-47	Dillon Point	53,300,000
13-A	4-47	Dillon Point	47,600,000
14	4-51	Point San Pablo	75,200,000
15	4-55	Point San Pablo	66,000,000
16	4-57	Point San Pablo	82,100,000

The preliminary estimates are believed to be conservative. Refinements in the final designs will probably result in reduction of quantities. All construction materials are readily available in large quantities and can be brought to any of the sites investigated by rail or water. Large manufacturing plants, foundries and machine shops are located nearby, all tending toward low unit costs. The estimates of cost are based upon present prices of material and labor. Should these change materially it will, of course, be necessary to make adjustments in the estimates.

Tides and Floods.

The most critical condition to be met is a combination of a large flood from the rivers, a storm on the ocean tending to pile up the water driven through the Golden Gate in the bays, and an unusually high tide. An analysis of past floods leads to the conclusion that provision should be made for the passage through the barrier of not less than 750,000 second-feet.

According to computations made the effect of a barrier of the type proposed, at the Army Point site would be to raise the water surface immediately above the structure 0.7 of a foot with a discharge of 750,000 second-feet. The effect would be felt less at the mouth of the rivers as a result of the smoothing out of irregularities by the reservoir created. The studies indicate that if a 750,000 second-foot flood from the rivers should coincide with a tide reaching the maximum height recorded at Army Point in 1909, but otherwise similar to the high tides of January 24 and 25, 1914, the elevation of extreme high water (8.5 feet above mean sea level) at Collinsville, as computed in flood plane studies made by the State Department of Public Works (Bulletin dated February 10, 1925) would not be exceeded.

It is probable that the rise in water surface at Collinsville, due to a barrier at the Point San Pablo site with equivalent gate area, would

* Foundations not developed by drilling, estimated cost includes 35 per cent for engineering, administration and contingencies. All other locations developed by drilling, estimated costs include 25 per cent for engineering, administration and contingencies.

be less than if located at the Army Point site, but it would not be safe to reduce the gate area at Point San Pablo for the reason that extreme tides through the Golden Gate are more effective near the gate.

At the Army Point and Dillon Point sites the ship locks are considered effective in passing extremely large floods but they are not considered available at the Point San Pablo site because of the greater necessity for keeping the locks open to navigation at that site, even during great floods.

The effect of a barrier at the Army Point site would be to reduce the tidal volume passing the Golden Gate by less than 8 per cent in comparison with about 35 per cent if it were built at the Point San Pablo site. The occurrence of frequent high tides in the bays due to piling up of water in them as a result of storms on the ocean would be eliminated above the barrier if one should be constructed. The effect on the elevations of tides immediately below the structure would be to raise them slightly according to the United States Coast and Geodetic Survey.

Navigation and Bridge Traffic.

Any plan for the control of salinity involving the construction of a dam across the bay or river channels must be coordinated with the requirements of navigation.

Ship locks are provided in number and size to meet the requirements of the present and immediate future. Provision for ultimate traffic at the time the barrier is constructed does not seem necessary since anticipated additional flood control on the upper rivers will permit the replacement of flood gates by ship locks as the need for them develops. A summary of the operation as it would have occurred on July 6 and 7, 1925, is shown in Table 6-33.

Although railroad and highway bridges are contemplated in most of the designs they are not regarded as indispensable and are omitted in some in anticipation of indifference on the part of railroad and highway interests toward the opportunities afforded by the barrier. In the studies made it is considered that traffic over them is subject at all times to the convenience of navigation. The bridges are designed to give a vertical clearance of 50 feet above high water when in the lowered position and 135 feet when raised. The interruptions to bridge traffic, as they would have been on July 6 and 7, 1925, are summarized in Table 6-40.

An examination of Plates 2-3 and 2-4, showing depths in San Pablo and Suisun bays, will indicate the limitations placed upon commerce under present tidal conditions. If the elevation of the water surface above the barrier were maintained at about 2½ feet above mean sea level, a constant depth equivalent to that at mean high tide under present conditions, could be obtained. Uncertain and varying tidal currents would be eliminated above the barrier and they would be reduced in velocity below, providing that present conditions of the channels are maintained. The maintenance of a constant water level would not only be convenient for navigators but would be a material benefit to owners of wharf property above the barrier.

The farther upstream the barrier is located the less it will interfere with shipping. Locking requirements can be satisfied with least expense at the Army Point site and conditions are most unfavorable at the Point San Pablo site.

The construction of a barrier at the Point San Pablo site probably would be looked upon with disfavor by the Navy Department for the reason that it would restrict free navigation through San Pablo Bay to the Mare Island Navy Yard by the necessity of passing war vessels through ship locks. This objection does not apply to the Dillon Point, Benicia or Army Point sites.

Storage in the Delta Channels and Bays.

For convenience the calculated storage in the tidal prism above each barrier site, between elevation —3.6 and +6.4 U. S. G. S. Datum (0 and 10, U. S. Engineer Datum), has been summarized in Table 7-2, Part Two of this volume.

Silt.

The problem has been attacked with the idea that any structure which would be detrimental to San Francisco harbor would be looked upon with disfavor by those in jurisdiction. Whether the scouring action of the tidal currents tends to maintain or destroy fixed channels in the bay system, and what will be the effect of a barrier upon silting, remain to be determined. Conclusions must, therefore, take the form of conjecture until studies more comprehensive than were possible in this investigation have been completed.

Salinity.

In years of normal river discharge there is no salinity problem in the delta. It is menacing for a few days in the fall only but, considering the marshes surrounding the upper bays and the towns and industrial plants along their shores, the encroachment of salt water presents a serious problem almost every year.

Conflict between irrigation interests in the upper valleys and in the delta region never will occur in years of large run-off for the reason that in the development of storage the construction of expensive reservoirs to hold the excessive run-off will not be practicable even though sufficient reservoir sites in which to store all of the run-off were available.

The introduction of salt water into the fresh water lake through the ship locks can not be prevented but means are provided for drawing off this salt water and thereby controlling the salinity of the water upstream from the barrier.

Leakage of salt water past the flood gates, although comparatively small in amount, can be prevented by maintaining the water surface above the barrier at a sufficiently higher elevation than below.

Deep gates, opening from the bottom, are essential to the successful operation of the barrier for dependence is placed upon them as a means of drawing off the heavier salt water which seeks the deep holes and channels, and for flushing out the reservoir above the barrier.

Unless fresh water is available for occasional flushing, the reservoir above the barrier will gradually become salty. Flushing can be accomplished quite readily if water be available for that purpose. The studies of water supply, although based on meager data, indicate that, on the average, there will be from eleven to twelve million acre-feet available for that purpose annually. In years of deficient water supply, there will be little, if any, fresh water available for flushing and the reservoir above the barrier may have to hold over one or more years without flushing.

Return Flow.

Return flow will increase with irrigation development in the upper valleys with the result that the salt menace in the Delta will be alleviated; but, even though the return flow should increase to the 3500 second-feet estimated to be sufficient to act as a natural barrier against encroachments of salt water, the demand for water will be such that it could not be used for that purpose unless it is replaced by water from mountain storage.

Control of Salinity by Storage in Mountain Reservoirs.

Salinity in the delta can be controlled through construction of storage reservoirs in the mountains from which water could be released during the season of low river discharge in the amount necessary to act as a natural barrier against invasions of salt water. Mountain storage would be a temporary expedient for the reason that, ultimately, there will be use for all of the available flow from the rivers, and the discharge into Suisun Bay and thence to the ocean, of water sufficient to act as a natural barrier against salt, would be an economic waste. However, storage created in mountain reservoirs constructed mainly for other purposes might advantageously be used for some time to control the salinity in the upper bays and delta channels during development of the requirement for full use of the reservoirs for the purpose for which they were primarily constructed, thus deferring the large investment in the Salt Water Barrier.

Teredo.

The factor of salinity is one of fundamental importance in the distribution of teredo. The average lethal salinity for teredo navalis, the species to be feared most in the upper bays, has been determined experimentally as 5 parts per 1000; therefore, if the water above the barrier is maintained at a concentration below the limit for irrigation use, teredo can not exist there.

Fish.

Fishing industries above the barrier, if constructed, should not suffer for the reason that, even though the fish ladder which is an integral part of the structure, should fail to function, the fish would not be prevented from entering the fresh water reservoir because they would have free access to it through the ship locks which, under normal conditions, would be operated many times throughout each day and night.

Sewage.

No investigation was made of the effect of the barrier upon sewage, but from investigations made elsewhere it appears that fresh water will be better adapted for receiving sewage than either salt or brackish water since, gallon for gallon, fresh water disposes in a normal manner of more sewage than salt water. It will be best, in this respect, to keep the water above the barrier fresh because the intermittent admission of salt water interferes with bacterial, animal and vegetable growths that effectively aid in taking care of and digesting sewage.

Use of Water from Barrier Lake.

The seven main sources of loss of fresh water accompanying the operation of the barrier are evaporation from the water surface of the reservoir created; water required for the operation of the ship locks; leakage around the flood gates; water used in operating the fish ladder; and water to supply the requirements of industries, municipalities and irrigation. With the exception of losses past the flood gates and through the fish ladder, which are constant for the same type of structure, the losses increase as the barrier is moved downstream and this factor has an important bearing upon the selection of a site.

Owing to the increasing difficulty of maintaining the reservoir created by the barrier free from salt water as the water surface is permitted to fall, and because of navigation requirements, it probably will not be advisable to allow the water surface to fall below mean sea level. Likewise, because of the nature of the delta levees and the cost of drainage in that region by pumping, the ultimate maximum allowable water surface, for periods of several months duration, may be assumed at 4.0 feet above mean sea level, although later developments may show that this maximum storage level can be increased to 5.0 feet.

It is not necessary to decide at this time at what elevation the water surface above the barrier should be maintained. To begin with, it should be held at, or a little below ordinary high tide level. As time goes on the elevation may be raised as experience dictates.

It would be desirable to replace water drawn from the fresh water lake for irrigation, domestic and industrial uses, as well as that required in the operation of the ship locks, with water from river flow or mountain storage for the purpose of maintaining a constant depth of water for the navigable waterways effected by construction of the barrier. In years of extreme low run-off the water surface could be drawn down to the elevation of mean sea level, or possibly, in an emergency, to the elevation of mean lower low water.

As the water surface behind the barrier is lowered, the cost of maintaining the delta levees, not considering floods, should become less; the cost of pumping water out of the lake for any use become greater; the cost of pumping seepage water would become less; the difficulties of keeping the lake fresh would increase; and the depth of navigable channels effected would become less.

Ship locks are provided in various sizes in order to economize on the use of fresh water and to prevent entrance into the fresh water lake of larger volumes of salt water than necessary by requiring vessels to use the smallest lock which will accommodate them. Intermediate lock gates are added for the same reason.

Economy in the use of fresh water in the operation of the ship locks can be effected through the adoption of lock gates divided horizontally at a depth to allow a large portion of the vessels having a shallow draft to pass through the locks without opening the lower half of the gates and it is assumed that this type of construction will be adopted. It is estimated that the resulting annual saving of fresh water, based on an average daily traffic as it was on July 6 and 7, 1925, would be

Army Point site	173,000 acre-feet
Dillon Point site	146,000 acre-feet
Point San Pablo site	295,000 acre-feet

it being assumed that the water surface above the barrier would be maintained at an elevation 2½ feet above mean sea level.

It will be necessary to flush the reservoir, preferably once each year, to rid it of accumulations of brackish water resulting, principally, through the inability to trap all of the salt water finding its way into the fresh water reservoir from one source or another. The amount of fresh water required can not be predicted with any degree of accuracy but a study was made of the amount of fresh water available for the operation of the barrier, based upon the assumption that storage in the mountains was well developed. The study is based upon meager data but the results are believed to be indicative.

From Table 10-13, it is evident that if the maximum height of water surface in the reservoir is restricted to 2½ feet above mean sea level, the water stored in the reservoir thus formed will not be sufficient to operate the barrier at any of the three sites studied during the irrigation season, even in years of heavy run-off, and it will be desirable, therefore, to seek the highest practicable elevation at which to maintain the storage level.

The shortage due to lack of reservoir capacity increases as the barrier is moved downstream, although the capacity of the reservoir is greater. This is principally due to the greater evaporation, and to the larger requirements of navigation, industries and municipalities.

As the storage elevation above the barrier is raised the amount of water available for flushing in years of low run-off is decreased. According to Table 10-13, no water would be available in the season 1923-24 for flushing out the reservoir created through construction of a barrier at the Point San Pablo site whether water were impounded to elevation +2.5, +4.0 or +5.0. It appears that, in any case, there would be no flushing water available in 1923-24 if water were stored to elevation +5.0, although in a normal year there would be a large amount available for flushing, regardless of where the barrier is constructed or of the elevation at which the water surface above the barrier is maintained.

If the above analysis is correct, it may be concluded that since one of the principal objects of the Salt Water Barrier is to conserve fresh water, it will be desirable to maintain the largest practicable storage capacity above the structure. Likewise, it is evident that the farther downstream the location for the barrier is chosen, the greater will be the quantity of water required for operation, and the greater will be the shortages during seasons of low run-off. Since the shortage must be supplied from mountain storage in order to maintain sufficient depth for navigation, and to hold the water level at an elevation where the reservoir will not be deluged with salt water whenever the ship locks are opened, it is apparent that consideration of the necessity for conservation of water would require the selection of one of the upstream sites, Army Point, Dillon Point or Benicia, if the latter, upon investigation, is found to be suitable structurally.

Advantages.

Stated briefly, the advantages to be gained through construction of the Salt Water Barrier are as follows:

(1) It would protect the delta against incursions of salt water, make possible the diversion of fresh water for irrigation, industrial and other uses as far down the bay as the chosen site of the structure, and conserve a large portion of the fresh water that would otherwise be required to act as a natural barrier against invasions of salt water. Its construction will aid in the physical solution of the serious problem resulting from the conflicting interests of the delta and upper valleys.

(2) It would make possible the reclamation of the salt marshes above the barrier now unfit for agricultural purposes.

(3) It would protect the upper bays and delta region against the piling up of high tides by storms on the ocean.

(4) It will be necessary for the practicable transfer of Sacramento River water to the San Joaquin Valley through the river and delta channels without danger of contamination by salt water unless sufficient mountain storage is created and released to act as a natural barrier.

(5) It would solve the teredo problem in the area above the barrier

(6) Until the time when sewage treatment is enforced, the sewage problem in the area above the barrier would be simplified.

(7) As a result of the maintenance of a higher average water level above the barrier, the cost of pumping irrigation water from the lake created thereby, will be reduced, and some areas now served by pumping can be reached by gravity.

(8) Navigation conditions above the barrier will be improved because of the maintenance of a higher average water level and greater minimum depth of water except in extreme emergencies and because of greater safety due to the elimination of tidal currents.

(9) Navigation conditions for some distance below the barrier will be improved because of the general reduction in current velocities, providing existing channels are maintained in their present size and condition.

(10) The bottoms of ships allowed to remain in the fresh water lake above the barrier would, in a short time, be cleaned of marine growths. Experience at the Lake Washington ship canal shows that boats entering the fresh water lake only two or three times a week, if for only a few hours each trip, are kept free from all sea growth.

(11) It can be made to carry railroad and highway traffic across the bay.

(12) If constructed at one of the upper sites, the operation of Southern Pacific ferry between Benicia and Port Costa could be eliminated. While trains would be delayed occasionally on account of the bridge over the ship locks being raised, the traffic studies made show that such delays for a bridge having a 50-foot clearance would not be serious, and these could be avoided by adopting a high level bridge such as presented for the Dillon Point site.

Disadvantages.

(1) Construction of a barrier would necessitate the use of ship locks and would, therefore, be an inconvenience to navigation.

(2) The studies made show that the effect of a barrier located at any one of the sites considered would be to raise the flood plane at Collinsville not to exceed 0.55 feet.

(3) Some levees would have to be strengthened or reconstructed, and on account of the character of the foundation for levees in some instances, it may become necessary to abandon certain reclaimed areas.

(4) As a result of the maintenance of a higher average water level above the barrier, the cost of pumping drainage water from some of the delta islands will be increased.

CHAPTER II

GENERAL CONSIDERATIONS

General Plan for Controlling Salinity.

Obviously any effort made toward the elimination of salinity in the delta region must be directed either toward increasing the discharge of the rivers during critical periods through release of winter water stored in mountain reservoirs to act as a natural barrier, or toward excluding the tidal currents from the region through construction of an artificial, positive barrier. Objections to the first plan have been raised on the ground that no fresh water should be sacrificed in the manner proposed for the reason that ultimately, every drop of water in the rivers in normal years will be required in irrigation or for other efficient use. The contracts under which the investigation was made provide for study of the latter plan only. In the following paragraphs an effort is made to present the problem and to discuss some of the factors controlling the design and feasibility of the structure proposed.

Precedent.

The idea of a Salt Water Barrier is not a new one. Work is now under way on a dike from the north Holland coast to the small island of Wierengen and thence to Piaam on the opposite Friesian shore which, when completed, will have the effect of transforming Zuyder Zee into an agricultural area and a fresh water lake in place of a shallow, briny arm of the North Sea. The first design is said to have been prepared in 1849.

The lower Mississippi and many navigable waters of southern Louisiana are used as a source of water for irrigation of the rice fields which are quite extensive through that part of the country. The United States Engineer Department built a lock to exclude salt water from Schooner Bayou and from the canal leading from Vermilion Bay to White Lake, and has also built a lock in the Sabine-Neches ship canal to keep salt water from injuring the rice fields. Although now destroyed, dams on the Trinity River in Texas are said to have functioned to protect the rice fields against encroachments of salt water.

Probably the project in this country most comparable to that herein considered is the Charles River basin at Boston, Mass., where a body of fresh water is maintained through the construction of a dam across the Charles River, equipped with gates to pass the discharge from the river and with locks for the passage of vessels. The dam has been successfully operated since 1908.

In 1916 the Lake Washington ship locks were completed at Seattle, Washington, making Lake Union and Lake Washington accessible from Puget Sound. Here there is an unusual opportunity to study the result of an attempt to separate salt and fresh water by a dam through which it is necssary to pass large vessels by the use of ship locks.

Previous Investigations.

It is reported that construction of a dam below the confluence of the Sacramento and San Joaquin rivers to prevent encroachments of salt water into the delta region, was proposed in the early sixties. It was again considered in 1879-80 during the administration of State Engineer Wm. Hammond Hall. The Southern Pacific Company has considered its feasibility and has made preliminary studies of structures at several points in Carquinez Strait to replace the ferries which are now used to carry their trains across the strait. A recent study of the problem was made by Captain C. S. Jarvis, Corps of Engineers, U. S. A. The results of his study and the discussion thereof are reported in Transactions, American Society of Civil Engineers, Volume LXXXIV (1921), under the heading "Control of Flood and Tidal Flow in the Sacramento and San Joaquin Rivers, California." In connection with the water resource investigation made by the State Department of Public Works, Mr. A. Kempkey, consulting engineer, made tentative designs and estimates of various types of barrier for construction at the westerly end of Suisun Bay or in Carquinez Strait. The studies are reported by Mr. Kempkey on pages 154-158, Proceedings of the Sacramento-San Joaquin River Problems Conference for 1923.

The Great Central Valley of California.

By reference to Plate 1-1 it will be seen that in the central part of California a very large valley, somewhat elliptical in shape, is formed by the merging of the Sierra Nevada and the Coast Range. The water shed is about 540 miles in length, has a width of from 120 to 150 miles and a drainage area of approximately 58,000 square miles, with a single outlet to the ocean through the Coast Range. It is drained from the north by the Sacramento River, heading in the region of Mounta Shasta, which reaches an elevation of 14,380 feet, and from the south by the San Joaquin which has its source in the vicinity of Mount Lyell, at an elevation of about 13,000 feet. The two rivers discharge into the easterly end of Suisun Bay, from either side of Sherman Island, through a common mouth in the vicinity of Collinsville and Antioch and find an outlet to the Pacific by way of Suisun Bay, Carquinez Strait, San Pablo Bay, San Francisco Bay and, finally through the Golden Gate.

The portion of the valley of greatest interest is the comparatively flat area between the foothills of the surrounding mountains. This portion is about 450 miles in length, about 50 miles in average width and contains approximately 14 million acres of arable land, about three-fifths of the agricultural area of the entire state. That portion north of the Cosumnes River is generally known as the Sacramento Valley, while that to the south is spoken of as the San Joaquin Valley. The Cosumnes, however, is selected as a boundary for convenience only for in reality there is no definite dividing line. The Sacramento Valley comprises a drainage area of about 26,000 square miles while the watershed tributary to the San Joaquin contains approximately 32,000 square miles.

In past ages the entire valley was undoubtedly an arm of the sea. The bottom has been built up gradually with material washed down from the mountains until at preesnt only San Francisco Bay remains with its appendages, San Pablo and Suisun bays. The erosion of the higher areas is still under way as evidenced by the shoaling of the upper bays.

Precipitation.

In the drainage basin of the Great Central Valley the year is divided into two well-defined seasons, wet and dry (winter and summer). Approximately 75 per cent of the average annual precipitation occurs in the months November to March, inclusive. In the Sierra, the greater part of the precipitation is in the form of snow.

The precipitation increases from south to north, ranging in average amount from about 15 inches on Tehachapi Pass to 90 inches at Inskip, near Mount Lassen. On the floor of the valley the range is from about 5 inches at the southerly end to approximately 25 inches at Red Bluff.

In the delta region the average precipitation is from 10 to 15 inches; on Suisun Bay from 12 to 15 inches and on San Pablo Bay from 15 to 20 inches; increasing in a westerly direction.

Run-off.

As given in State Bulletin No. 4, the mean annual run-off from the Sacramento drainage area is about 25,200,000 acre-feet and that from the San Joaquin about 12,300,000 acre-feet. In general terms the annual run-off from the drainage area of the Great Central Valley varies from about one-third to 3 times the normal. The largest run-off in recent years occurred in the season 1889-90 while the lowest year of record is 1924.

The rainfall in the Sacramento Valley is greater than in the San Joaquin Valley and, although the drainage area of the latter is 25 per cent greater than that of the former, the run-off is only 50 per cent as much. The bulk of the water from the San Joaquin is discharged later in the season, thus sustaining the discharge into Suisun Bay necessary to keep back the salt water.

Since the Sacramento furnishes much the larger part of the water available for use in the Great Central Valley, the attention of delta waters users is naturally directed to it. On the average, 75 per cent of the run-off from the Sacramento drainage area occurs during the months December to May, inclusive. Without storage reservoirs in the upper valley the bulk of this water runs to waste into the ocean. The discharge decreases gradually until June or early July when the last snow disappears from the higher mountains. In years of low precipitation the run-off during the summer and fall months is not sufficient to supply the demands of irrigation in the upper valley and therein lies the difficulty, particularly with respect to the delta region.

The Bays.

Inspection of Plate 2-1 will show that the San Francisco Bay System is made up of three irregularly shaped bays, San Francisco Bay (northern portion shown on Plate 2-2, San Pablo Bay (Plate 2-3) and Suisun Bay (Plate 2-4). San Pablo and Suisun bays are connected by a deep, narrow channel named Carquinez Strait. At the easterly end of Suisun Bay, about 50 miles by water from the city of San

Francisco, the Sacramento and San Joaquin discharge the run-off from the Great Central Valley into the bay through their common mouth at Collinsville. Above the junction both rivers meander in a network of channels through an extensive delta region of islands, sloughs and marshes with its apex toward the bay, contrary to the usual formation.

The total water surface area of the bays and delta chnnnels at mean high tide, including the larger sloughs, is about 541 square miles made up of 297 square miles in San Francisco Bay proper; 125 in San Pablo Bay; 8 in Carquinez Strait; 50 in Suisun Bay and 61 in the lower river and delta channels.

Suisun Bay is of particular interest in this report. A study of Plate 2-4 shows it to be a shallow body of water with meandering channels and many tidal flats, almost entirely surrounded by salt marshes. The whole appears to be a delta in the making, with the water sufrace area becoming less as the tidal flats, through the silting process, are gradually raised to become marsh land. The typical unreclaimed marsh is a plain, covered principally by the tule and cat-tail rush, and traversed by systems of sloughs. At low stages of tide the marsh is uncovered, except for water in the sloughs which communicate with the bay. As the tide oscillates in the bay, water flows in and out of the sloughs. The higher tides cause the water to leave the sloughs and flood the marshes. With each turn of the tide the water in the bay flows back and forth through the dividing and reuniting channels, over shoals and into the marsh sloughs. The bay and its surrounding marshes, therefore, are in effect a basin in which the salt water from the ocean and the fresh water from the rivers are efficiently mixed. The agitation of the shallow water by winds and by the propellers of numerous vessels assist in the mixing..

Golden Gate and the Bar.

There are about 62,000 square miles of drainage area tributary to the Golden Gate, the only connection between the bay system and the ocean. Of this area 58,000 square miles are embraced in the drainage area of the Great Central Valley; 557 square miles are in the watersheds of streams entering Suisun Bay; 964 square miles are tributary to San Pablo Bay; and 2014 square miles are tributary to San Francisco Bay proper. The balance consists of the 480 square miles of water surface in the bays, at mean high tide, below Collinsville.

The run-off from the above drainage area, combined with the tremendous tidal flow, has served to cut and maintain the outlet to the ocean through the Coast Range to a minimum width of a mile and to a maximum depth of over 300 feet. There is one sounding showing 382 feet of water. Toward the ocean the depth gradually becomes less as the sand, under the combating forces of nature, is spread out on the floor of the ocean in a broad, fan-shaped, submerged delta, as it were, terminating in a crescent-shaped sand bar lying about five miles beyond the headlands forming the entrance to the Golden Gate. The bar is shown on the General Chart, Plate 2-2. It is in an unstable state, held in equilibrium by the action of the ocean waves on the outer side and by the tidal currents on the inner slope.

The sand of the bar is believed to be derived from three sources: from the erosion of the cliffs along the ocean, from the erosion of the cliffs along Golden Gate and the bays, and from streams tributary to the bays. Mr. Grove K. Gilbert, in his report upon "Hydraulic-Mining Debris in the Sierra Nevada," U. S. G. S. Professional Paper 105, concludes that the principal sources of sand are the ocean cliffs and the cliffs bordering the Golden Gate. He says, on page 91 of his report:

> Finally, a portion may have come from Sacramento and San Joaquin Rivers. The body of sand delivered to Suisun Bay by the rivers has been great, and the present annual contribution is evidently large, but there is room for doubt as to the delivery of river sand on the bar.

It is believed that more recent investigations made by the Army engineers have not led to a different conclusion.

The bar is entirely submerged, the depth of water on its crest being generally from 33 to 36 feet except at the northerly end where the minimum depth is about 23 feet, and at a point directly in line with the Golden Gate where there is a depression having a minimum depth of 37 feet. The length of the bar is approximately 13 miles as measured along its crest and is continuous except for a channel along the shore at each end. Most ships entering San Francisco Harbor cross the bar in its central portion, although the north channel is used quite extensively by coastwise vessels. During heavy storms it is dangerous for large ships to cross the bar as they are apt to strike bottom when in the trough of the waves.

The size and position of the bar is said to be affected by the supply of sand of which it is formed and by the force of the tidal currents across it, which in turn depend upon the volume of the tidal prism of the bays inside the Golden Gate. It is argued that a reduction in the volume of the tidal prism results in less velocity of the tidal currents through Golden Gate and across the bar; reduction of tidal velocities causes the crest of the bar to move landward; the retreat results in a shortening of the bar; which, in turn, tends to restore the velocity.

On page 70 of Mr. Gilbert's report, it is stated:

> Any modification of natural conditions which has the effect of increasing the supply of sand will cause the bar to grow and will bring its crest nearer the surface.

He further states:

> But for the tidal currents the bar would extend in a direct line from Point Lobos to Point Bonita, and its crest, a continuation of Ocean Beach, would be above the level of high tide. Its great distance from the shore and its deep submergence are due entirely to the speed and volume of the ebb tides. Any modification of the bays which has the effect of reducing the volume of the tides tends to cause the crest of the bar to move landward and to rise nearer to the surface of the water.

Naturally, any proposal to build a dam or barrier at any point in the bays is looked upon by many with considerable apprehension since the depth of water on the crest of Golden Gate bar is of vital importance to the Port of San Francisco. Depending upon the location of the barrier, the tidal currents through the Golden Gate and across the bar might be strengthened, weakened or unaffected, as will be brought out in Chapter V. With regard to the barrier sites for which designs were prepared, the nearer the Golden Gate the barrier is built the greater will be the reduction in the tidal prism and the less will be the velocity through the gate.

Silting of Bays.

Aside from its effect upon the Golden Gate bar much interest attaches to the effect of a Salt Water Barrier upon the future silting of the bays to the detriment of navigation and industrial interests.

Surveys which have been made of the bays at various times indicate that there has been a general shoaling of the entire system through the deposition of material carried to the bays by the rivers. The principal source of the deposits is attributed to the debris from hydraulic mining, augmented by soil washed into the rivers, the latter increasing in volume with agricultural and industrial development in the Great Central Valley. It has been estimated that since gold was discovered in California, there has been a total of 1,146,000,000 cubic yards of material deposited in the San Francisco Bay System. The rate of deposition increased very rapidly until 1884 when it was suddenly checked through restrictions that were placed upon hydraulic mining in California. Since that time the rate of deposition has decreased to the point where it is again somewhere near normal.

Mr. Gilbert estimates that between 1849 and 1914, inclusive, material was deposited in the bays as follows:

Suisun Bay	200,000,000 cubic yards
Carquinez Strait	50,000 000 cubic yards
San Pablo Bay	570,000,000 cubic yards
San Francisco Bay	326,000,000 cubic yards

He also estimates that the average deposition on the shoals during the 41-year period studied was:

In Suisun Bay	3.3 feet
In San Pablo Bay	2.5 feet
In San Francisco Bay	0.7 feet

The shoaling has been accompanied by a reduction in the water surface area of the bays, for the salt marshes, as they have been elevated by the deposition of the silt carried by the overflowing higher tides, have steadily encroached upon the open water. The effect has been to reduce the tidal prism of the bays to the extent of 2 or 3 per cent. This reduction, combined with encroachments on the tidal prism through the reclamation of marsh areas, has resulted in an estimated reduction in the tidal prism tributary to the Golden Gate of about 4 per cent, and about 10 per cent reduction in the tidal prism unstream from Pinole shoal in San Pablo Bay. See Plate 2-3.

The sand and gravel from the mountains is reduced by attrition in the journey down the rivers to the degree that nothing but sand and mud reach Suisun Bay. Nothing coarser than fine sand gets beyond Pinole shoal. Material reaching the ocean is carried there in suspension.

On page 35 of Mr. Gilbert's report it is stated that:

> The material deposited on the shoals is fine mud that is brought by the rivers in suspension. Deposition is determined in part by the slackening of currents as the muddy water enters a bay and in part by flocculation as it is mingled with salt water. Deposition from slackening would be much heavier in the first settling reservoir than in the second, but deposition from flocculation would begin wherever the salt water was met. At low stages of the rivers the principal meeting occurs in Suisun Bay, but at low stages there is little mud in suspension. In times of great flood, when the largest load of mud is brought down, the river current dominates over tidal currents in Suisun Bay, and the principal meeting with brine takes place in the larger water body (San Pablo Bay) beyond Carquinez Strait.

The direction of the current through the bays is reversed four times each day as a result of tidal movements. The characteristics of the tides in San Francisco Bay are such that the ebb currents have the greater strength and as a result the net movement of the material carried in suspension, and rolled along the bottom is toward the ocean. It is generally believed that the tidal currents, alternating back and forth through the bays, maintain the various channels. The tidal currents are reinforced by the discharge from the rivers which, of course, has a net movement toward the ocean.

If a salt water barrier were built at any of the sites studied in this report the tidal prism tributary to thę Golden Gate would be reduced materially and, as a result, many changes would be introduced. Tidal currents above the barrier would be eliminated, while those for some distance below would be reduced providing the channels are maintained in their present condition. Silting would not occur under changed conditions of tidal currents but under different conditions of salinity. In effect, the mouth of the rivers would be transferred to the flood gates through the barrier, and, theoretically, deposition of colloidal silt by flocculation would occur farther downstream.

Although the rate of silting in the bays has diminished to almost normal it is estimated that shoaling, even under present conditions, will continue, as, according to the most reliable estimates, there are still about 400,000,000 cubic yards of mining debris in the moutains and river beds which, within the next 50 years, will find its way to the bays. It is estimated that in addition there will be 400,000,000 cubic yards of soil waste brought down, resulting in a total of 800,000,000 cubic yards of material, practically all of which will be deposited on the shoals of the bays in the form of mud.

Maintenance of navigable channels across the shoals is already a matter of considerable expense and it is natural to speculate as to the result of building a barrier across the bay. Although comparatively little has been done toward the study of the silt problem, an effort has been made to analyze available data. A discussion of the silt problem is contained in Chapter VIII.

The Delta.

Along the lower course of the two rivers a delta containing approximately one-half million acres has been formed, extending up the Sacramento River from Suisun Bay nearly to the city of Sacramento, and up the San Joaquin to a point 20 miles south of Stockton. In the delta there is an aggregate length of navigable channels amounting to about 550 miles. Some of them obtain depths of 50 to 60 feet. The mode of travel is by water rather than by road. Most families have their own speed boat; others patronize the ferries which take the place of the commonly known highway bus. A map of the delta region is included as Plate 2-5.

Before the levees were constructed the character of the area was that of a permanent tule marsh of boggy peat, impregnated with silt, over which the water surface oscillated regularly with the tides in Suisun Bay. The river channels divide into numerous winding waterways, giving to portions of the marsh lands the character of islands from a few hundred to several thousand acres in extent. Some of the channels connect the two rivers so that much of the delta, in its original state, was inundated by a flood from either river.

In the report upon the San Joaquin River and Stockton Channel, House Document No. 554, 68th Congress, 2d session, it is stated that, in its natural condition, the land of the delta region was a peat formation ranging in depth from 10 to 60 feet, underlaid by a substratum of hardpan, the peat apparently having formed at about the same rate as the subsidence of the general land level, while the river beds and banks have been built up by deposits of sand and clay, or loam, carried down from higher ground. Before the extensive construction of levees the overflow of the rivers in flood stage built up their banks with the deposit of the lighter materials carried in suspension. Consequently the rims of the islands are of firmer soil and are higher than the interior. It is said that the interior elevation of some of the islands is from 6 to 7 feet below mean low tide. Originally the ground was not so low but under cultivation the soil settles, due to the rotting and compacting of the peat. Upon first cultivation the settlement on raw land is said to be as much as 18 inches.

Delta Levees.

The exceptional fertility of the delta lands was a great attraction to the early settlers. Attempts to reclaim some of the islands were made as early as 1852. The levees at that time were small, two to four feet high, and were built to shut out high tides. Though small, and of little weight, difficulty was experienced in their maintenance, and during the flood of 1861-62, they were overtopped with disastrous results.

In the later development of agriculture, much more substantial levees were built. The levee system has now been extended to either fully or partly protect every island in the delta against floods from the rivers as well as from extreme high tides. After expending millions of dollars in construction, the system is now practically complete except for strengthening to secure greater safety.

The levees were not built without difficulty, particularly in the San Joaquin area where the top layer of peat is underlaid in turn by fine sand, blue clay, and, finally, by a very fine, soupy sand which, under load, acts much like quick sand. Under the weight of the constructed bank the ground under it, and for a short distance each side, settles, the theory being that the soupy material, not being stable enough to support the load, moves out laterally until stability is established. As a result of the settlement the ground immediately back of the levee is lower than the general elevation of the island and the water collecting there tends to aggravate conditions by softening the spongy peat foundations.

The levees are maintained only through constant vigilance. In many instances they are built of peat. Chunks containing as much as 5 or 6 cubic yards have been known to slough off and float away, demonstrating the low specific gravity of the material. In June, 1924, the writer observed the behavoir of a levee on Venice Island, located in the lower portion of the San Joaquin area, where a bank built principally of peat rested on the same material. The levee was cracked along its crest in several places over about one half mile of its length.

In places the whole levee had settled; at others the front half was apparently tipping toward the channel; at others the back half was tipping landward; and at still other places the front portion appeared to be sliding into the river. On the whole it presented to the writer's mind a precarious condition although those in charge did not appear to be alarmed, supposedly on account of their many similar experiences.

In the past, an attempt has been made in the lower delta to maintain a 4-foot freeboard above the high water marks of 1907, but this practically has been given up and in many cases it is not more than 3 feet. Mr. Geo. A. Atherton, General Manager, California Delta Farms, Inc., has said that in his opinion 13.3 U. S. Engineer Datum (9.7 feet above mean sea level) would be a reasonable elevation at which the levees could be maintained permanently. This is 3 feet above the high water mark of 1907 as recorded at the junction of the San Joaquin and Old rivers, near Bouldin Island.

The elevation at which the Salt Water Barrier would hold the water permanently against the levees is a question of much concern to those living in, or having investments in the delta region. The suggestion has been made that the elevation of the water surface above the barrier be raised to increase the depth of navigable channels materially, to provide storage of fresh water for use by municipalities and industries, and for the irrigation of the bordering marshes and nearby higher valleys. Although the adoption of such a plan would result beneficially to many interests, the plan is believed to be impracticable and not possible of accomplishment without hazard to the delta region which it is proposed shall share in the benefits to be derived through construction of the barrier.

It is the belief of some most familiar with the situation that it will not be practicable to hold the water surface permanently against the delta levees at an elevation exceeding 6 feet, U. S. Engineer Datum, or about $2\frac{1}{2}$ feet above mean sea level, which, under present conditions, is about the elevation reached by the ordinary high tides during the non-flood period. Although some of the islands are below sea level the cost of pumping to prevent inundation resulting from seepage under the levees is not prohibitive under present conditions of a fluctuating tide and it is not believed that difficulties would be experienced from excessive seepage unless in the operation of the barrier an attempt were made to raise the water surface, outside, more than is contemplated in this report. Moreover, the capacity of the levees to resist the pressure of water permanently held against them at heights materially above ordinary high tides is questionable, especially in regions where peat predominates.

The height to which it is found practicable to maintain the water surface above the barrier fixes, to a large degree, the amount of water available for the operation of the barrier. This subject is a vital one and is discussed at considerable length in Chapter X.

Irrigation in the Delta.

The principal crops raised are potatoes, onions, beans, barley, corn, asparagus and celery. On the higher lands large quantities of fruit, principally pears, are raised. The asparagus crop is rapidly increasing in importance and may become the most important. Most of the crops are transported to San Francisco, Sacramento and Stockton by boat.

As reported in the Proceedings of the Sacramento River Problems Conference held in Sacremento on January 25 and 26, 1924, Mr. George S. Nickerson estimates that there are 556,000 acres in the delta region which are dependent upon the lower river and delta channels for irrigation water, of which 475,000 acres are in reclamation districts and islands and 81,000 acres in the uplands.

Various methods of obtaining water are employed. On a very large portion of the low lying lands siphons or tidal flood gates are used, the latter usually operated to take water at high tide. Some of the low lands receive their irrigation water by seepage through, or under, the levees. In case of the higher lands water is pumped through low heads, usually not exceeding 7 feet.

In general, the water is applied by the method of subirrigation, supplemented by surface irrigation during the latter part of the growing season. The main ditches are permanent but the distributing ditches which are dug with small trenching machines, are usually plowed under each time the land is plowed. The elevation of the water plane is controlled by pumping back into the channel over the levee. The cost of pumping this water is a consideration in the determination of the elevation at which the water surface should be held in the operation of the barrier.

Salinity in the Delta.

The numerous channels form the reservoir from which water is drawn for the irrigation of the delta. Under normal conditions of run-off from the Great Central Valley the discharge of the two rivers not only replenishes the supply of fresh water, but serves as a natural barrier against the encroachment of salt water from the bays by reason of the continuous discharge into Suisum Bay. During the flood season of a normal year the salt water is forced seaward until Suisun Bay is flushed clear of brackish water, only to become salty again with the falling off in the discharge from the rivers.

With the development of irrigation in the upper valleys the demand for water has increased to the extent that fresh water, sufficient to act as a natural barrier against encroachments of salt water, no longer reaches Suisun Bay during the summer and early fall months of dry years, with the result that the water available for the irrigation of the lower portion of the delta is no longer fresh. The most critical months are July and August. It has been roughly estimated that in 1920 approximately 25 per cent of the delta lands were severely affected by salt. Irrigation was actually discontinued on some of the lands farthest downstream. Not only do crops suffer at such times from lack of water but more permanent damage results through seepage of the salt water through and under the protecting levees. The limit of salinity of water for irrigation use is generally considered as 100 parts of chlorine per 100,000 parts of water. In 1920 it is reported the water in all of the delta channels contained in excess of 20 to 30 parts chlorine per 100,000 (33 to 50 parts of common salt).

Amount of Fresh Water Required to Act as a Natural Barrier Against Salinity in the Delta.

After making a study of salinity conditions, particularly in the dry years 1920 and 1924, the State Water Supervisor in his report for 1924, estimates that under present conditions a combined flow of 3500 second-feet, as measured at Sacramento on the Sacramento River and at Vernalis on the San Joaquin, is necessary to prevent the encroachment or cause the recession of salinity at the common mouth of the rivers. At some of the upper stations the indications are that a considerably greater flow is required to cause the recession of salinity than to prevent encroachment.

In his report for 1925, the State Water Supervisor states, on page 116:

> A study of the relation between the advance and retreat of the salinity and the river discharge as presented by the 1925 observations would seem to indicate that a greater combined discharge at Sacramento and Vernalis for the two rivers would be needed to control the salinity at any definite point than was indicated by the 1924 investigations.

It is believed that, for want of better data, 3500 second-feet may be adopted in studies presented in this report as the amount of water required to serve as a natural barrier against encroachments of salt into the delta region.

In comparison with the 3500 second-feet required, the combined flow of the two rivers in 1924, at the stations referred to, was 1898 second-feet in June; 1329 in July; and 1786 in August. The combined discharge was less than 3500 second-feet for 116 days from May 26th to September 20th. During that period an additional 363,000 acre-feet of water, as measured at Sacramento and Vernalis, would have been required to supplement the combined discharge to an average of 3500 second-feet, and a total of 812,000 acre-feet would have been required to supply the 3500 second-foot average flow throughout the 116 days.

It may be concluded that not only would the Salt Water Barrier serve to protect the delta against encroachments of salt water, but would make possible the conservation of a large amount of fresh water otherwise required to serve as a natural barrier. With the barrier constructed, the amount of fresh water flowing to the ocean during the irrigation season would be reduced to that required in the operation of the barrier. The fresh water leaving the Great Central Valley would be reduced to that required to supply the needs of municipalities and industries; to irrigate the bordering bay marshes and valleys; and to replenish operation losses. The latter would include evaporation, leakage around flood gates and water used in locking vessels past the barrier.

Amount of Fresh Water Available Under Present Conditions to Act as a Natural Barrier Against Salinity in the Delta.

During the irrigation season the bulk of the water passing through the delta channels to Suisun Bay comes from the Sacramento River since the entire low flow of the upper San Joaquin River and its tributaries has been used in irrigation for a number of years. Return flow from the San Joaquin Valley has increased with irrigation development to the extent that the delta is better off at present than for a number of years, in so far as the San Joaquin River is concerned. Therefore, principal interest centers in the discharge of the Sacramento River when considering the problems of the delta region.

The normal low flow of the Sacramento measured at Red Bluff, where the river leaves the canyon section, is about 4500 second-feet. In 1924 the discharge dropped to 2800 second-feet which was further depleted through irrigation diversions until only 705 second-feet passed the city of Sacramento on July 17th, at the time the flow reached the minimum for the season.

The following quotations from a paper read before the Fifth Annual Convention of the California Section of the American Waterworks Association at Sacramento, on October 24, 1924, by Mr. Edward Hyatt, then Chief of Division of Water Rights, State Department of Public Works, are of interest in considering the future of irrigation in the delta.

Speaking of the Sacramento Valley, Mr. Hyatt says:

The division of Water Rights has issued permits for about 4800 second-feet. Unapproved applications are approximately 2000 second-feet more. These figures do not indicate the actual amount of water which will be diverted, since each permit includes some unirrigable land, or some portion of its land must line fallow each year, or perhaps some portion of the right will be forfeited through nonuse. From the records of use of water on these projects at present on file at the Division an estimate is made that the applications and permits now before the office will ultimately be issued licenses or final water rights to about 3600 second-feet. * * *

From records of water pumped, and such other information as is available, it is estimated that about 2000 second-feet should be allowed for the total of other used rights, both appropriative and riparian, on the river, making a total of about 5600 second-feet of actual existing rights by use, or which may be secured under applications now pending.

There are in addition large areas of riparian land along the river which have not as yet used water, and if Section 11 of the Water Commission Act regarding riparian rights is overruled by the courts possibly 2000 second-feet more would be ultimately demanded by these lands, making a total of around 7500 second-feet. Adding up the total claims on the river, without reducing them in accordance with actual use, brings up the total to over 10,000 second-feet.

Summarizing the figures quoted, you will note that there are rights by use to the water of the river to an estimated figure of 5600 second-feet, which is just double the 1924 low flow of 2800 second-feet; therefore, considering only irrigation above Sacramento, it would seem the supply is fully appropriated and that new projects will be forced to store winter waters.

* * * The irrigable area in the floor of the Sacramento Valley is 2,700,000 acres besides the foothill lands, which will some day need water. Considering that by the census there are only about 300,000 acres irrigated at the present time, it is seen that irrigation development will not be stopped by lack of suitable agricultural lands in Sacramento Valley. * * *

* * * The delta landowners claim water rights both by riparian rights and appropriation and also claim the right to have enough water in the river to keep the salinity condition below the danger point, and have stated that for this purpose it is necessary that 3500 second-feet be allowed to pass Sacramento. You will note that this is considerably more water than there was available in the river above diversions during the past summer (1924).

The Antioch Suit.

The outlook for the delta is such as to cause considerable apprehension. The salt menace will increase in succeeding years unless storage of water is provided to supplement the summer flow of the rivers or a Salt Water Barrier is constructed. If diversions for upstream irrigation are permitted to increase under present conditions of flow, the delta water users are faced with a very serious problem. It was the consideration of this prospect that led to a prolonged and expensive law suit in 1920 between the water users in the Upper Sacramento Valley and in the delta region. The suit is referred to as the Antioch case.

Supported by an organization of delta landowners, the town trustees of Antioch applied to the courts for a temporary injunction, asking that a number of appropriators of water from Sacramento River above the city of Sacramento, be enjoined from taking more water from that river than would permit a flow of 3500 second-feet past Sacramento. The superior court of Alameda County granted the temporary injunction but upon appeal to the Supreme Court of California the decision of the lower court was reversed. In the decision of the Supreme Court it was stated:

> Our conclusion is that an appropriator of fresh water from one of these streams at a point near its outlet to the sea, does not by such appropriation, acquire the right to insist the subsequent appropriators above shall leave enough water flowing in the stream to hold the salt water of the incoming tides below his point of diversions.

Pending Suit.

Another large suit has been filed, and is now pending, in which 143 landowners in the delta have brought action against nearly 500 of the principal users of water from the Sacramento and San Joaquin rivers, the contention of the plaintiffs being that they, as riparian owners, are entitled to the fresh water which they have enjoyed for a great many years. It is understood that this later suit is being held in abeyance, awaiting the outcome of the investigation reported upon herein.

Navigation.

Although it may be argued that the interests of irrigation are paramount to those of navigation in Sacramento and San Joaquin valleys, the effect of a Salt Water Barrier upon navigation must be given careful consideration.

The Sacramento and San Joaquin rivers, as well as the bays, are important highways of commerce which have been under improvement by the War Department for many years. San Francisco Bay is accessible to the largest vessels afloat. Ocean going vessels receive and discharge their cargoes at the wharves of the many industrial plants along the shores of San Pablo and Suisun bays and Carquinez Strait. Deep water now extends well into the lower rivers, and under present development the cities of Stockton and Sacramento are accessible via channels 9 and 7 feet deep below mean low water, respectively, regular schedules being maintained by boats plying the rivers and bays between these cities and San Francisco. Surveys have been made of deep waterways to both Sacramento and Stockton and it is probable that construction of a channel providing a minimum depth of 26 feet to the latter will be under way in the near future. Mare Island Navy Yard is located at the easterly end of San Pablo Bay and, obviously, the way to this strategic point must not be blocked, especially in times of stress. It is evident that any plan for the control of the salt water situation must be coordinated with the requirements of navigation.

Conflict in the Use of Water.

Under conditions of unregulated river flow the time has arrived when there is a conflict in the water requirements of the upper valleys, of the delta and for navigation. It appears that the interests of the delta and of navigation are somewhat the same. It is safe to say that, in the final settlement, the irrigators in the upper valleys will not be prevented from diverting their much needed water supply, nor will they be permitted, for long, to divert water in quantities injurious to the delta region. A remedy must be devised and put into operation or permanent injury to the irrigation development of the State is bound to result.

Chances for Betterment of Conditions Without the Barrier.

(a) The maintenance of navigation on the Sacramento River below Sacramento is of vital importance to the commerce of the Great Central Valley and of the San Francisco Bay region. Since it is classed as a navigable stream it is under the control of the United States Government through the Army Engineer's office. In the interest of navigation the government might undertake to prevent the upstream diversion of water with advantage to the delta to the detriment of upstream irrigation.

In House Document No. 123, 69th Congress, first session, the District Engineer, in reporting upon preliminary examination and survey of the Sacramento and San Joaquin rivers with a view to improvement for navigation, recommends that direct diversion from the Sacramento be limited to such as can be made without reducing the flow in the river below Vernon to less than 3500 second-feet. He states on page 35 of the document:

> While the actual needs of navigation will not be fully met by less than 4000 to 5000 second-feet, it seems reasonable, in view of the high value of and great need for water for other purposes, that the United States should assume the increased cost of maintenance that would result from there being a somewhat less amount of water in the river. Under the circumstances it would be fair and equitable for the department to demand for navigation a minimum flow of 3500 second-feet in the river at Sacramento, which is also the minimum estimated as necessary to protect the lands of the delta against the salt-water menace.

(b) As the two valleys are further developed by irrigation the return flow will increase possibly with benefit to the delta, particularly in the late summer months at the itme of maximum salinity.

(c) A material increase in irrigation development in the valleys is not feasible without storage of flood waters. If storage reservoirs are built, as planned, the flood menace in the delta will be partly, if not fully, relieved.

Tides and Floods.

Tidal fluctuations of the ocean are transmitted to the bays through the Golden Gate. As determined at Presidio, the mean range of tides in Golden Gate is 3.93 feet; the great tropic range, 6.23 feet; and the greatest observed range between the highest and lowest water surface is 10.5 feet.

The rivers, in their lower reaches, have very low gradients. In the 61 miles from the city of Sacramento to Suisun Bay, the Sacramento falls at the rate of about .07 foot per mile while on the lower 42½ miles of the San Joaquin, from the mouth of Stockton Channel to Suisun Bay, the fall is at the rate of about .02 foot per mile. It follows that at low stages of river discharge the tidal fluctuations extend up the river: on the Sacramento to the mouth of Feather, and on the San Joaquin to a point a few miles above the Western Pacific Railroad crossing, decreasing in amplitude with increasing distance. Tides are therefore effective at Sacramento and Stockton, as well as throughout the entire delta region, during the irrigation season.

During 1924, when the run-off in the Sacramento River was the lowest of record. the automatic gage at Verona, located at the mouth of Feather River, did not record any tidal fluctuations but it was reported that the tidal influence was felt at the pumping plant of the Central Mutual Water Company, about 4 miles downstream from Verona. The maximum tidal fluctuation at Sacramento in 1924 was 3.4 feet on July 30 in comparison with 2.12 feet as measured on July 7, 1925. On the same date the maximum range at the Mossdale bridge of the Southern Pacific Railroad, just below the Western Pacific Crossing, was 1.42 feet.

There is a reversal of flow in the rivers far above their mouths. On July 16 and 17, 1924, at which time the discharge of the Sacramento River reached the minimum for the season, measurements were made by the State Water Supervisor (Water Supervisor's Report for 1924, Bulletin No. 4, p. 107), at a point about six miles upstream from the Southern Pacific bridge at Sacramento, which show that, at low tide, there was a maximum flow downstream of 1600 c.f.s., with a mean velocity of 0.5 f.p.s., and that at the highest tide on July 17, there was a maximum upstream flow of 1080 c.f.s., with a mean velocity of 0.3 f.p.s. The mean discharge past the station during the tidal cycle of about 25 hours was 750 c.f.s. Meteorological conditions were favorable for tides, as on July 15th the moon was at its maximum southern declination and was full on the 16th. The predicted range at the Presidio was 7.8 feet, near the maximum for the month.

The point of no reversal of flow, as well as that of no tidal fluctuation, moves downstream as the river discharge increases and as the tidal fluctuations in the bays become less. During periods of high river discharge, such as occurred in 1907 and 1909, it is probable that tidal fluctuations do not extend much above Rio Vista on the Sacramento, nor above the entrance to the Stockton Channel on the San Joaquin. In all of the above the term "tidal fluctuation" is descriptive of a perceptible lowering and rising of the water surface resulting from the tidal movements in the ocean.

Of particular interest in the delta is the height to which the tides rise above mean sea level since in time of flood from the rivers the water surface against the levees is further raised by the effect of the tides. In the bays the highest water has not been caused by extreme floods from the rivers but rather through a piling up of water in the bays by severe storms on the ocean, coincident with high tides. The highest tide of record at Presidio occurred in November, 1918, at a time when neither the Sacramento nor San Joaquin rivers were discharging excessive amounts of water. The tide rose to 5.2 feet above standard sea level at Presidio. In upper Suisun Bay one of the highest waters of recent years occurred in January, 1914, at which time a severe storm on the ocean, combined with the seasonal high water in the rivers, resulted in the water at high tide rising to 6.83 feet above mean sea level at the point where the San Francisco and Sacramento Railroad crosses the bay. In February, 1917, the tide rose two inches higher than in 1914 (to elevation 7.00) although there is no record of river floods of considerable proportions in that year. In January, 1909, during one of the greatest floods of recent years on the Sacramento, the maximum elevation of water surface reached at Collinsville was 6.1 feet above mean sea level.

As far as known, great floods from the two rivers have not occurred simultaneously, nor have great river floods been coincident with extreme tides. If the latter should occur conditions similar to those described for 1861-62 are not beyond conception whether or not the Salt Water Barrier is constructed. In this connection, Mr. Geo. A. Atherton, general manager, California Delta Farms, Inc., in letter of August 4, 1924, states:

> Your assumption that floods of short duration raising the water surface as high as in 1907 (El. 10.3 U. S. E. D.) could again be passed with no more serious results than developed in the flood of 1907 or 1909 is quite true, but those results were sufficiently serious that we are not anxious to have them recur as they were very disastrous and we certainly would be very much opposed to a situation that would result in the water being any higher which I assume would not be planned. As to this elevation 10.3 for the maximum flood water height, we must, under any and all conditions assume that it may come again and, in fact, would come with similar weather conditions even though no dam (barrier) were constructed.

In the design of the barrier particular interest centers, not in the maximum momentary elevation reached by the water surface in the bays, but in the maximum average elevation over an entire tidal cycle, for the reason that the capacity of the flood gates through the barrier to discharge a flood is dependent upon the available head, not only at high tide but throughout the cycle. The critical condition to be met would result through the coincidence of a large river flood, a severe storm on the ocean and an unusually high tide.

It is readily seen that the study of floods is inseparable from that of tides and for that reason they have been combined in one chapter of the report. In the study the assumption is made that a combined flood of 750,000 second-feet from the rivers must be discharged through the barrier under conditions of tidal fluctuations in the bays as they were during the severe storm of January, 1914, the most critical found, considering head available for discharge through the flood gates.

Since the memorable flood of 1861-62, when the overflow from the rivers is reported to have formed a navigable body of water from Sacramento to Stockton, and to Suisun Bay, surveys and plans have been made for their control by the government and by the state. At present work is under way upon straightening and enlarging the lower Sacramento River which, when finished, should greatly relieve the flood menace in the delta region. The work is being done by the War Department under the general direction of the California Debris Commission, with funds contributed by the government and by the state.

Any structure placed below the common mouth of the rivers, obviously, must be designed to pass the floods without materially increasing the flood heights at upstream points as otherwise many miles of delta levees would have to be raised and strengthened to a degree which experience has shown to be impracticable.

Water Available for Flushing.

In the operation of the barrier, the entrance of a certain amount of salt water into the fresh water pond above the structure through the ship locks, and as leakage past the flood gates, can not be prevented. Therefore, unless water is available for flushing the pond clear of salt water the salinity of the water will gradually increase until, in time, the water would no longer be fit for domestic, industrial or irrigation use.

With a combined normal annual run-off from the drainage area of the Great Central Valley of 37 million acre-feet, it might be supposed that there would be no question as to the adequacy of the supply of fresh water for use in flushing. Under present conditions of river flow, in which only a small portion of the natural run-off is held in storage reservoirs in the upper valleys, the flow is sufficient, in most years, to clear Suisun Bay and Carquinez Strait of salt water. Even in years like 1920 and 1924 the natural flow during the high water season is sufficient to clear the delta channels and upper portion of Suisun Bay of salt water. Salinity in the delta is most pronounced in the late summer and fall, following seasons of low run-off. Water available to act as a natural barrier under present conditions, or for flushing, in the event a barrier is constructed, will decrease with the development and utilization of storage in the upper valleys.

Obviously, if the run-off should be only one-third of the normal, as it was in 1924, there would be a severe shortage of water in the upper valleys even though all of the run-off were stored unless a large amount of water were held over from previous years. There would be very little, if any, water available for flushing unless deliberately released from mountain storage for that purpose and it is not probable that this would be done except as a last recourse in an emergency. It seems likely that the barrier will occasionally have to carry over one season without complete flushing, and perhaps more in case of successively dry years. The subject is discussed in Chapter X.

Transfer of Sacramento Valley Water into San Joaquin Valley.

With an arable area of one and one-half times that of the Sacramento Valley, the San Joaquin Valley receives from its drainage basin, on the average, only half as much water as runs off from the Sacramento drainage area. The available supply per acre then is only one-third that for the Sacramento Valley.

There are areas in the southern part of San Joaqiun Valley, on which the draft from underground storage for irrigation by pumping has exceeding the supply, with the result that the water plane has been lowered to an alarming degree. There are other areas which are approaching a similar situation and unless water can be brought in from some source outside the San Joaquin drainage area, the abandonment of irrigation in a portion of the valley is inevitable.

In a Supplemental Report on the Water Resources of California (Bulletin No. 9, Division of Engineering and Irrigation, State Department of Public Works) by Mr. Paul Bailey, it is stated that from a study of the water resources it has been determined that, if distributed by a coordinated plan, there is sufficient water in the drainage basin of the Great Central Valley for all its agricultural lands. The plan evolved provides for taking the surplus water of the Sacramento Valley to areas of deficient supply in the San Joaquin Valley. If the plan were adopted the surplus water from the Sacramento River would be diverted at sea level into the mouth of the San Joaquin and boosted, by pumping, up its channel for a distance of 154 miles southward and to a maximum height of 159 feet above sea level. The plan contemplates the construction of 14 dams, with movable crests, in the present river channel, creating quiet ponds, each successively higher than the next downstream. Through an exchange of water within the San Joaquin Valley, water now used to irrigate lands in the northerly (lower) portion could be transferred southward to the higher areas, leaving the lower lying lands to be supplied with water imported from Sacramento Valley. In the report it is stated that, at present, the plan can be declared feasible only as to the physical works required in its execution.

The ultimate plan involves the construction of large storage reservoirs on the Sacramento and some of its tributaries, and of the Salt Water Barrier below the confluence of the Sacramento and San Joaquin rivers. The barrier is therefore an integral part of the state's comprehensive plan for the conservation of the waters of the Great Central Valley. Its constuction might be deferred. The following is quoted from Mr. Bailey's report:

> * * * Except for possible legal entanglements, it (the first unit of the comprehensive plan) could be developed either by the construction of a mountain reservoir in the Sacramento Basin or by the construction of the barrier below the mouth of the Sacramento and San Joaquin rivers. If the equivalent to the water released from storage into the Sacramento River were pumped from the lower San Joaquin, it would not particularly disturb the condition of low water flow in the two rivers. Thus, although the barrier is not a physical necessity to the first unit of the comprehensive plan in the San Joaquin Valley it is an essential feature of the ultimate diversion of Sacramento River water into the San Joaquin, for without it, there can not be the complete conservation necessary to develop the large volumes of surplus Sacramento water for exportation; but unless its construction were assured, undoubtedly the first unit of the comprehensive plan would become embroiled in the water right controversies surrounding the incursions of salt water into the delta region of the Sacramento and San Joaquin rivers, and be subjected to court injunction.

Without the barrier, the ultimate plan could not be realized since, with full conservation, water necessary to act as a natural barrier against encroachment of salt would no longer be allowed to flow to waste. If fresh water in amount less than about 3500 second-feet were not allowed to flow into Suisun Bay, and on out to the ocean, the water, in its transfer through the delta channels from the Sacramento to the San Joaquin would be contaminated with salt.

Economic Aspects.

The investigation of the proposed Salt Water Barrier covered by this report has not been extended to cover the economic phases of the problem, being limited to consideration of the physical features only. Such an economic study must be made to determine whether the benefits to be derived from the construction of the barrier will be commensurate with its cost. The economic phase is very ably discussed in Mr. Dan

Hadsell's letter of July 2, 1926, to Dr. Elwood Mead, Commissioner, Bureau of Reclamation. The letter is included in volume 2, page 22, as Exhibit 10. Mr. Hadsell's discussion is predicated upon the assumption that a body of fresh water can be created and kept fresh through construction of the barrier.

CHAPTER III

FIELD INVESTIGATIONS

Barrier Sites Suggested.

An examination of the general maps of the San Francisco Bay system leads one to believe that there are numerous sites at which the construction of a barrier might be feasible. No less than eleven sites have been suggested at various times. Proceeding downstream, they are shown on Plate 2-1 as follows:

A. At the westerly end of Sherman Island.
B. At Chipps Island near the town of Pittsburg.
C. Army Point to Suisan Point.
D. At Benicia.
E. Dillon Point to Eckley.
F. At Vallejo Junction.
G. Point San Pablo to Point San Pedro.
H. Molate Point to Point San Quentin.
I. Castro Point to California Point.
J. Point Richmond to Bluff Point.
K. At the entrance to the Golden Gate.

The Sherman Island and Chipps Island sites were dropped from consideration early in the investigation for the reason that even though foundation conditions might be found favorable, a dam at either place would develop comparatively little storage back of it and, as will be brought out in this report, storage is desirable in the operation of the barrier. The foundation at either of the sites would be of peat, sand and silt, similar in character to that found in the delta and described in Chapter II. As the barrier, to fulfill the requirements, must be designed to pass a flood of 750,000 second-feet, foundations can not be considered too lightly.

The Golden Gate site was not considered, first: because a structure there would obstruct the full use and development of San Francisco Bay as an ocean port or naval base; second, because a dam located at any point between the headlands and the bar would be constructed on the unstable sandy slope to the bar, and third, because, as indicated on Plate 3-1, the structure would be located on or in the immediate vicinity of the San Bruno fault zone.

Although the Benicia site has been attractive from the beginning, it was not selected for development by drilling for the reason that a brief geological examination made by Mr. Alfred R. Whitman for the State Division of Engineering and Irrigation in 1922, had tentatively fixed the location of the Sunol fault as crossing Carquinez Strait from the west side of Martinez to the east side of Southampton Bay. Reference to Plate 3-2 will show that a fault line so located would cut through the point off Benicia where, if that site were adopted, the flood gates and ship locks would probably be located to take advantage of shallow rock foundations. Moreover, a barrier at this site, built to take advantage of the shortest distance across the strait, would be transverse to the general trend of fault lines in this locality which would not be desirable.

The Vallejo Junction site, at the westerly end of Carquinez Strait, was at first considered a likely site. Subaqueous drilling done by the Southern Pacific Company at this point had developed bedrock at a maximum depth of about 110 feet. No designs were prepared for this site for the reason that the distance across the strait is considerably more than at the Dillon Point site; conditions along the precipitous shores are less favorable for construction of ship locks and for railroads and highway approaches; and if a barrier were built there a large number of ocean going vessels destined for Crockett would have to be locked past the barrier, which would not be necessary with the barrier built at one of the sites just upstream.

The Point Richmond to Bluff Point site is believed to be the most westerly site that, in any case, should be considered and for this reason the geological study made in the course of the investigation included it. The distance across the bay is here about 3.3 miles, the depth of water, especially on the west side (where there is one sounding of 108 feet) is comparatively great; and, as stated in the geological report, there was a possibility that unsatisfactory foundation conditions would be found if drilled. As at the Benicia site, the direction of the barrier, if built here, would be transverse to that of the two nearby major fault zones. The site has no apparent advantage over the Point San Pablo site where the distance between shores is in comparison only about 1.8 miles.

It is argued by some, and very ably, that a wide site is desirable, if not essential, to provide length of dam crest on which to install flood gates in number sufficient to pass the river floods. With the type of gate proposed in this report, a wide site is not necessary and it appears that selection of a wide site would result in additional cost although no designs or estimates for the very wide sites were prepared. A wide site presupposes the installation of wide, shallow flood gates, while in the design proposed the gates are deep. It is the writer's belief that the adoption of shallow gates would defeat the purpose of the barrier for reasons which are discussed in Chapters IX and X.

The Molate Point to Point San Quentin site, or the Castro Point to California Point site, have no particular advantage over the Point Richmond to Bluff Point site except that the depth of water is less. They have the same unattractive features. A review of the eleven sites listed will show that all but three are eliminated from consideration at the present time.

Comparison of Sites.

Generally speaking, the farther down-stream the barrier were located the greater would be the benefits to irrigation and industrial interests and the greater would be the effect upon navigation interests. Stated more fully the farther downstream the barrier were located the greater would be:

The area of salt marsh possible of reclamation;

The length of shore line for use of industrial plants requiring fresh water in their operation;

The protection against the ravages of the teredo;

The loss of fresh water by evaporation;

The area from which tidal fluctuations and currents could be eliminated;

The reduction of tidal velocities through the Golden Gate and across the Bar;

The number of vessels to be handled in locks;

The number and size of ship locks; and

The amount of fresh water required to flush out the area back of the barrier.

Advantages and disadvantages are discussed elsewhere.

Sites Selected for Investigation.

Following out the general plan of procedure agreed to by all parties to the contract (Exhibit 7), field work in connection with the development of sites was confined to the following three sites:

Army Point to Suisun Point.

Dillon Point to Eckley.

Point San Pablo to Point San Pedro.

In the report they are referred to as the Army Point, Dillon Point and Point San Pablo sites, respectively.

It will be noted, by reference to Plate 2-1, that a barrier at either of the two upper sites would serve to create a body of fresh water in Suisun Bay and the delta channels, while a barrier constructed at the San Pablo site would make possible the inclusion of San Pablo Bay as well. In reality there are but two general plans involved, the Army Point and Dillon Point sites being alternative sites for a barrier to protect Suisun Bay and the delta channels against salt.

It is believed that the sites selected for investigation are typical of any site suggested, with the exception of those at the eastern end of Suisun Bay and that in the ocean at the entrance to San Francisco harbor. The Dillon Point site represents a narrow site where the depth of water is great; the Point San Pablo site is representative of a wide site; while at the Army Point site average conditions are found.

Although a barrier constructed at either of the upper sites were estimated to cost less than one at the Point San Pablo site, an economic study might show a barrier at the latter, to make San Pablo Bay fresh as well as Suisun Bay, to be much more valuable. With this in mind an effort was made to develop each site in sufficient detail to permit the preparation of designs and estimates of a character to be of value in the study of the economic feasibility of the structure.

Geology.

One of the first steps taken was to have a brief geological examination made of the sites selected to determine whether they were geologically suitable before money was expended in their development by subaqueous drilling. The examination was made in August, 1924, by Mr. Kirk Bryan, geologist, United States Geological Survey. His report is attached as Exhibit 11.

By reference to Plates 3-1 and 3-2, it will be noted that the Army Point, Dillon Point and Point San Pablo sites are all located away from the principal fault zones and in each case the direction of the barrier would be approximately parallel to the general trend of the faults. In reporting upon his examination of Carquinez Strait, Mr. Alfred R. Whitman says:

> If a severe earthquake were to be produced by a longitudinal differential movement on the Sunol or Avon fault there would probably be a tendency for the mud of the strait to shift forward and backward in the direction of the fault movement, rupturing the dam if this lay diagonal to it; but if the dam lay along a line parallel with the faults it would be least in danger from shifting mud. The safest point and direction for the dam would be between the Sunol and Avon faults extending from Bulls Head Point to a little northeast of Army Point.

In summarizing the Bryan report the following points are of particular interest:

1. The region is one where earth movements of considerable magnitude have taken place in comparatively recent times.
2. He predicts that earth movements will continue and states that they may be considered as an irregularly recurrent hazard to structures.
3. Regardless of the risk of earth movements, engineering structures should be built to meet present conditions and contingencies.
4. In the design of structures for this region consideration should be given to the possible effect of earthquakes.
5. Major fault lines should be avoided as they represent lines of greatest weakness along which earth movements are most likely to recur.
6. Minor faults, between the major fault zones, have little effect on the character of the sites as future movements on these lines are unlikely.
7. A fault is suspected as lying in the draw just east of Eckley and crossing the strait into Glenn Cove. It would be of the older type, considered no longer active, but if it exists it may cut through the southerly end of the Dillon Point site.
8. There is no objection, geologically, to the Army Point, Dillon Point or Point San Pablo sites with the possible exception mentioned under (7). Mr. Bryan apparently does not consider the exception as of any importance.
9. The rocks at all sites are suitable as foundations for structures of ordinary size.
10. The quartzite in the vicinity of the Point San Pablo site is excellent material for riprap and for crushed concrete aggregate.
11. The harder sandstones found at the upper sites are suitable for riprap.
12. "As material for embankments under water it seems likely that the shales and fragments of sandstone from the thinner beds will fill the voids of the larger stones derived from the massive sandstone beds and form a tight and relatively stable structure."

Earthquakes and Construction.

The following quotation from pages 171 to 174 of Geologic Atlas of the United States, Folio 193, San Francisco Bay, California, by Andrew C. Lawson, U. S. Geological Survey, may be of interest:

> The well known susceptibility of the region about San Francisco Bay to earthquakes naturally raises the question how, in the light of geologic knowledge, loss of life and property due to violent shocks may be guarded against or minimized. In considering this question it should be noted, first, that more than 99 per cent of the earthquakes that affect the region are harmless. They are tremors of the earth's crust due to the adjustments of minor stresses in the rocks far below the surface. In regions where such tremors are frequent, however, as in the region about San Francisco Bay, violent and destructive shocks occur also, though at comparatively long intervals, and it is to these greater shocks, of course, that attention is particularly directed.
>
> Next, among the many faults thus recognized it is necessary to discriminate between those upon which there is no probability of future movement and which are therefore harmless and those which lie in zones of active stress and which are therefore dangerous. Of the many faults discovered in the region of San Francisco Bay only two are certainly known to be zones of active stress. These are the San Andreas fault and the Haywards fault, each of which is a record of a catastrophic earthquake. Other zones of active stress may yet be discovered, but most of the faults are the expression of energies that have been long spent and are not in any sense a menace. It is, moreover, barely possible that the stresses in the San Andreas fault zone have been completely and permanently relieved by the fault movement of 1906.
>
> * * * If we have positive evidence of recent movement—evidence of any of these three kinds (historic, or geomorphic, or geologic), then all structures such as roads, bridges, aqueducts, pipes, and tunnels, which cross the fault, are in danger of destruction, and every effort should be made in their design not only to minimize the destructive effect, but also to supply auxiliary structures to tide over a period of repairs. * * *
>
> * * * Even where there is no reason to suspect recent movement on fault lines engineers should avoid them as far as possible in locating important works. * * *
>
> Besides the dangers that arise from the rupture and displacement of the ground and that may either be avoided by wisely selecting the locations for important structures or be minimized by providing auxiliary structures and facilities for speedy repairs, there are other more general dangers due to the vibration of the ground, concerning which a word of caution may be of service. The principle to be observed by those who may design and locate large buildings or works in this region is that all structures which rest on solid rock are very much safer than those which rest on loose, unconsolidated ground, whether the ground is natural or artificial, and that loose ground saturated with water is the most dangerous of all.
>
> Another principle to be observed in any region subject to severe earthquake shocks is simplicity and unity of structure. Two structural types combined in the same building and not intimately and strongly tied together vibrate with different periods and mutually tend to destroy each other. * * *
>
> * * * In general, all buildings erected in a country subject to severe earthquakes should be made stronger than buildings erected elsewhere, and the best provision against partial destruction is a large margin of safety in strength.
>
> Finally, it may be remembered that, although the coast of California has never suffered in historic times from a sea-wave generated by a fault on the sea floor, such an event is not beyond the range of possibility.

As will appear in Chapter IV the ship locks and flood gates of the proposed barrier are so located as to be founded entirely upon bed rock; they are made as simple as possible; all parts of the structure have been tied together; and, in cases where the structure does not rest upon bedrock, a type of dam (rock fill) has been adopted which, it is believed, most nearly satisfies the conditions suggested by the warning "and loose ground saturated with water is the most dangerous of all."

Plan of Development of Sites by Drilling.

In the general plan adopted a cross-section of the channel was first developed by drilling a number of holes on a line from one shore to the other at each of the three sites selected, followed by the development of foundations under the proposed ship locks and flood gates and over the area of approach to and exit from the flood gates. In each set of drilling work started at the Army Point site and ended at the Point San Pablo site, the development of foundations at the former site not being undertaken until after the cross-section drilling at all three sites had been finished. The cross-section drilling furnished data upon which to base preliminary designs. The drilling to develop foundations followed a plan laid out to fit the structures as tentatively designed upon the basis of the preliminary cross-section drilling.

Results of Drilling Operations.

A detail log of each hole drilled is included in Volume III of this report. Following is a summary of the results.

In general, bedrock is overlaid in turn by gravel, sand, clay and mud. An exception to the general rule is found at the Dillon Point site where water, at one place, just off the Point, was found running on bare rock at a depth of 136 feet below mean sea level. At each site investigated both abutments are of rock and the concealed rock forming the floor of the bay was found to be of the same character as that exposed on shore.

It was early apparent that ship locks and flood gate structure should be founded upon rock and preliminary studies of gate area required to pass river floods indicated that with gate sills 44 feet below mean sea level, the length of the flood gate structure would be about 2000 feet. The desirable site would therefore be one where bedrock would be located at a depth of about 50 feet over about one-half mile of its length. The nearest approach to this condition was found along the Martinez water front. A sloping bench of fair length was found at the southerly end of the Army Point site and a very short one at the southerly end of the Point San Pablo site. At the Dillon Point site the rock drops off abruptly on both sides. A bench, just offshore at Benicia, is suspected.

The mud varies from a soft, black slimy ooze to clay, as depth is gained. In general the mud is gritty, the sand increasing in size with depth from an almost impalpable grit. The clay varies from soft, plastic, to hard clay, which is in reality softened shale overlying the drier rock formation. Gravel is usually encountered below depths of from 100 to 135 feet and would not be involved to any great extent in excavations for structures except at the Dillon Point site, where a concrete structure, founded on bedrock clear across the channel, is considered as an alternative for the rock fill type of barrier. It has been assumed that pumping will prove to be the most economical method of excavating all material overlying the rock.

The statement contained in the geological report by Kirk Bryan (Exhibit 11), to the effect that the rock at all sites selected for investigation is suitable as foundations for structures of ordinary size, was borne out.

The rock, in all cases, is sandstone and shale alternating in layers, generally from one-fourth inch to 24 inches thick. At Point San Pablo site the sandstone and shale is associated with quartzite. In rare instances the sandstone is found in layers as much as 15 feet thick. As a usual thing the sandstone is very fine grained and poorly cemented, approaching a sandy shale. With a little effort it can be cut with a knife. In some instances, the cementing is so poor that pieces one inch in diameter can be crushed and rubbed to sand between the fingers. The harder layers are extremely hard and analysis has shown the rock to be a silicious limestone containing as much as 30 per cent lime. These hard layers are found at all three sites. The shale weathers badly upon exposure to the atmosphere and at Army Point site swelling ground was encountered by the diamond drill bit.

The strata dip downstream (to the southwest) at angles between 45 degrees and 90 degrees. The usual dip does not exceed 70 degrees from horizontal, the strike being across the channel. In most cases the percentage of core recovered in diamond drilling was small, due, perhaps, to the comparatively thin strata, their steep inclination and the friable character of the rock. Evidently it was ground up in the core barrel although a double tube barrel, yielding 1⅝-inch diameter core, was used.

The core recovery was approximately as follows:

Army Point site	5.6% to 30%
Dillon Point site	15.0% to 50%
Point San Pablo site	6.2% to 25%

Generally speaking, the rock at the Army Point site is softer than at either of the other sites and the strata at the Dillon Point site are thicker, especially at the north side of the strait. It is believed that a dredge with powerful cutter head would handle most of the rock at the Army Point site but it is just about on the border line and it probably would be unwise to figure on this type of excavating equipment unless extensive experiments showed it to be practicable. It is believed that the rock will drill easily. The only difficulty expected would be due to the steep inclination of the strata.

ARMY POINT SITE

Features of the Site.

Reference to Photo 3-1* will show that if constructed at this site the barrier would join two prominent points, Army Point on the north and Suisun Point on the south. The line on which the drilling across the channel was done was so chosen that the length of the barrier would be the minimum consistent with good alignment and approaches for the railroad and highway if it were found desirable to carry them across the water on top of the barrier. A topographic map and layout of all holes drilled in the development of the site are shown on Plate 3-3.

Both points are of rock rising to elevations in excess of 100 feet. The main line of the Southern Pacific Company from the east and north rounds Army Point on the way to the ferry crossing at Benicia. The point is occupied by the U. S. Army Arsenal. Practically no interference with existing construction would be occasioned on this

* Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

side of the channel but construction of a barrier would interfere with the plant of the Mountain Copper Company and Associated Oil Company on Suisun Point. As will appear in Chapter IV, alternative designs have been prepared in an effort to reduce interference to the minimum. Various features of the site are shown on Photos 3-2 to 3-6 inclusive.

In drilling holes to the west of Suisun Point the "desirable bench" on which to build the flood gate structure and ship locks was apparently located. As preliminary designs had indicated that a crescent shaped area, such as that along the Martinez water front, would be required to accommodate the structures and provide a channel for by-passing river-floods, it was decided to extend the drilling operations to develop the site from Martinez to Army Point. The axis of the barrier in this case was located to give the most suitable foundation conditions under the ship locks and flood gates; good railroad alignment at the Army Point end without materially lengthening the barrier; and a railroad approach at the Martinez end which would interfere least with present construction. In the plan adopted the railroad would be carried under the residence portion of Martinez in a tunnel; would encircle the town to the south and continue down the west side of the valley of Alhambra Creek to the present location of tracks along Carquinez Strait. The conditions to be met are indicated on Photo 3-7.* It will be noted that there is at present no construction of any importance on the marsh land so that right of way should be comparatively inexpensive. The railroad would pass under the hill at the left of the picture and return to the present location of tracks at the extreme right.

Channel Cross-sections.

The cross-section between Army and Suisun points was developed by drilling 12 holes to and into bedrock as shown on Plate 3-4. The following summarizes the results obtained:

Distance between shores	about 4900 feet
Maximum depth of water	69 feet
Average depth to gravel	115 feet
Maximum depth to bedrock	167 feet
Deepest hole drilled	183.8 feet
Area of waterway (below M.S.L.)	204,500 sq. feet

As the holes are, in general, 500 feet apart, there is no assurance that the deepest rock was located.

The bottom of the bays, almost everywhere, is soft mud, incapable of supporting any material load. As a rock fill dam is the type to which principal consideration has been given in the preparation of this report it was of interest to learn something relative to the supporting power of the mud. In order to throw some light on this important feature a record was kept of the depth to which the drive pipe used in drilling sank of its own weight. The weight of the pipe and the depth to which it sank without wash boring is shown on the section, Plate 3-4. Additional data are presented later.

Another cross-section was roughly developed from Martinez to Army Point by sinking three holes on line "M" in addition to those sunk

* Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

in the development along the Martinez water front. In driving these three holes it was the object to locate supporting ground for a rock fill. Although the fill might not settle clear through the mud, clay and sand to gravel it was assumed that it would, in any event, not settle into the gravel. Instructions were therefore given to discontinue driving when it was reasonably certain that continuing gravel had been reached. Although no diamond drilling was done the indications were that bed rock was reached in all but one hole. The results of drilling on line "M," which is in reality a continuation of line "W 4500," are shown on Plate 3-6 and may be summarized as follows:

Distance from intersection with Southern Pacific tracks at Martinez to Army Point (measured along Line W 4500 and Line M) about	8650 feet
Maximum depth of water	59.2 feet
Depth to gravel	80 to 110 feet
Maximum depth to bedrock (rock not reached in one hole)	121.8 feet
Deepest hole drilled	128.8 feet

Development of Foundations and Areas to be Excavated.

As the bench off Suisun Point, located when drilling the cross-section of the channel, was not sufficient to accommodate the ship locks and flood gate structure as tentatively designed, it was evident that Suisun Point would have to be encroached upon. The site was developen by drilling holes on radial lines around Suisun Point and approximately normal to the shore line along the Martinez water front as indicated on Plate 3-3. The details of the drilling are shown on Plates 3-4, 3-5 and 3-6 and by the drill logs which are contained in Volume III.

It will be noted that there is a rock bench under the Martinez marsh and tidal flat, terminating off Suisun Point. If 90 feet is assumed as the maximum practicable working depth for the pneumatic caisson process, structures built by that method could be founded on rock as much as 1200 feet off Suisun Point and approximately 2000 feet out from the Southern Pacific tracks on line "W 4500." East of Suisun Point the rock drops rapidly and would not be encountered but for a short distance from the point in excavations proposed in Chapter IV.

The low saddle through Suisun Point, and the marsh to the east between the point and the nearby hill, suggest the possibility of constructing ship locks "in the dry" in a position to avoid serious interference with present structures. This is the explanation of the drilling on the marsh adjacent to the Mountain Copper Company plant.

Where there was interest only in the character of material to be excavated for estimating purposes the holes were drilled from 60 to 70 feet deep only, as there are no excavations having a contemplated depth greater than this. In drilling the cross-section off Suisun Point the holes were carried well into the rock to determine its character to the depth of the proposed excavations.

The borings indicate that the bedrock under the Martinez marsh and tidal flat, between Alhambra Slough and the submerged draw issuing from back of Suisun Point, is in general a soft, sugary, comparatively coarse grained sandstone in which the cementing material has very little strength. It is this material that can be rubbed to sand between the fingers.

DILLON POINT SITE

Features of the Site.

As indicated on Plate 2-1,* and by Photo 3-1,* a barrier built at this site would have less length than at any point in Carquinez Strait or in the bays. The axis of the proposed structure was fixed to give the best alignment possible for the railroad and highway around Southampton Bay if it proves desirable to carry either across the strait on top of the barrier, and to take advantage of the draw at Eckley Station in making the right angle turn to the west. A topographic map and layout of the system of holes drilled in developing the site are shown on Plate 3-7.

The rock on each side of the strait rises abruptly to elevations 150 feet and more above the water surface. The main line of the Southern Pacific Company to Oakland and San Francisco skirts along the south side of the strait, the Benicia to Port Costa Railway Ferry crossing being located just east of the barrier site. The precipitous hills on either side suggest the possibility of a railroad and highway crossing at an elevation to clear the masts of vessels being locked past the barrier without the necessity of raising bridges. The narrow channel, and the comparatively little channel filling, suggests a barrier of the articulated type in which the present waterway would be closed by large gates carried between concrete piers resting on bedrock. Such a type is presented in Chapter IV as an alternative for the rock fill type.

By inspection of Photo 3-1* it will be noted that there would be practically no interference with existing construction. Present construction consists of the Southern Pacific Railroad, the high tension suspended transmission line belonging to the Pacific Gas and Electric Company and a submarine telephone cable owned by the same company. Features of the sute are shown on Photos 3-8,* 3-9* and 3-10.*

Channel Cross-section.

The cross-section was developed by drilling 7 holes on line to, and into, rock as shown on Plate 3-8. Following is a summary of results obtained:

Distance between shores	about 2740	feet
Maximum depth of water	136	feet
Depth to gravel	88 to 136	feet
Maximum depth to bedrock	148	feet
Deepest hole drilled	152.6	feet
Area of waterway (below M. S. L.)	211,600	square feet

There is no assurance that the deepest rock was located since the holes are spaced a considerable distance apart but the information obtained is considered sufficient as a basis for preliminary designs and estimates. It should be noted that the rock drops off rapidly on each side of the strait and that at Dillon Point water runs on bare rock the tidal currents being sufficiently strong to keep it swept clean.

Development of Foundations and Areas to be Excavated.

As there is no bench in the present waterway upon which to build ship locks and a flood gate structure it was evident that if a rock fill type of barrier were built it would be necessary to build the locks and

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flood gate structure in the position now occupied by Dillon Point which, in turn, means that approach to and exit from the flood gates would have to be excavated in the region of Southampton Bay and Glen Cove respectively. The site was therefore developed by drilling holes on radiating lines around Dillon Point and on lines normal to the general direction of the shore as indicated on Plate 3-7. The details of the drilling are shown on Plates 3-8 and 3-9 and by the drill logs which appear in Volume III.

The investigation shows that the rock of Dillon Point along the strait is swept clean of any loose deposits; that on the eastern side the rock drops rapidly as along the strait, and that a rock bench underlies Glen Cove. As indicated on Plate 3-8 the excavation of approach to the flood gate in Southampton Bay would be almost wholly in mud, clay and sand. While of small extent, excavation over the area of exit in Glen Cove would be partially in rock. See Plate 3-9.

POINT SAN PABLO SITE

Features of the Site.

As will be seen by reference to Plates 2-1 or 2-2, the site between Points San Pablo and San Pedro is the narrowest which could be utilized to make San Pablo Bay fresh through the construction of a Salt Water Barrier, with the exception of the Golden Gate.

In selecting the line on which to develop a channel a cross-section consideration was given to the shallow depth of water at the downstream end of Point San Pedro in comparison with that of the upstream end. The shoal water at the downstream end indicated the possibility of the existence of a rock bench on which to build the flood gate structure, whereas there was no possibility of the existence of such of a bench at the upstream end. If the barrier were built at the upper location it would be slightly shorter and more nearly parallel to the general direction of fault lines, but quarry operations there would be a source of inconvenience, if not of danger, in the operation of trains and vehicles across the barrier. A topographic map of the site and layout of holes drilled in its development are shown on Plate 3-10.

Both points are of rock and rise to an elevation in excess of 200 feet. There would be no interference with present construction on Point San Pedro unless a railroad were carried across the bay on the barrier, in which case small adjustments might be necessary in case of the brickyard now operating there. At point San Pablo there would be interference with the Belt Line Railroad which serves practically all industrial plants on the point and with plants located on the tip end of the point. Some features of the site are shown on Photos 3-11* to 3-14,* inclusive.

The existence of marsh country east of the ridge which terminates in Point San Pablo suggests the possibility of building the ship locks associated with the barrier "in the dry" somewhere on the marsh and joining them with San Francisco and San Pablo bays by ship channels excavated in mud. Although available funds did not permit investigation of this plan, pictures were taken to show what would be encountered if such a plan were adopted. The country which would be traversed is shown on Photo 3-15.*

* Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

Channel Cross-section.

The cross-section was developed by drilling 14 holes on line as shown on Plate 3-13. In the first drilling that was done rock was developed at each end of the site to depths of over 100 feet, and over the rest of the length of the site holes were put down 1000 feet apart to develop gravel as was described for the Martinez to Army Point site. Later, on two holes, located at about the third points of the length of the site, were drilled to and into rock to give a general idea of bedrock conditions. Following is a summary of results obtained:

Distance between shores	about 9560 feet
Maximum depth of water	87 feet
Average depth to gravel or coarse sand	140 feet
Maximum depth to bedrock (rock not reached in all holes)	240 feet
Deepest hole drilled	255 feet
Area of waterway (below M.S.L.)	489,000 square feet

As at the Army Point site, a record was kept of the depth to which the drive pipe used in drilling operations sank into the mud of its own weight. The weight of the pipe and the depth to which it sank without wash boring is shown on the section, Plate 3-13.

The three holes of particular interest are holes 2500, 3500 and 6500. In hole 2500 the only gravel encountered was contained in a stratum of clay and gravel 10 feet thick from 168 to 178 feet depth. This stratum is underlaid by soft clay of an undetermined thickness, but at least 50 feet. In drilling hole 3500 nothing larger than coarse sand was encountered above elevation —217.6. In hole 6500 a stratum of sand and gravel over 50 feet thick rests on about 50 feet of mud and sand. Similar conditions may have been developed in other holes had they been drilled to greater depths. In the preliminary studies it has been assumed that a rock fill barrier will not settle below the top of gravel or coarse sand but in the preparation of final designs careful consideration should be given to the character of the channel filling in arriving at its suitability as a foundation of a rock fill of great weight.

Development of Foundations and Areas to be Excavated.

The cross-section drilling failed to develop a rock bench at the Point San Pedro end of the site nor one at the Point San Pablo end sufficient to accommodate ship locks and flood gate structure. It was therefore apparent, as at other sites investigated, that if a rock fill type of barrier were adopted space would have to be provided for the ship locks and flood gates, if they were to be founded upon rock by removing a part of a point of land. Other things being equal the ship locks should be located at Point San Pablo in order to be on the course at present traveled by the majority of vessels. Conditions making it desirable for large vessels to take the middle course, would, to a large extent, be changed with the barrier constructed.

The site was developed by drilling on lines normal to the general direction of the shore line as indicated on Plate 3-10. Details of the drilling are shown on Plates 3-11, 3-12 and 3-13, and by the drill logs referred to previously.

The investigation shows that there is a small rock bench off Point San Pablo where the depth to rock is less than 90 feet for 1000 feet out from shore. The bench is not in position to be of use in connection with flood gates but is well adapted for the ship locks. The rock drops off rapidly on either side of the point so that it would not be involved to a great extent in excavations over the area of approach to and exit from the flood gates. The excavation would be largely in mud, clay and sand.

It will be noted that the bottom of the channel between Point San Pablo and the Brothers Islands is swept clean to bedrock. The rock here, at depths not exceeding about 90 feet, is attractive in connection with the flood gate structure.

In drilling in the region of Invincible and Whiting rocks a ridge was located, the high points of which protrude above the water surface as the Brothers Islands. The ridge looked promising as a foundation for ship locks until studies of vessel traffic indicated that locks in number too great to be accommodated by the ridge were required at this site.

BENICIA SITE

Features of the Site.

Although the site at Benicia was not developed by drilling there is a possibility that a barrier could be built here at less cost than at any other site. Examination of Plates 2-1 and 2-4 and Photo 3-1* will show that on account of the low narrow point extending into the strait at Benicia, and the marsh just upstream from it, the above water excavations necessary to construct ship locks on a line drawn from Port Costa to the tip of Suisun Point would be comparatively small. A study of test pile data obtained in this locality several years ago by the Southern Pacific Company which will be presented later, indicates that rock possibly extends out from the Benicia Point at depths, and for a distance, to accommodate the flood gate structure. Whether the site actually has merit can only be determined by development drilling.

The principal difficulty probably would be the interference with operations of the Southern Pacific Company in the event advantage was not taken of the barrier to carry trains across the strait. Aside from this feature interference with present construction would be limited to a few plants, warehouses and buildings in "the lower end of town." As a recompense deep water would be made available in place of the present mud flats.

As previously stated, this site was not considered seriously for the reason that a fault line was suspected as passing through it. In view of the geologist's statement found in Exhibit 11:

> It follows, therefore; that engineering structures should be undertaken to meet present conditions and contingencies that may be reasonably predicted during the life of the structure, without regard to the risk of earth movements which is inherent in the region and is a part of man's life in the area.

it is probable that the consequences anticipated as a result movement on the fault line, if it exists, are overestimated. Perhaps the possibility of earth movement should be overlooked in case it later develops that a large amount of money could be saved through adoption of the site. With this in mind preliminary designs and estimates were prepared for the Benicia Site, based upon foundation conditions which were, very largely assumed. A map of the site and the assumed underwater conditions are shown on Plate 3-14.

DATA RELATIVE TO UNDERWATER CONDITIONS

Other Cross-sections in the Bays.

During the investigation many data were gathered relative to underwater conditions. Some of the most pertinent of these appear on Plates 3-15 to 3-19 inclusive. They include 17 channel sections at various points from the eastern end of Suisun Bay to the lower end of San Pablo Bay. Changes in the channels due to silting are shown, in some cases from 1857 to 1925. The record of borings at Vallejo Junction by the Southern Pacific Company, at Valona by the American Toll Bridge Company and at Chipps Island by the San Francisco-Sacramento Railroad Company are shown, as are test pile data obtained by the Southern Pacific Company in the vicinity of Army Point and Benicia.

By reference to section 14, Plate 3-18, it will be noted that at Chipps Island no rock is reported to have been encountered although a number of the holes were put down about 130 feet; and that hard material, probably a mixture of clay, sand and gravel, was located under the present channel at depths of about 100 feet.

It is interesting to compare the test pile data, section 12, Plate 3-17, with the drilling record obtained in the present investigation as shown on Plate 3-4, since the work was done on practically the same line between Army and Suisun points. The similarity of the profiles indicating the depths to which the test pile and pipe used in drilling settled of their own weight is quite remarkable. Off Suisun Point the small penetrations, and consequent high calculated safe loads, indicated the probable existence of rock. Its existence was demonstrated in the drilling operations. In fact, the top of rock as indicated by test pile 2a is checked exactly by drill hole 1000. The test piles across the remainder of the channel were not driven far enough to reach the sand and gravel developed by drilling, but the more compact material found in drill hole 3000 was indicated by test pile 7. The absence of other material than mud in drill hole 4500 explains the low calculated safe loads as determined from test pile 11. The discrepancy in the distance between shores, shown on the two plates referred to, is probably due to noncoincidence of the lines on which the sections were developed.

As shown on section 15, Plate 3-19, the channel filling about 0.7 mile upstream from Army Point is firmer than between Army and Suisun points. The conclusion to be drawn is that this location is better adapted to a structure supported on piles although the distance between shores is almost twice that between Army and Suisun points. The approaches to a structure at the upper location, however, would be across marsh land which has little supporting power.

Comparison of results obtained at the Army Point site with Southern Pacific test pile data at Benicia led to the belief that rock would be found extending out from Benicia in the form of a flat bench which previously has been referred to, as at that location test piles showed no penetration. The results obtained by the Southern Pacific Company are shown on section 9, Plate 3-16. These data were used in drawing in the assumed underwater rock contours shown on the general map of the Benicia site, Plate 3-14.

Sacramento River Channel.

The channel of the Sacramento River has undergone very noticeable changes since the gold mining era in California. Data compiled and very kindly made available by Mr. George S. Nickerson, consulting engineer of Sacramento, appear on Plate 3-20. The data were compiled from surveys made at various times between 1849 and 1917, from the city of Sacramento to Suisun Bay. The information relative to the lower reaches of the river are of particular interest in this investigation.

The Key System Pier Fill at Oakland.

It was of interest to learn of the experience of others in building embankments in the bays. The following is quoted from a memorandum of a discussion with Mr. Edward M. Boggs, consulting engineer of Oakland, in December, 1925. Mr. Boggs, as assistant to the general manager, was the engineer in charge of construction of the pier.

> Originally the Key System's work in San Francisco Bay consisted of a double-track railway trestle three miles long, thirty feet wide, curved and widened near the end into the form of a golf club; all carried upon wooden piles.
>
> The trestle was in its original condition when the earthquake of April, 1906, occurred. It would have been interesting to have seen the behavior of this long wooden structure under the heavy shocks of that unusually severe earthquake; but so far as known no one observed it, the 'quake occurring at an early morning hour before train service had begun for the day. The supposition is that a series of waves, both vertical and horizontal, and of considerable amplitude, comparable to swells on a smooth water surface, must have traversed the entire length of the trestle. All that is known, however, is that whatever the distortion may have been the structure settled back into its proper position with almost perfect accuracy, and without material injury. Trains were run over it a few minutes later and regularly thereafter. After the more urgent matters were taken care of the appearance of the tracks was improved somewhat by "spike-lining" the rails at a few places, to the maximum of perhaps two inches; but nothing more was required.
>
> In 1908 a small portion of the trestle extending 1667 feet westward from the subway crossing of Southern Pacific tracks was filled. All the remainder of the present "pier fill" was constructed between June, 1913, and March 16, 1915, as to the dredge fill and December 1, 1915, as to the rock walls. The apparent paradox in the dates of completion of the two principal classes of work is explained by the fact that the rock contractor was many months in arrears with the placing of the "facing rock"—heavy rock on the outer face of the wall.
>
> The fill consists of two parallel rock fills with a theoretical cross section indicated on Drawing 9444-D, between which soft material borrowed from the bottom of the bay was pumped. Some modifications were made in building the fill. One of these reduced the width of the trench to be dredged as a footing and gave it a form more readily excavated. The resulting fill has an overall top width of 200 feet. The depth of water below mean lower low water varies from nothing at the land end to about 8 feet where the pile structure begins. (The drawing referred to appears as Plate 3-21.)
>
> The rock work was done by the Daniels Contracting Company using quarry run rock from McNear Landing with the following limitations:
>
> The core of the rock fills making up 80 per cent of the rock was to be free from dirt and waste and no piece less than one-half pound in weight was to

be used. The core was to consist of rock from one-half pound to one cubic foot or as much larger as practicable. The face rock making up not less than 20 per cent of the total rock was to range in size between one cubic foot and six cubic feet or as much larger as practicable. The quantities of rock were as follows:

Core rock, 577,478 short tons.

Face rock, 28,018 short tons.

The weight of the rock used was approximately 1⅓ tons per cubic yard.

In placing the rock, bottom dump barges were used where possible. Otherwise the rock was loaded into skips at the quarry and hauled to the job by flat deck barges. The skips were handled at the fill by a derrick barge. The contract price was 82½ cents per short ton (about $1.10 per cu. yd.) in place. Considerable trouble was experienced in getting the tug men to dump the rock where the engineer in charge wanted it due to tidal currents and the disposition to get rid of the rock in the easiest and quickest manner.

The dredging of the trenches for the rock fills was done by contract at 15 cents per cubic yard measured in the solid. The digging was done by a clamshell dredge. The material was deposited in the prism between the rock fills by simply swinging.

The pumped fill between the rock fills was done by contract. The material was obtained from the bottom of the bay alongside of the rock fills but at a safe distance away.

2,456,313 cubic yards measured in the excavation were pumped at a contract price of 8½ cents per cubic yard.

Work was carried on 24 hours a day.

Actual dredging occupied 76½ per cent of the calendar.

Actual dredging occupied 82¾ per cent of working days.

The average discharge for 204 24-hour working days was 12,040 cubic yards, measured in the excavation, 500 cubic yards per hour.

During the construction three local side slips of the rock fills were experienced due to the side pressure developed by the hydraulic fill. None of the slips were serious. Never had a slump in the fill.

The terminal is built on what is apparently a subaqueous hill. All of the structures are carried on piles about 45 feet long (assumed below M. L. L. W.) There are no depths anywhere at the terminal, or under the trestle approach, over 70 feet to hardpan.

The hardpan is a fairly well cemented sandy clay. As a usual thing piles 60 feet long, or less are required. With piles 60 feet long no settlement has been noticed although they are supporting their load by skin friction only.

Mare Island Dike No. 12.

As shown on Plate 2-3 the dike extends into San Pablo Bay in a westerly direction from the end of Mare Island. It is reported to have been built in 1912 for the purpose of creating a scouring velocity below Mare Island Strait. Another object was to build land back of the dike through deposition of silt in the quiet water there. Originally the dike consisted of a line of 12-inch sheet piling driven between waling timbers and supported laterally by batter piles. The timbers were attacked by the teredo and damaged to the extent that it became necessary to reinforce the wall with rip-rap placed along the outer side. The rock work was done by the Daniels Construction Company under contract dated January 2, 1923. About 400,000 cubic yards of quartzite from the quarries at McNear's Landing, said to weigh approximately 2450 pounds per cubic yard in barges was used. Part of the rock was dumped from barges, the remainder being placed in the dike by derrick barges handling the rock in skips.

To determine the behavior of the rock fill two test sections were selected as indicated on Plate 3-22. Soundings were made to develop the original bottom and were repeated during the progress of the work. After placing of rock had been completed a line of holes was drilled in the center of each test section to develop the cross-section of the rock fill. The results are shown on the plate referred to.

It will be noted that the rock settled into the mud to depths as great as 30 feet; that there was a bulging of the bay bottom out from the fill; and that the resulting fill is about 125 feet in width. Apparently equilibrium was established through consolidation of the mud and by the bulging of the bottom outside the fill. The timber wall restricted lateral movement in one direction and the reactions of this wall probably explain the peculiar shape of the rock fill.

It is understood that in placing the rock a toe wall was first built parallel to, and at the proper distance from, the timber wall. If it is assumed that the toe wall was placed to produce a 1 on $1\frac{1}{2}$ slope it must have moved laterally from 90 to 110 feet before equilibrium was established. It is interesting to speculate what the shape of the rock fill would have been had there been no timber wall to confine the movement in one direction.

In the design of the Salt Water Barrier it has been assumed that if the rock were all dumped within narrow limits along the axis of the fill a wedging action would result. As the rock sank into the mud the latter would be displaced horizontally, allowing the rock fill to attain width. The bottom would bulge in the amount necessary to establish stability. It is possible that lateral movements could be controlled by dumping the first rock in an excavated trench but the utility of this trench is not altogether apparent. Its cost would not be excessive however and future studies may demonstrate its utility. Settlement might be controlled by resorting to the use of brush mats similar to those used in building dikes in Holland.

American Toll Bridge Test Pile No. 12.

Foundations for the bridge across Carquinez Strait, at Valona, were very carefully investigated by drilling and with test piles. Data which have been made available through the courtesy of officials of the Bridge Company are valuable for inclusion in this report in that the results obtained are probably typical of those which might be expected at any one of the sites investigated for the Salt Water Barrier, where similar materials were encountered. Test Pile No. 12 is of particular interest. It was driven just inside the pierhead line, 80 feet west of the center line of the bridge, where the water was about 32 feet deep at mean high water. Data compiled from company records are shown on Plate 3-23. The location of the test pile is shown on section 4, Plate 3-15.

By comparing the calculated safe loads with the material encountered in a nearby drill hole it will be noted that very little resistance was developed by the mud, fine sand or vegetable matter above elevation —70. Considerable resistance was developed by the clay, and increased at a nearly uniform rate until the soft sandstone was struck. From here on the pile was driven through soft sandstone and soft shale. The average penetration of the pile, just before driving was stopped, was 0.36 inch per blow of the 5000-pound steam hammer having a stroke of 3 feet. It will be noted that there was very little settlement, if any, at the end of the month during which the pile carried a load of 25 tons of steel rails.

Caissons at American Toll Bridge Site.

Experience gained in sinking the caissons for the center pier is of value in considering the alternative design of the Salt Water Barrier which is suggested in Chapter IV for adoption at the Dillon Point site.

At the center pier of the bridge the depth of water below mean high water was about 80 feet. As the cutting edge of the open caisson neared the bottom, the effect of the increased tidal velocity under the caisson was to scour out approximately 20 feet of mud. While the excavation inside the caisson was reduced· the hazard in landing the cassion was, no doubt, increased.

Deep Wells.

Data relative to the formation in Carquinez Strait at the point marked "A" on Plate 2-4, which were supplied by the California and Hawaiian Sugar Refining Corporation, are shown in Exhibit 12.

The following are extracts from various reports on the well drilled at Benicia Arsenal at the location marked "B" on Plate 2-4:

> Chief of Ordnance Report for 1876,
>
> Page 8—By June 30, 1875, a depth of 1049 feet had been reached. At the time the report was written the well was down 1093 feet.
>
> The ground surface at the well is about 20 feet above mean sea level.
>
> Page 45—The strata are upheaved in all directions, and, in some places, are nearly vertical, and the number and nature of the strata to be pierced before reaching a level at which a large supply of water can be obtained are unknown.
>
> Chief of Ordnance Report for 1877.
>
> Page 693—On reaching a distance of 1099 feet from the surface, the stratum changed to that of hard sand rock, and the tools immediately gave evidence of this change * * *. Changed from hard sand rock to sand and shale and finally to shale. This stratum of shale seems without limit in extent. At about 1212 feet a bed of dense lime rock was struck—not very thick—then sand rock and shale. At 1407 feet struck coal. Gas burned at the mouth of the hole with a yellow flame. A new stream of water also came in.
>
> Chief of Ordnance Report for 1879.
>
> Page 216—There were two sources of water—at depth 960 and 1407. The water was very soft but organic matter made it unfit for food. It was used mixed with the hard water of the small well, for irrigation and for the animals. It did not disagree with the animals but violets which were irrigated faded and died. It agreed with the grass and trees. Caving ground caused a great deal of trouble.

The formation under the Suisun marshes, as developed in the drilling of several wells, is indicated in Exhibit 12. The well marked "K" on Plate 2-4 is of particular interest as it throws additional light on the foundations of a dam if located at the Chipps Island site referred to previously. The exact location of the well was not determined but it is reported as being on Van Sickle Island.

DRILLING OPERATIONS

Summary.

Plan of procedure agreed upon by parties to the contract on June 9, 1924. See Exhibit 7.

Crews organized and drill equipment assembled during July and first half of August, 1924.

Drilling started	August 16, 1924
Drilling completed	August 7, 1925

Number of holes drilled—

Army Point site	138
Dillon Point site	79
Point San Pablo site	105
Total	322

Character of drilling—

Water	8,363.8 feet	34.0%
Channel filling	15,477.7 feet	62.8%
Rock	798.6 feet	3.2%
Total	24,640.1 feet	100.0%

Division of time—

Moving and repairs	243 shifts	41.8%
Wash boring	274 shifts	47.1%
Drilling rock	64¼ shifts	11.1%
†Total	581¼ shifts	100.0%

Average progress per shift including proportional part of moving and repairs—

Total measured from mean sea level	42.4 feet
Channel filling between mud line and rock	56.5 feet
Drilling rock	12.4 feet

The deepest hole drilled was Hole 6500 at the Point San Pablo site. It was sunk to a depth of 255 feet below mean sea level.

The carbon loss amounted to 8.77 carats or at the rate of 0.011 carat per linear foot drilled in rock.

Time spent at each site—

Site	*Cross section*	*Foundations*
Army Point	August 16-October 7, 1924	December 30, 1924-March 28, 1925
Dillon Point	October 10-October 31, 1924	April 1-May 4, 1925
Point San Pablo	November 3-December 23, 1924	May 7-August 7, 1925

Equipment Used in Development of Sites.

The equipment used in drilling operations consisted of a drill barge carrying tools necessary for wash boring and diamond drilling, and a tugboat serving as a tender. The equipment is shown on Photos 3-16* and 3-17.* In the former, the drill column is lowered in working position and in the latter, the drill column is raised while the barge is being moved from one hole to another.

The Tug.

The tugboat "Bear" was chartered from the Crockett Launch and Tugboat Company for the entire period of operations. It has an overall length of 42 feet, beam 11.9 feet, draft 4.6 feet and is propelled by a 3-cylinder, 80-horsepower Atlas gasoline marine engine. It proved to be an excellent boat, very dependable, seaworthy and with ample

† Includes shifts worked between August 16, 1924, and August 7, 1925, and does not include time occupied in assembling or dismantling the equipment used.

power except that during severe wind storms the barge could not be handled unless the tide was favorable. The vessel is shown on Photo 3-18.*

The Drill Barge.

U. S. Navy Coal Barge No. 187 with pile driver equipment, minus the hammer, was obtained from the Mare Island Navy Yard through an interdepartmental arrangement. The barge has an overall length of 110 feet, beam 30 feet, depth 8 feet 2 inches and a rated capacity of 250 tons. See Photo 3-19.*

The barge was equipped with three 8-inch by 10-inch twin engine double drum hoists. One, manufactured by the Washington Iron Works of Seattle was used to handle the drill column, cage and tools while the two Lidgerwood hoists, one on each end of the barge, handled the four anchor lines. Fuel oil was used in the generation of steam.

The leads of the pile drivers were 66 feet high above the skids. As will be noted on the photographs, an outrigger was added near the top with pulleys arranged directly over the center of the drill platform; and at the bottom a timber yoke was built as a support and guide for the drill column.* These features, and the skids attached to the drill column to provide for the rise and fall of the barge, are shown on Plate 3-24.

Other miscellaneous barge equipment consisted of four 2500-pound and two 1200-pound fluke anchors; four 800-foot lengths of three-fourths-inch 6 by 19 galvanized steel anchor cables; a 14-foot diameter, 10,000-gallon water tank for boiler water; a portable shack; a skiff; a "genco-light," model 19, Type A, electric lighting set of 32 volts, 30 ampere capacity, manufactured by the General Gas and Electric Company; fog signals and signal lights.

The Tools.

From inspection of the bay charts it was known that drilling would be necessary in water about 140 feet in depth at high tide. It was evident that the tools must be designed to withstand lateral loads to which they would be subjected by tidal currents in excess of 6 feet per second. To meet the conditions a latticed steel column was designed as a support for the drill casing within which the drill rods were to be operated. The column was built in the shops at Mare Island Navy Yard according to designs prepared in the Berkeley office. It was 24 inches square and made in sections which were bolted together to give any desired length within about 6 feet. There were six sections 20 feet long, two 9 feet and one 6 feet, making a total length of about 145 feet. The lower end of one of the 9-foot sections was equipped with a cutting edge. In the center of each long section a funnel-shaped guide was provided which also served to hold the drill casing in a steady position in the center of the column. The design of the drill column is shown on Plate 3-25. It will be noted that the connecting plates were made heavy, long and were provided with plenty of connection bolts. The calculated deflection of the total column, due to a 6-foot tidal velocity, was about 11 inches and it is believed that the actual deflection in operation was approximately that amount.

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*Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

Drilling could not be well done from the deck of the barge on account of the constant rise and fall of the tide, and the rocking of the barge in rough weather. A platform 10 feet square was therefore designed to be mounted on the drill column which in turn rested in the mud, or on the rock of the bottom. All wash boring and diamond drilling was done from this platform, steam and water being supplied through flexible hose. A cage, operated from one drum of the drilling hoist, was built into the pile driver leads so that in drilling a man could be kept in position opposite the water swivel regardless of the stage of the tide, or the position of the chopping bit or the diamond bit. The details of the drill platform are shown on Plate 3-26 while the drill rig, in full operation diamond drilling in rock, is shown on Photos 3-19* and 3-20.* The skids on the drill column, forming the sliding connection between the column and barge, are clearly shown in Photo 3-20.*

The diamond drill used is shown on Photo 3-21.* Its compactness and small weight made it particularly suited to the work. The hydraulic feed was well adapted to the character of rock drilled. Size "B" drill rods were used, equipped with double tube core barrel yielding a core $1\frac{3}{8}$ inches in diameter. Three sizes of casing were used, $2\frac{1}{2}$-inch pipe inside of 4-inch and 4-inch inside of 6-inch. The three sizes, in combination, were used only where the anticipated depth of driving through channel filling was great.

Holes on the marshes at the Army Point site were put down by hand. In this operation the tools included a timber tripod, "E" drill rods and a hand pump. No diamond drilling was done in these holes.

The Crew.

Operations were carried on during six days a week upon a two 8-hour shift basis. Both crews were directed by one diamond drill foreman who was in direct charge of all operations. He was a high type man and his ability to operate a transit saved the services of an instrument man to "spot the holes." Each drill crew included a diamond driller and two helpers. A repairman was included on the day shift and a watchman was always on the barge during the "graveyard shift." The captain of the tug was on duty during both working shifts but worked only as required in moving the barge and transporting men and supplies.

Datum and Level Control.

According to practice established in the San Francisco Bay region, all measurements are given as from water surface. In order that elevations reported may be referred to, the same datum as that used on land (U. S. G. S.), mean sea level was adopted as the plane of reference rather than mean lower low water, which is the plane of reference upon which the charts, prepared by the U. S. Coast and Geodetic Survey are based. Level control was established at the Army Point site by levels run from the U. S. G. S. bench mark at the Martinez courthouse; at the Dillon Point site by levels run from the U. S. G. S. bench mark at Port Costa; and at the Point San Pablo site by connecting the U. S. C. & G. S. bench marks on Point San Pablo and Point San Pedro.

* Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

In drilling operations depths were measured from the drill platform, the elevation of which was determined by leveling from shore. This elevation established, the depths of hole were adjusted to read below mean sea level.

Designation of Holes.

Holes drilled were usually designated by "line" and distance, in feet, from an initial point, ordinarily the closest point to the water's edge where it was practicable to set up a transit. The transit points are indicated on Plates 3-3; 3-7 and 3-10. Along the Martinez water front a system of coordinates was adopted for designating holes drilled.

Reports.

The progress and results obtained were made the subject of daily reports by each diamond driller. From these reports the foreman prepared his log. The drill logs accompanying this report were prepared from the original daily reports of the diamond drillers, supplemented by data supplied by the foreman.

Methods Used.

The drill barge was spotted with a transit, distance being determined by the stadia method. White targets were painted on the pile driver leads and no difficulty was experienced in spotting the barge, either as to alignment or distance, except in foggy weather.

With the drill column raised, the barge was towed to the approximate location of a hole. One anchor was dropped from the barge located so that the tide would carry the barge toward the line of drilling. The tug then "ran out" the second anchor against the tide. These anchors in place, the other two were "run out" by the tug. The anchors were so placed that an anchor line left each corner of the barge at about 45 degrees, so that the barge could be accurately "spotted" by hauling in on one line and paying out others. Long anchor lines were used to allow the barge to rise and fall with the tide without dragging the anchors. As the verticality of the drill column depended upon the support given it by the barge it was essential that the latter be kept in one position. It was often necessary to "plumb the column" by manipulation of the anchor lines.

In some areas the mud would not support the weight of the drill column without excessive settlement and to overcome this difficulty a timber step bearing was added at the lower end. Where the mud was unusually soft the anchors would move, particularly during wind storms, when the high pile driver leads proved a very efficient sail. At first 800-pound anchors were used. These were soon abandoned in favor of 1200-pound anchors and when the barge was moved to the Dillon Point site, where severe conditions were to be encountered, 2500-pound anchors were adopted. During stormy weather at the Point San Pablo site, two 1200-pound anchors were used in combination with the four 2500-pound anchors ordinarily used off each corner of the barge, one directly upstream and the other downstream.

Fogs interfered with the work to a considerable extent. No accident occurred although vessels came near striking the barge on several occasions. Rough weather was experienced at the Point San Pablo site. At times it was dangerous for the men to work above the deck

At only one place did other construction interfere with the drilling. At the Dillon Point site, the line on which to drill the cross-section was chosen to avoid possible damage to the Pacific Gas and Electric Company's submarine cable across Carquinez Strait by the drill column or anchors. If it had not been for this the section would have been drilled directly off Dillon Point. See Plate 3-7.

Samples.

Three kinds of samples were obtained. Wash samples were gotten by catching the return water from wash borings at the top of the casing. The sample is not representative as the fines are carried away in suspension and since the velocity of the return water, up the casing, is not sufficient to carry the heavier material. They are of considerable value in drilling operations, however, and drillers keep constant watch of the "returns."

Drive samples, if properly taken, are truly representative. A number were obtained by driving the hollow drill rods with the chopping bit removed, or the 2½-inch pipe, into the material being sampled. Upon withdrawal of the tool the sample was extracted.

Diamond drill core, representing bedrock, was obtained in the usual way by drilling into the rock after seating the casing and sealing the joint.

All core obtained was stored in ordinary core boxes. The wash samples and drive samples were put into glass fruit jars. Each was identified according to the drill logs and as shown on the drawings. All were shipped to the State Department of Public Works, Division of Engineering and Irrigation, at Sacramento, upon completion of the work.

Cost of Drilling.

The detail cost of drilling, and the distribution of costs, are given on the following pages. It will be noted that unit costs are referred to depths below sea level and below mud line. Following established practice, all measurements of depth were referred to water surface. It is believed that it is proper to include the water as part of the drilling although the unit costs are thereby reduced. Difficulties of drilling increased with depth of water and the total cost of a hole was affected more by the depth of water than by the depth of "mud."

SACRAMENTO VALLEY INVESTIGATIONS—SALT WATER BARRIER

SUMMARY OF DRILLING COSTS

FIELD COSTS

Item	*Total cost*	*Cost per shift*
Direct labor—		
Total time book charged to drilling	$12,847 92	$22 10
Indirect labor—		
Boatman, watchman, repairman and proportion of Berkeley office expense	7,614 27	13 10
Tugboat—		
Rent, fuel and oil	4,710 70	8 10
Drill barge—		
Fuel, oil and water	691 87	1 19
Carbon loss	342 92	59

SUMMARY OF DRILLING COSTS—Continued

Item		*Total cost*	*Cost per shift*
Automobile expense—			
Transportation for drill crews		$843 81	$1 45
Miscellaneous supplies and freight—			
Material and supplies—Navy Yard	$2,018 71		
Other supplies	1,356 05		
Freight on equipment	234 79	3,659 55	6 30
Preparatory and dismantling expense—			
Railroad fare and expense of crews	$116 64		
Labor—Navy Yard	2,687 37		
Labor—Bureau of Reclamation	1,590 56		
Dockage	24 00	4,418 57	7 60
Depreciation		2,131 82	3 67
Total field cost as of December 31, 1926		$37,261 43	$64 10

Drilling was begun on August 16, 1924, and finished on August 7, 1925. Total number of shifts worked, 581¼.

Wages paid—	
Diamond drill foreman	$250 00 to $275 00 per month
Boatman	180 00 per month
Diamond driller	7 00 per day
Diamond drill helper	5 00 per day
Repairman	6 00 per day
Watchman	5 00 per day
Tug boat rent (including insurance)	320 00 per month

Overhead—Field office only—	
Time of engineer in charge	40%
Time of clerk	40%
Operation of one automobile	40%

6—70686

DRILLING—SALT WATER BARRIER

Distribution of Field Costs

Item	Wash boring			Diamond drilling		Combined		
	Total cost	Below sea level 23,841.5′	Below mud line 15,477.7′	Total cost	Total diamond drilling 798.6′	Total cost	Below sea level 24,640.1′	Below mud line 16,276.3′
Direct labor	$6,072 86	$0.255	$0.393	$1,414 95	$1.771	$7,487 81	$0.304	$0.460
Indirect labor	3,607 99	0.151	0.233	842 47	1.055	4,450 46	0.181	0.273
Tugboat	2,235 66	0.094	0.144	526 02	0.659	2,761 68	0.112	0.170
Drill barge	331 77	0.014	0.021	73 43	0.092	405 20	0.016	0.025
Carbon loss				342 92	0.428	342 92	0.014	0.021
Automobile	404 18	0.017	0.026	88 36	0.111	492 54	0.020	0.030
Miscellaneous supplies and freight	1,214 23	0.051	0.078	359 82	0.450	1,574 05	0.064	0.097
Preparation and dismantling	2,555 35	0.107	0.166	677 22	0.847	3,232 57	0.131	0.198
Depreciation	1,035 50	0.043	0.067	229 21	0.287	1,264 71	0.051	0.078
Totals	$17,457 54	$0.732	$1.128	$4,554 40	$5.700	$22,011 94	$0.893	$1.352
Proportion of moving	12,673 79	0.532	0.819	2,575 70	3.223	15,249 49	0.618	0.937
Totals	$30,131 33	$1.264	$1.947	$7,130 10	$8.923	$37,261 43	$1.511	$2.289

NOTE:—Total cost is given in Exhibit 9 from which it will be noted that about 17% should be added to the above field costs to include superintendence, accounts and general expense.

CHAPTER IV

DESIGN AND CONSTRUCTION

GENERAL

Object and Scope of Studies.

Assumptions fundamental to studies of design and construction involve many debatable technical points which have important bearing on the cost of the barrier. Diversity of opinion may, therefore, lead to a wide range of results in the preparation of preliminary estimates.

An attempt has been made to follow conservative engineering practice but this object has been attained only in part. Certain conditions have led inevitably to some structures that are unprecedented in one or more respects. Unusual features are in the minority, however, and the treatment of structures, in general, does not express undue optimism. Studies have been carried no farther than necessary to insure proper functioning of the main features of the barrier and to establish the elements of cost where precedent is lacking.

Nineteen estimates are presented in Part Two of this volume for works at the following sites:

Army Point—Suisun Point.
Army Point—Martinez.
Benicia.
Dillon Point.
Point San Pablo.

The provisions of the various estimates are described in connection therewith.

No attempt has been made to include a study of docks, wharves or warehouse facilities which will naturally find place adjacent to the barrier, for the reason that such a study is considered outside the scope of this report.

Foundation.

All concrete structures are founded on rock, and foundations which it is proposed to construct behind cofferdams are limited in depth to 90 feet below mean sea level at the original surface of rock. This limit has been fixed in consideration of pneumatic work which may, ultimately, be deemed preferable to the open cofferdam construction provided for in the estimates. The placing of concrete by the tremie method is contemplated when conditions make it necessary to exceed the 90-foot limit, as described subsequently.

The surface of sand and gravel occurs, generally, at greater depths than 90 feet below mean sea level at the three sites and these materials are therefore eliminated from foundation considerations by the foregoing restriction, except as a support for piling.

The feasibility of supporting concrete by piling merits discussion. Structures of this type have heretofore been proposed for the barrier and seem to offer an advantage in cost. Large quantities of excavation could be avoided by locating the structure wholly within the present submerged areas, a plan that can not be followed with the imposed limitation on account of the depth of rock. It is not claimed that pile structures are impracticable, but it is believed that their permanence can not be predicted with certainty. In connection with the rock embankment considered farther on in this chapter the action of the silt overlying the sand and gravel is discussed. Piling would necessarily penetrate this silt, which it will appear is of a shifting, unstable character, for considerable depth before reaching the firmer sand and gravel. A bodily movement of this material at the structure during a seismic disturbance is not inconceivable and might result in partial or total destruction of the structure. Even a slight movement caused by unbalanced water pressure would be a source of inconvenience, if not danger, by interfering with the operation of floodgates. In this connection the report that the Ferry Building at San Francisco, constructed on piles, has settled approximately 14 inches since its completion in 1898 is of interest.

The cost of some of the proposed structures is largely influenced by the allowable foundation pressure. Those subject to appreciable modification in correspondence with various assumptions are discussed separately later on. No pressures have been allowed to exceed 12 tons per square foot. They are generally limited to 10 tons but a margin of 2 tons has been allowed to avoid unnecessary refinement in design. It is believed that any criticism invited by this limitation will favor greater liberality and that the requirements of conservatism are satisfied to a degree sought in the studies. It was not considered warranted to distinguish between the bearing qualities of the rock at different sites.

Materials in Salt Water.

The doubtful aspects of reinforced concrete in salt water have received consideration and structures that do not require reinforcing steel have been adopted where practicable. The greater bulk of the plain concrete structures, however, frequently leads to larger quantities under other items, particularly excavation, and the effect may be so far-reaching that any disadvantages of reinforced concrete become relatively insignificant. The choice of material, accordingly, represents a balance of conflicting factors. All reinforcing steel is protected from salt water by 12 inches of concrete.

It is not within the province of this report to discuss, at length, the action of metals when exposed to salt water. Experience at Panama indicates the need of careful selection, as described in *Engineering News Record* of June 27, 1918, under the title, "Protecting the Panama Lock Valves against Electrolysis." At the Lake Washington Locks metals have resisted corrosion satisfactorily. The following is quoted from W. J. Barden, Colonel, Corps of Engineers, at Seattle:

> No trouble due to galvanic action has been noted at the Lake Washington Canal Locks. Bronze is used under water only for bushings of rollers, for roller trains, washers at ends of rollers, bushings and washers for gate cable sheaves. Bronze bolts or nuts are not used on lock valves or gates nor on any iron in contact with salt water. Babbitt metal is used in bottom seals for Stoney gate valves, and valves and lock gates inside and outside are painted with bitumastic solution and enamel.
>
> At Panama the bottom seals for the valves were changed from Babbitt metal to greenheart lumber and all bronze bolts were replaced with steel bolts.

Zinc strips were bolted to the valves on the lower edge on each side of the bottom casting.

The use of metals at Lake Washington has been followed in the design of structures for the Salt Water Barrier.

In salt water, where the teredo is active, the short life of timber structures, particularly when unprotected, is a matter of common knowledge. The belief that certain woods possess teredo-resisting qualities is evidently unwarranted. Colonel Barden is quoted again as follows:

The iron bark for guard gate seals which was used in place of the greenheart at the Lake Washington Lock was badly eaten by teredo in two years, and the greenheart timber attached to the concrete mitre sill was also destroyed by teredo.

Rubber and steel were substituted for the iron bark and greenheart at Lake Washington and complete satisfaction has resulted. *Engineering News Record* of October 12, 1922, contains a description of the disappointing results from the use of greenheart at Panama, notwithstanding definitions quoted therein from the New International Encyclopedia and the Encyclopedia Britannica which justify confidence in its permanence.

The use of submerged timber has been avoided in designs for the barrier so far as practicable. No other material appears suitable, however, for fenders on lock gates. Guide walls in certain locations are of timber to avoid expensive cofferdam or caisson construction. The estimates contemplate creosoting in such cases. Gate fenders could be renewed at little expense and it will be noted that the lowest estimates provide for concrete and steel guide walls, though for reasons which have no relation thereto.

Excavation.

Wet and dry excavation in extremely large quantities is necessary. Sand and silt under water would be removed by suction dredges and disposed of at convenient locations along the shore. It may be practicable to reclaim large areas of tidal lands with this material and introduce an element of profit in connection with the operation.

Sides of cuts in sand and silt for permanent structures require a slope of about 1 on 5 to insure stability according to local Army engineers, whose experience in harbor improvements constitutes reliable authority.

Special equipment would be required for wet rock excavation owing to the unusual depths, with a maximum of 70 feet at mean tide. In general, a large amount of wet and dry rock excavation would be required for fill and further study is necessary to determine the feasibility of taking it directly to the fill after removal without introducing objections as described later. Slopes of 1 on $\frac{1}{2}$ have been adopted for unprotected sides of permanent cuts in rock.

Excavated Rock Used for Fill.

There is generally sufficient material available from excavation for structures to satisfy the needs of the embankment and other permanent fills of broken rock. Borrowing is necessary in some schemes, however, to supplement the supply from excavation and the cost of the fill would depend upon the source of material. The fill in any scheme for the barrier comprises a number of distinct units for which the cost could not be expressed as a function of the source of supply without prescribing the disposition of each cubic yard of excavated and borrowed rock. It was more convenient to allow for borrowing in all unit costs for fill and make a single adjustment in the estimates corresponding to the quantity available from excavation.

Following the gross total near the end of each estimate the above adjustment appears as a credit. To make its purpose clear a summation of the quantities in rock embankment and fill is presented in terms of loose and solid measurement, the latter being necessary for comparison with material to be excavated. The lesser of the two quantities in solid measurement represents the overallowance for borrowing which should be deducted. The swell of the rock when excavated is discussed under embankment.

The foregoing considerations are of importance in studying the influence of the various elements of cost on the total cost of the barrier since the significance of those which involve rock fill is appreciably altered by the subsequent adjustment.

Obstruction of Existing Waterways.

The formulation of a construction program which does not entail dangerous restriction of flood and tidal action, and at the same time promotes the utmost efficiency in construction, is a matter which merits intensive study. A fixed obstruction across the existing waterway would not be permissible until artificial means of accommodating floods had been substituted therefor and a problem develops in connection with the disposition of the excavated material which would ultimately comprise the embankment but could not be deposited at that location as it became available.

A large quantity of the material would sink into the silt and it could undoubtedly be deposited to an elevation somewhat above the bed of the channel without serious consequences. In many cases the cofferdams constitute an initial obstruction that would influence the program for the rock embankment. The situation could be greatly improved by devising means for putting a portion of the flood channel and gates into service while construction was in progress on the remainder. This possibility exists in the schemes proposed for Estimates 1 and 2 as described later.

By avoiding temporary storage of excavated material and subsequent rehandling, a large saving would be assured and the matter will undoubtedly be given thorough study before construction is undertaken. It has been assumed that success will attend these efforts and, accordingly, no need for handling the material twice is recognized.

UNWATERING

Work Included.

Unwatering includes the items under the same caption in the preliminary estimates. The construction of cofferdams required for unwatering at Stoney gate locations in Estimates 10 to 13, inclusive, is itemized under control works. These cofferdams are formed by caisson gates as shown on Plate 4-40, and since the caisson gates are intended to provide access to the Stoney gates as required after the completion of the barrier, their cost is not included with temporary works.

The construction of cofferdams involves excavation within the limits of permanent structures that is essential to the operation of the latter, aside from cofferdam considerations. These structures should, and do, bear the cost of this work, but in order that the initial expenditure for unwatering may be given in its entirety, the preliminary estimates show a gross total from which items otherwise chargeable are subsequently deducted. The salvage value of sheet piling discussed later is included with these deductions.

Types of Cofferdams.

With modifications more or less fundamental according to the various needs, the main cofferdams are of the type adopted for the construction of a 1000-foot pier at New York City, described in *Trans. Am. Soc. C. E.*, 1917. For structures offshore from Suisun Point, Martinez, Benicia, Eckley (Dillon Point site), and to a limited extent offshore from Point San Pablo, as described later, the type closely resembles that used at New York and is shown on Plate 4-4. The maximum height is considerably more, however, and splices, in large quantity, are necessary to attain lengths of sheet piling up to about 130 feet for the deepest portions. Off shore from Point San Pablo much of the rock is bare and in the absence of supporting material for the piling, a timber trestle has been provided with a rock jetty, immediately upstream, to deflect the current during cofferdam construction. See Plates 4-51 and 4-55. Smaller cofferdams are required in considerable variety. In Estimates 3, 4 and 5 (Plates 4-18, 4-20 and 4-22) the east cofferdam consists of a single line of sheet piling driven to rock through silt in its original position. The west cofferdam is located in silt where bedrock is close to the surface and no sheet piling is necessary in combination with the rock fill.

The rock off shore from Dillon Point is bare but with a required maximum height of about 40 feet, and with structures not opposing the force of the current, construction is somewhat simplified. Cofferdams at this location are built with the aid of a trestle to support the piling before placing the rock fill. See Plates 4-33, 4-35, 4-37 and 4-47.

In addition to the main cofferdams at Point San Pablo, Estimate 16 requires a rock fill similar to that in the west cofferdam at Suisun Point (Estimates 3, 4 and 5). See Plate 4-57. The north cofferdam for Estimate 16, though comparatively small, is of the type shown on Plate 4-4.

The west cofferdam for Estimate 6 (Plate 4-25) is necessary for the construction of the retaining wall which protects the Martinez shore against erosion. It consists of a wide trench, formed by a double row of sheet piling with heavy timber bracing between.

In most estimates large areas, at present above sea level, must be excavated to elevations below water surface. To carry on this work in the dry so far as possible, the construction program contemplates leaving material in place along the shore line, below El. 10, in the form of a dike with a slope of 1 on $\frac{3}{4}$ on the land side and a top width of 30 feet to accommodate a double-track construction railroad. Excavation within the protection of the dike would be carried to grade in the dry and the dike subsequently removed as wet excavation. The dike has been termed "natural cofferdam" in the estimates for lack of a better term.

Steel Sheet Piling.

Preliminary estimates provide for sheet piling of uniformly heavy section similar to Lackawanna, or United States, weighing about 43 pounds per linear foot and having a strength of approximately 9500 pounds per linear inch at the interlock. A weight of 95 pounds per linear foot is assumed for the three-way piles at the intersections of longitudinal and transverse rows. The Bethlehem Steel Company states, in letter dated August 7, 1925, that lengths greater than 55 to 65 feet are impracticable without splicing and that splices for Lackawanna piling to meet the requirements would weigh 68.7 pounds each.

Cofferdam Construction.

The construction of many of the cofferdams described briefly above involves difficulties and risks which are unavoidable without materially increasing the cost of other items. If it may be granted, however, that accomplishment will continue to transcend precedent, the feasibility of the proposed schemes is not a matter for concern. In the time allotted to the study of similar works, it became evident that there is no radical departure from accepted practice. As the success to be attained in the construction of the ship locks and flood gate structure in many of the designs presented is dependent upon the feasibility of unwatering the site, a discussion of cofferdam construction is, however, considered warranted.

The first operation in constructing cofferdams of the type shown on Plate 4-4 is the driving of sheet piling which would progress from the shore at both ends. Methods for driving the piling in the positions shown on the drawing have been developed to meet earlier needs and will not be discussed. Material to be penetrated would offer little resistance and the driving is expected to be a simple operation. Splices would be attached when the top of the lower section is a few feet above water surface.

Excavation on both sides of each longitudinal row of piling would closely follow the operation of driving. Material would be removed to within about 20 feet of rock along the piling on the side to be unwatered, thence sloping flatly to the rock surface. Beyond the toe of this slope, material would be removed over the area ultimately to be occupied by the rock fill. Beyond this area it may be left in place temporarily, on as steep a slope as consistent with assurance against movement. It is expected that the rock fill will displace the material left along the piling and reach rock with its interstices filled adjacent to the bottom of the piles. At the same time the surface of silt in the pile pockets would be lowered, maintaining the surface about 15 feet above that of the material inside the cofferdam. The surface of material at the piles on the outside of the cofferdam would be maintained at the elevation of that in the pockets, and the mud would slope flatly upward from the piling to its original surface.

Experience indicates the necessity for internal pressure at each pocket to provide some tension at the pile interlocks and thereby avoid danger of collapse. Care must be taken, however, to avoid stresses exceeding the strength of the interlock and it has been demonstrated that unbalanced pressures of approximately the intensity to be expected from the foregoing program will lead to satisfactory results.

It is assumed that excavation in construction of cofferdams will be performed by suction dredges. The material is almost entirely sand and silt. Clay is encountered at these depths in quantities too small for recognition in the estimates.

At this stage of the operations the piling would be largely unsupported and there would be, in addition, an unbalanced pressure. A pile section of appreciable horizontal length, if left thus, might invite disaster and it is important to have the operation of placing rock follow the excavation as closely as practicable. Owing to the flat slopes that must be maintained to avoid movement of the silt, there would be a number of pile pockets left unsupported to a greater or less degree, but it will be noted that this section must receive support from those at either end whose stability is assured by the presence of rock fill, or silt, in its original position. The rock fill is to be placed on both sides of the double row of piling and the surface of the material in the pockets would be raised, maintaining the original relative positions, by depositing clay brought to the site on a standard gauge construction railroad. It is important to maintain a fair balance in pressure from rock fill on opposite sides of the piling, as well as an excess of pressure from the material in the pockets. The completed fills are shown on Plate 4-4.

If it is feasible to allow some of the silt to remain inside the cofferdam during the placing of rock it would be excavated before the cofferdam is unwatered by the method employed for material adjacent to the piling.

Off shore from Point San Pablo the situation is complicated by the absence of mud over large areas. At such places some modification of the foregoing plan is necessary. Cofferdams extending into the current (Estimates 14 and 15) seem to require the protection of a rock jetty during their construction. (See Plates 4-51 and 4-55.) Slopes of 1 on 2 with 10-foot top width are contemplated for this structure.

With the assurance of still water within the area of operations, a timber trestle of 6-pile bents on 10-foot centers, with outer piles battered for stability, would be built along the cofferdam line to furnish support for the steel sheet piling. Waling pieces would hold the piles in place at the top and, for convenience, pockets rectangular in plan (16′ x 24′) are proposed. The trestle must be loaded to overcome buoyancy. To insure a fixed position at the bottom, and to improve water tightness, piles would be driven to refusal in the rock which is generally soft at the surface.

The pile pockets are to be filled to a depth of about 10 feet with clay as soon as they are ready to receive it, so that the danger of collapse would be removed as previously stated. The width of trestle that appears necessary for stability and proper arrangement of the sheet piling will accommodate a double-track railroad of standard gauge.

Subsequent operations would follow the program devised for cofferdams shown on Plate 4-4 until the surface of rock fill reached the bracing near the top of the trestle. The bracing would then be removed to facilitate the removal of the entire cofferdam described later. For the same reason the timber piles would be cut off at the surface of the fill after completion and the track laid on the fill.

The cross-section of completed cofferdam would differ from that on Plate 4-4 only in respect to the slope of rock fill, which would be 1 on $1\frac{1}{2}$ on both sides, and the uniform width of 16 feet between the two rows of piles. This leaves a level portion 17 feet wide at the top of the rock fill on the outside. The fill, of course, would rest upon bedrock on both sides of piling.

Sketches of the structure were prepared in connection with estimates of quantities, but, except for the trestle, their similarity to the type of cofferdam previously discussed makes it unnecessary to reproduce them in this report. Estimates 14 and 15 require about 3500 linear feet of this type of structure with the remainder, where mud is present (about 2300 linear feet) as shown on Plate 4-4.

The smaller cofferdams present in a lesser degree the problems already discussed and are omitted from further consideration.

In connection with the natural cofferdam, which was described briefly with other types on a preceding page, Estimates 1 and 2 include an item termed "plug" which requires explanation. Its purpose is to fill a temporary gap opened in the natural cofferdam to permit construction of the control works without discontinuity at that point. See Plates 4-1 and 4-14. With the plug in place around the completed control works the unity of the natural cofferdam is restored, and the main cofferdam may be removed before construction within the natural cofferdam has been completed. An equivalent area across the original waterway would thereby be made available for depositing excavated material along the location of the rock embankment before completion of the flood channel and control works.

Removal of Cofferdams.

The functions of the barrier can not be realized without removing all, or part, of the cofferdams as will be seen by reference to the general layouts. The lower portions of the cofferdams might generally be left in place without causing interference. In such cases piles would not be entirely freed from surrounding material and it becomes necessary to decide between the alternatives of cutting and pulling to accomplish their removal. Estimates contemplate pulling steel piles when the penetration does not exceed 25 feet and cutting in other cases. The determination of this limit is influenced somewhat by the salvage value of the piles. It is assumed that 50 per cent of those removed will be fit for further use and may be disposed of to lessen the ultimate cost. Investigation indicates that it is becoming common practice to cut steel piling under water and no difficulty is anticipated within the depths required for the barrier, where the maximum would not exceed 70 feet. It has been assumed that timber piles would be cut when their removal is necessary.

FLOOD CHANNEL

Requirements.

The capacity of the flood channel is fixed by that of the control gates.

Hydraulic Properties.

Gradual slopes and transitions have been provided so far as practicable to minimize the losses. Velocities vary uniformly from the minimum at the upstream and downstream ends to the maximum at the gates. These characteristics involve expenditures which may in future studies be deemed unnecessary. Steeper slopes and more abrupt changes in cross-sectional area may be advocated for excavation with assurance that the waters will scour their own channel. This view may be carried to great extremes, however, and the more conservative treatment of providing a thoroughly adequate channel by artificial means is favored in this report, with recognition of the margin that exists. Moreover, the uncontrolled deposition of large quantities of silt at points downstream from the barrier might result in a hindrance to navigation.

CONTROL WORKS

Requirements.

The gate area necessary to pass the maximum flood from the Sacramento and San Joaquin rivers, estimated to be 750,000 cubic feet per second, is discussed in Chapter V. Requirements are satisfied by thirty 50-foot by 60-foot gates or fifteen 70-foot by 80-foot gates, the first dimension being the width of waterway between gate piers and the second the depth of gate sill below El. +10. At Point San Pablo the freeboard requires greater height for the same elevation of gate sill. Additional gates are provided in some cases when conditions permit their use as an alternative for rock embankment which would otherwise be required.

Substructure.

The term substructure has been applied to the concrete portion of the control works below elevation +12 at Point San Pablo and below elevation +10 at other sites. Greater exposure to the elements at the former site indicates the need for more freeboard.

Two distinct types of substructure are contemplated in alternative schemes as shown on the drawings. At Army Point, Benicia, Point San Pablo and in one case (Estimate 9) at Dillon Point, the construction would be carried on within open cofferdams. In schemes which provide for control works across all, or part, of the present waterway at Dillon Point, however, the foundation attains depths too great for the success of this method and estimates contemplate the depositing of concrete by tremie in caissons sunk to rock as described later.

Reinforced concrete is contemplated for substructures of the type shown on Plates 4-5, 4-16 and 4-24, built by the cofferdam method. The width of gate piers influences the width of flood channel and it will be seen from the general layouts that, with the position of the offshore end of structures fixed by the 90-foot limit previously discussed, the amount of excavation would be materially increased by the use of wider piers of plain concrete.

Each gate pier, with the footing parallel to its horizontal axis, has been designed as a unit. Resistance to overturning at the elevation of the floor and bottom of footing has been determined transversely by assuming an excess of head amounting to 10 feet on one side of the pier, a condition that might be approached, if not realized, if one of the adjacent gates were up and the other down. It was further assumed that caisson gates were in place on one side of the pier in the positions shown by the caisson gate seats on the drawings, and that the space between was unwatered for access to the Stoney gate. a tractive force of 100,000 pounds from a locomotive on the bridge was added to the unbalanced water pressure, and stability was provided with uplift due to full hydrostatic pressure over the entire area of the base.

The floor beams, which connect the footings and make an integral structure of the control works, are an added factor in its stability rather than a necessity, except when the space adjacent to the Stoney gates is unwatered. Their value in the event of an earthquake is apparent; probabilities of a disaster are more remote than if the piers were isolated; and they perform the additional function of preventing the serious undercutting of strong currents. Although the footings are adequate to resist transverse overturning, except as previously stated, the floor beams must inevitably take their share of the stress when unbalanced external forces are acting and they consequently require heavy reinforcement.

Resistance to unbalanced longitudinal forces provides for a wind load of 30 pounds per square foot on all structures above water surface, including the Stoney gates when raised. With gates down, unbalanced heads of 12 feet downstream and 10 feet upstream were separately investigated in combination with wind load and uplift.

Foundation pressures under the solid type piers do not exceed 10 tons per square foot and sliding does not require special provisions in any case. The dimensions are governed by stresses in the concrete and necessary resistance to overturning and would not be influenced by more liberal allowances for foundation pressure.

Features of the design and construction of the substructure for control works across the present waterway at Dillon Point site are shown on Plates 4-39 and 4-40. The design is further shown by control works drawings for Estimates 10 to 13, inclusive. (Plates 4-41, 4-42, 4-43, 4-45, 4-46, 4-49 and 4-50.) In this case the limiting foundation pressure is directly responsible for the hollow type of pier adopted.

Steel caissons for the deep portions of the channel are of enormous weight, notwithstanding the adopted working stress of 24,000 pounds per square inch. Unbalanced pressures are avoided so far as practicable. It was assumed that mud would be excavated to elevation —70, where rock is below that elevation, before caissons are sunk, hence only the lower portions must resist pressure from this source. Unwatering is not contemplated. Salt water within the caisson can, of course, be replaced by fresh water before concrete is deposited in case the salt water is considered objectionable.

Studies of pressure induced by silt, made in connection with Colorado River investigations, indicated that material weighing 100 pounds per cubic foot would exert a horizontal pressure of about 80 pounds. The studies included pressures recorded by Goldbeck cells in a number of hydraulic fill dams and recommendations of various experimenters in addition to data secured at Boulder Canyon, and may be considered fairly representative of conditions in San Francisco Bay. On this basis the external pressure below elevation —70, after excavation is begun, would be 80—62.5 or 17.5 pounds per square foot (in fresh water) for each foot in depth. The weight of one cubic foot of "ooze," or slimy silt, as taken from the tidal flat just off Suisun Point has been found to be 81 pounds. The ooze contains about 70 per cent moisture and, although of comparatively light weight, probably exerts lateral pressure almost, if not quite, equal to that exerted by the material found at greater depth.

A cofferdam is necessary for constructing the abutment pier at the side of the flood channel near Eckley. See Plates 4-35, 4-37 and 4-47. This pier is similar to those at the ends of control works previously discussed. After completing the rock embankment inshore from the pier an area of sufficient size is available for erecting the traveler shown on Plate 4-40. Subsequent operations, prior to concreting, need no explanation further than to state that the traveler controls the position of the pier caissons during sinking and the latter performs a similar function for the corewall caissons.

The inner and outer skin plates of the pier caisson terminate at different levels at the bottom to allow the tremied concrete to cover the entire area within the outer plate to a depth of 15 feet.

With this type of pier the gate sill is at elevation —70 in all cases and the foundation is never higher than elevation —75. Above this elevation the design presents for unbalanced forces acting transversely and longitudinally, but at lower elevations it has been assumed that they would be absorbed by the rock fill shown on the drawings, and that no inequality can exist in the distribution of pressure over the foundation, except from the eccentricity of the resultant of the vertic loads. Pressures include weight of water in the hollow portion the pier up to elevation 0.

Transverse stability, when the base is at elevation —75, satisfi the assumptions of unbalanced head (10 ft.), unwatering betwe caisson gates and locomotive traction that have been discussed in co nection with solid piers of reinforced concrete. Resistance to unb anced longitudinal forces, however, is based on slightly differe assumptions owing, in part, to progress in studying flood and ti action during the period which intervened in the designs of the t types of piers. The same provisions were made for wind loads, an unbalanced head of 10 feet was assumed to act either upstream downstream and uplift was anticipated over only two-thirds of base area under full hydrostatic head. The conditions to be satisf are, therefore, somewhat less severe than in the previous case.

When the base is lower than elevation —75, it is evident that stabil is dependent upon the rock fill, except for the support the corew and pier afford each other by reason of their individual failure necessarily being subject to the same combination of circumstances.

Foundation pressures under the hollow type piers do not exc 12 tons per square foot and are generally lower. Tension does occur at any horizontal section. Uplift is of importance in this nection at elevation —75, but at lower elevations its effect is negligible, owing to the absorption of horizontal forces by the rockfill. The eccentricity of the resultant of vertical forces is so slight that the danger of tension is not approached under the influence of uplift. The maximum pressure in the concrete of the pier is about 15 tons per square foot and occurs at the top of the solid base. Sliding factors are very low. In contrast with the solid piers previously discussed, the allowable foundation pressure is of prime importance.

Pressure from the rock fill on the sides of the hollow piers indicates the need of diaphragms below elevation —90 in most cases. The caissons are somewhat complicated by this requirement but the height above the top of diaphragm provides sufficient horizontal continuity and rigidity when supplemented by bracing at lower elevations.

In the preparations of the designs considerable thought was given to the action of salt water upon concrete although the salinity in the vicinity of the barrier will never equal that of the ocean, on account of the operation of the ship locks. It appears that there should be no particular cause for apprehension providing the concrete is proportioned to give low permeability. It is believed that good, tight concrete may very readily be secured by careful grading and proportioning of the aggregates and by demanding a high class of workmanship. The subject is discussed by Mr. Irving Furlong, associate chemist, Bureau of Standards, in a letter included herewith as Exhibit 13.

Mr. R. R. Arnold, county engineer, Contra Costa County, has used salt water in gaging concrete for highway work and states that after 2 or 3 years service, (December, 1925), the concrete appears to be as good as any in the county. The action of sea water on concrete structures is summarized in Exhibit 14 which includes extracts from a report upon the subject, compiled by the Standard Oil Company.

There appears to be considerable precedent for building deep piers by the open caisson method and for placing concrete by the tremie method.

The following are extracts from Vol. 1 (1916 Edition) of Waddell's "Bridge Engineering":

> The open dredging process for deep foundations has been in use only about thirty years, the oldest examples of it being the Poughkeepsie Bridge over the Hudson River, where a depth of 134 feet below high water was reached, the Morgan City Bridge over the Atchafalaya River, where eight-foot cylinders were sunk to a depth of 120 feet below high water and the Hawkesbury River Bridge in Australia, where the remarkable depth of 160 feet was attained.
>
> Probably the greatest depth ever reached was on the bridge over the Ganges River at Sara, India, the cutting edge of one of the piers for this structure landing 160 feet below lowest water, or 190 feet below high flood level.
>
> In the Oregon and Washington Railway and Navigation Company's vertical lift bridge over the Willamette River, at Portland, Oregon, * * * the two main piers * * * were sunk by the open dredging process under great difficulties. The depths to which their bases had to go, viz, 132 and 145 feet below low water, rendered the open-dredging process obligatory. In plan, each caisson was 36 feet by 72 feet. The borings showed a bed of cemented gravel and boulders amply solid for a foundation; but unfortunately, it was far from level, in one case there being a difference of elevation of 19 feet between the diagonally opposite corners of the caisson. Before any sinking was attempted, the foundation was prepared by blasting to receive the caisson.

Open dredging within caissons at depths found at the Dillon Point Site is considered practicable in view of the character of the channel filling. No trouble in seating the caisson on the bottom is anticipated on account of the generally soft character of the rock.

In connection with placing concrete under water the following references should be noted:

Engineering News, September 24, 1903. The new graving dock of the Kawasaki Dock Yard Company at Kobe, Japan. The article described the construction of a dry dock supported on piles, in which 27,200 cubic yards of concrete were placed under water by means of buckets. The thickness of the floor was 9 feet. Before concrete was placed the salt water was replaced by fresh. An interesting feature was the attempt to build coffer-dams on soft silt and sand, with resulting settlement of the fill and building of the ground adjacent to it.

Engineering News Record, April 15, 1920. Heavy foundation work for bascule bridge at Seattle. Concrete placed under water by means of tremies was used to seal two caissons, the seal at one caisson being 23 feet thick with bottom of footing 54.5 feet below the water surface, the seal at the other caisson being 15 feet thick with the bottom 43 feet below water surface. A total of 6,493 cubic yards of 1:2:4 concrete was deposited under water at an average rate of 25 cubic yards per hour. It was found that concrete which flowed readily on a 1 on 3 slope in metal spouts would flatten out and flow a distance of 30 feet at a slope of 1 on 6.5 under water. Examination after the caissons were unwatered disclosed hard, dense concrete without any lamination except in small spots and on the toe of one pier.

Engineering News Record, May 26, 1921. Concrete Sea Wall. Poured in Block Sections By Tremie. Sea wall 6 feet thick on top and 12 feet thick at the bottom was placed on rock foundation about 15 feet below low water surface, the concrete being poured through tremies. This wall served as part of foundation for a steam plant of the United Electric Light and Power Company on the East River, New York City. 1:2:4 concrete was used.

Engineering News Record, November 3, 1921. Concrete River Wall Poured Inside Large Steel Forms. Ohio Basin Terminal of Barge Canal at Buffalo. Under water concrete placed true to line and grade by flexible system of forms. A concrete gravity wall 1,550 feet long was founded on rock 21 to 28 feet below normal water, part of the concrete being poured under water. The portion of wall below an elevation 12 feet below mean water surface was specified as 1:3:6 concrete providing that one extra sack of cement per cubic yard of concrete would be used if the concrete was placed in water, which the contractor elected to do. The form is of novel construction, designed by the Blaw-Knox Company. In order to examine the concrete several 30-inch diameter test wells were provided and examination showed that the concrete is of excellent quality.

Transactions, A. S. C. E., page 223, Vol. LXXX. Pearl Harbor Dry Dock. Approximately 14,840 cubic yards of concrete deposited through tremies in water varying in depth from 54 to 44 feet. Article contains a large amount of good information about placing concrete through tremies and about deep water foundation work.

Transactions, A. S. C. E., page 289, Vol. LXXIV and *Engineering News*, March 17, 1910. The Detroit River Tunnel. Concrete placed through tremies in water from 60 to 80 feet deep. Samples of 1:3:6 tremie placed concrete, 2 years old, tested from 2740 to 4000 pounds, per square inch. Article contains much valuable information about under water concrete work.

Superstructure.

In most cases the proximity of the bridge to the superstructure of the control works has suggested a single structure to meet the requirements of both, with its cost shared according to its functions.

The term, "pedestal," has been applied to the concrete supports under the gate towers which are shown in combination with concrete bridge piers. The pedestal presents no unusual features. The extreme test of stability occurs with a wind load of 30 pounds per square foot and the gates raised. The steel gate towers are stressed to capacity under the same conditions.

Stoney Gates.

Stoney gates seem to offer the best solution of the problems of flood control and salinity. They are easily operated and function properly with any size of opening above the gate sill. It has been demonstrated that the salt water will seek the lower levels in the basin above the barrier and some provision for drawing off this water from the bottom is an established necessity.

Gates have been designed to withstand a head of 15 feet from the upstream side. With water on both sides, the unbalanced head is, of course, constant below the elevation of the lower water surface. The gates would be appreciably heavier with a skin plate on each side since both would have to resist the head above the gate sill.

The double skin plate would provide protection for interior members and prevent the deposition of silt and debris on the horizontal girders. However, since protection against corrosion is of greatest importance on the salt water side, this danger may be largely avoided with a single skin plate. With only one skin plate the annual task of painting the gates would be simplified. These considerations, and the advantage of presenting a smooth surface in opposition to the greatest wave action, led to the arrangement shown on the drawings. The amount of silt in suspension on the fresh water side is not likely to be great when the gates are down and the skin plate would unavoidably, at times, be on the tension side of the gate since it is expected that the elevation of the salt water will occasionally exceed that of the fresh. The thickness of the skin plate which is perhaps somewhat unusual is a precaution against corrosion.

Preliminary designs for the gates are shown on Plates 4-8 and 4-17. It will be noted that concave rollers are provided in anticipation of deflection of the gate leaf, and that staunching rods are provided to prevent leakage from either side.

Counterweights.

Counterweights were studied in connection with their relation to the weight of the Stoney gates and in the brief time allotted to this work it seemed advantageous to make their weight equal to that of the submerged weight of the gate and two-roller trains.

The heavy steel members are intended to serve the double purpose of supporting the forms while the counterweights are being concreted in place on the gate piers and of taking the place of reinforcing steel subsequent to construction.

Operating Mechanism.

Details of the operating mechanism have been worked out as shown on Plate 4-7 but do not warrant discussion. By placing the motors at the middle of the spans across the gate towers unequal torsional deflection in the shafts connecting them with the sprockets is avoided and the movement of the lifting chains is synchronized. The designed lifting speed is 4 feet per minute. The load on a motor during the raising of a gate is more constant than might be supposed. As a gate emerges from the water it gains in weight, but the rolling friction, due to water pressure, becomes less and the combined effect of these two factors is fairly constant at times of maximum head.

Caisson Gates.

Reference to caisson gates will be recalled in the preceding discussion. Their function is to provide access to the Stoney gates and gate seats when either of the latter are in need of inspection, repair or replacement. After floating the cassion gates to place, and sinking at the gate seats shown on the drawings of control works, the water between the caissons would be pumped out. The space between the caisson gate seats has been made as narrow as consistent with freedom of action during the progress of work on the Stoney gates for reasons that have appeared in the discussion of stability of the piers. A further use for the caisson gates which has also been mentioned is illustrated on Plate 4-40.

The cost of the caisson gates is a comparatively small item in the construction of the barrier and since their form is not unlike the guard gates in the larger ship locks, the latter have served to determine their weight, after due allowance for differences in size and water pressure.

BRIDGE

Requirements.

The bridge is more or less an accessory to the barrier. It has not been regarded as indispensable and is omitted from some schemes in anticipation of indifference on the part of railroad and highway interests toward the opportunities afforded by the barrier. This attitude will undoubtedly be influenced by the choice of site, which will to some extent determine the communities that may be served and the benefits that would accrue. A barrier at the Point San Pablo site would not offer railroad facilities to replace the Port Costa-Benicia Ferry, and proximity to the Carquinez Bridge would lessen its value as a crossing for the highway. It is, however, not for the purpose of this report to argue the case or to predict the outcome, but rather to anticipate either alternative.

If the need for a bridge accommodating railroad and vehicular traffic be granted, the provision of two tracks is evidently indicated. The width of highway has been fixed at 30 feet as a result of correspondence with R. M. Morton, State Highway Engineer, who states:

> We consider that a 20-foot width of roadway will handle, at a reduction of speed, 10,000 vehicles per day. A 24-foot width will handle no more inasmuch as it does not greatly increase the opportunity for vehicles going in the same direction to pass each other. A 30-foot width provides three definite 10-foot lanes for traffic, and makes it possible, at times of peak load, for two lines to proceed in one direction and one line in the opposite direction.
>
> The designers of the Carquinez Bridge have provided a 30-foot width of roadway, I believe, with sidewalks in addition, and it would be my judgment that 30-foot widths should be provided at barrier "A" (Army Point Site) and "C" (Point San Pablo Site), but in estimating, a 20-foot width of surfacing would probably be sufficient for a time, the balance of the space to be occupied by a sidewalk. Then, when the traffic required additional space, the sidewalk could be thrown into the roadway and some scheme devised to

overhang or support a sidewalk structure over the slope of the rock embankment.

If the need for a sidewalk across the bridge develops, it can easily be constructed below the level of tracks and roadway by utilizing one of the girders of the railroad bridge and a truss under the highway which are shown on Plates 4-5 and 4-16. The double-deck bridge in Estimates 11 to 13 (Plates 4-41, 4-45 and 4-49) does not offer the same convenience but cantilever construction at the highway level would be feasible.

Grades of 1 per cent have been adopted as the limit for the railroad. The highway is necessarily in conformity therewith, except in some cases at the ends where grades up to five per cent have been allowed. Curves were unavoidable at some locations. Their use is governed by limits of 6-degree curvature for railroad and 23 degrees for highway.

Bridge clearances over navigable waterways are discussed in Chapter VI. Estimate 13 (Plates 4-48, 4-49, and 4-50) provides for a high crossing which eliminates all sources of interference between bridge and water traffic but, with this exception, a clearance of 50 feet above high water at the locks has been adopted, with the consequent necessity for lift spans over all but the 40-foot ship lock. A clearance of 135 feet above high water is attained by the bridge in Estimate 13 and by the lift spans in highest position.

Bridge Piers.

The piers present no unusual features. The same allowance for locomotive traction (100,000 pounds) that was used in determining the control works substructure is applicable in this case.

Superstructure.

The double-deck type of superstructure was adopted when conditions permitted, but owing to the general use of rock embankment, such cases were limited to the Dillon Point site, estimates 11 to 13. The upper deck would necessarily be extended over a portion, at least, of the rock embankment and the inevitable settlement of the latter would lead to difficulties. It will be noted that in estimates 11 to 13 the superstructure is supported by piers which reach bedrock under the embankment (Plates 4-38, 4-44 and 4-48).

In studying the superstructure, preliminary designs were prepared of concrete and steel bridges. Where 50-foot x 60-foot flood gates are used the piers supporting the bridge are spaced 65 feet apart while if 70-foot x 80-foot flood gates are adopted, the pier spacing is 90 feet, or 120 feet, depending upon the type of pier used. For the 65-foot spans it is believed that, in case of the highway, at least, reinforced concrete girders would be found cheaper than steel trusses but with the longer spans the use of steel trusses would result in economy. In any event, steel spans have been adopted in all preliminary designs as they are considered better adapted to a structure subject to possible seismic disturbances.

Further study is necessary to determine the best type of lift spans. Estimates were prepared by approximate methods for a vertical lift span but figures were submitted by The Strauss Bascule Bridge Co. and the Scherzer Rolling Lift Bridge Co. for alternative types. While the estimates and drawings present the data for the vertical lif preference is not thereby implied and the matter of selection is lef entirely without recommendation.

The requirement for a movable bridge over the lock gates sugges the possibility of utilizing the bridge as the upper support for th emergency lock gate. Such a combination has been adopted for th locks of the Trolhattan Canal at Strom, Sweden. The designs wer prepared by the Strauss Bascule Bridge Company. A description o the structure is contained in the July, 17, 1919, issue of *Engineerin News Record.*

The weights of fixed and movable spans and of towers for the vertica lift, have been computed by formulas with no investigation of stresse Cooper's Class E-60 loading was used for railroad spans. Informatio from the California State Highway Commission relative to span length and weights of several bridges now in operation served to indicate formula of general application which satisfied the requirements in thes specific instances.

SHIP LOCKS

Requirements.

The requirements as to number and size of ship locks are discusse at length in Chapter VI. With these features established, the subs quent work of designing and estimating was materially expedited b the acquisition of data on the Lake Washington Ship Canal Lock through the courtesy and consideration of William J. Barden, Colone Corps of Engineers, and his assistants, at Seattle. Owing to the sim larity between many features of the barrier locks and those at Lak Washington, which has been realized to the utmost both by necessit and intention, it has been advantageous to estimate their cost fro drawings furnished by Colonel Barden. Other features were adaptab with changes more or less fundamental. Reports of the Isthmian Can Commission constitute another source of information that has bee of great value.

As previously stated, it is the opinion of officials at the Lake Was ington Locks that interruptions to bridge traffic would be reduced a minimum when the bridge is located at the upstream or downstrea lock gates. It would, of course, be impracticable for the bridge to cro at an intermediate point because the lift span would then remain in raised position while the vessel occupied the lock. Aside from traff interference, if the bridge crossed at a point removed from the ar bounded by the lock gates, an extension of lock walls would be necessar to provide support for the piers and junction with the control work It was deemed preferable, on account of the detrimental effect of sa water on concrete, to locate the bridge at the downstream lock gat so that the greater part of the locks would be in fresh water but th arrangement was generally not adaptable to the topography.

The proximity of the flood channel in some schemes may be regard as a menace to navigation on account of the occasional high velocitie Maximum velocities are shown on Plates 5-17, 5-18 and 5-19 to ran up to about 20 feet per second momentarily during a 750,000 secon foot flood. Although the guide walls afford some protection to vesse it is expected that those interested will favor an arrangement of stru tures which eliminates this danger, such as that shown on Plates 4-1 4-20 and 4-22.

Lock Walls.

It was impracticable to rely entirely on precedent in determining the dimensions of lock walls and computations for stability were therefore prepared. They are, however, not thorough, owing to lack of time and further investigation is recommended in the belief that a saving in cost can be effected.

The width of lock walls at the top is fixed to some extent by considerations of operating space for workmen and machinery, except where fill behind the wall provides the equivalent. Bridge piers and gate anchorages determine the minimum width at some points. It was not apparent that the locks could be built in space appreciably more confined by using reinforced concrete, hence plain concrete was adopted. Reinforcing steel, is, however, required at localized areas such as gate anchorages, footings and adjacent to culverts and other openings. Freeboard is the same as for the control works substructure.

The investigation of stability followed the customary procedure for gravity sections, allowing for openings in the concrete and unwatering of locks, with pressures against the opposite side of wall from submerged rock fill, silt and water, or water only, as the case might be. Uplift was assumed to act over two-thirds the base, under full hydrostatic head on the water side of the wall, diminishing to zero at the unwatered side. At gate recesses stability allows for a gate on the unwatered side in position against the gate sill, a condition in which the horizontal force at the top of the gate acts with maximum component in the same dierction as the forces on the opposite side of the wall.

Pressures were limited to 10 tons per square foot. No tension was permitted at the base but was contemplated at higher elevations in some cases where reinforcement could be provided. The rock fill shown between the lock walls on some of the drawings is an added factor of safety which may be omitted if so desired. There are, however, obvious advantages in having a level bottom at the elevation of gate sill and the space below offers a convenient means of wasting excavated material.

Lock wall quantities would not be affected by more liberal allowance in foundation pressure when the base is at the higher elevations, but when the location of the locks is fixed by the 90-foot limit in depths of rock previously discussed some saving would result although the base width is, in general, fixed by provisions for safety against overturning and tension. If it were assumed that the rock fill would absorb the horizontal forces in the manner previously discussed in connection with control works substructure across the present waterway at the Dillon Point site, the quantity of concrete would be materially less, but the saving in cost would not correspond if it were necessary to borrow the rock for fill.

The least total length of lock walls results from arranging the locks in order of size across the channel and, in general, concrete quantities vary accordingly. It will be noted, however, that the arrangement at the Point San Pablo site is somewhat different (Plate 4–53) in that the 60-foot lock is located between the two of next larger size. The additional length of wall needed for this arrangement seemed to require less material than a wider wall to accommodate two culverts of the size necessary for adjacent 80-foot locks, since it did not appear feasible to locate one above the other in this case. It is not unlikely however, that further study would suggest advantageous modifications.

Sills for Miter Gates and Emergency Dams.

As reference to the drawings will show, the purpose of the sills is to furnish horizontal support at the bottom of the miter gates and emergency dams when they occupy positions across the locks. There are no features that merit discussion.

Miter Gates.

All gates are intended to be electrically operated. The guard gates must withstand unbalanced head above the gate sills and are consequently heavier than the service gates which are designed only for head between the extremes of water surface elevations up and down stream. Each lock requires but two pairs of guard gates, but, owing to the necessity of providing for an excess of head from either direction, twice that number of service gates are required, exclusive of intermediate gates. The purpose of the intermediate gates is discussed in Chapters VI and IX. The requirements are the same as for service gates at either end. All gates are intended to resist water pressure only from the side away from the sill.

No drawings of miter gates were prepared for the report. Estimates are based on designs for Lake Washington and Panama, correcting by approximate methods when necessary for differences in height and width. The minimum depth on gate sills is very nearly the same for locks of the same width but the lift of the locks, and consequently the unbalanced heads on the service gates, would be appreciably less at the barrier. The range in water surface elevation is shown on the drawings of locks in cross-section, Plates 4-10, 4-30 and 4-54.

Stoney Valves and Cylinder Valves.

The Stoney valves and cylinder valves which control the flow through the culverts during lockages have been estimated from data on the Lake Washington locks, with due allowance for differences in size and head where requirements are not the same. Valves have been provided in pairs for security against interrupted service in the event of damage, the number of valves being double the requirements for operation. Stoney valves have been provided for emergency use and also for continuous service, except in the 40-foot lock where cylinder valves are contemplated at times other than in emergencies.

Emergency Dams.

Emergency dams are provided to maintain the elevation of water surface above the barrier in the event of damage to miter gates, and to prevent losses and accretions respectively of fresh and salt water in such an emergency.

For these structures also, data from Lake Washington and Panama were used in preparing estimates. The emergency dams for the 110-foot lock are of the swing bridge type used on the Isthmus while those for the smaller locks include a derrick for placing the bridge. The type used for the 80-foot lock at Lake Washington served to determine their weights by applying corrections according to differences in size.

Salt Water Relief Conduit.

The necessity for drawing off water from a sump located at the upstream end of the locks, to retard contamination of the basin is discussed in Chapter IX. The conduit to serve this purpose is shown on the lock drawings. A capacity of 250 second-feet was assumed and it is expected that at times pumping will be necessary. However, if a short conduit can be used, a gravity flow will occur under favorable conditions, although the most favorable would probably exist during floods when the purpose of the conduit would be more effectually served by the flood gates.

Fish Ladder.

Considering the number and size of the ship locks, it appears that no anxiety need be felt about fish finding their way past the barrier, but a fish ladder has been included in the designs and estimates for the reason that omission of this detail might be interpreted as an intention to evade the law.

The locks seem to offer the most convenient location for the fish ladder and, with a view to their supplementing the latter as a means of access for the fish to the fresh water basin the proximity of the two structures is advantageous.

The chief problem is to provide a structure that will function with an excess of head from either side of the barrier. It is also important to avoid losses of fresh water and to exclude the salt water from above the barrier. These requirements are fulfilled to a limited degree by the structure that is proposed but modifications would not necessarily add to the cost and, from this standpoint, exhaustive study is not warranted at this time.

It was estimated that a flow of 25 or 30 second-feet would provide sufficient depth to accommodate the fish. During floods, however, when the gates are open and the conservation of fresh water is not an object, the flow from the fresh water basin may be allowed to exceed this amount. Under other conditions partial submergence provides the necessary depth with much less discharge.

To avoid the interchange of waters in some degree the use of water from the salt water conduit is proposed. The purpose of the salt water conduit has been explained. Its operation involves an unavoidable loss of fresh water. The chlorine content of the mixture would be considerably less than that of sea water and contamination of the fresh water basin would be retarded by allowing a small amount of water from the conduit to return by way of the fish ladder, in place of an inflow of an equal quantity from the salt water side. Furthermore, the loss of fresh water would be diminished by providing for the discharge of water from the conduit through the fish ladder to the salt water side.

A pool was provided at the summit of the fish ladder to receive water from the salt water conduit through a feed pipe as shown on Plate 4-12. Pumping is necessary under certain conditions while others are favorable to gravity flow. Water would flow downstream or in both directions from the pool according to upstream and downstream water surface elevations. The bottom of the pool is below low water on either side, but by maintaining the proper elevation of water surface therein, the flow from either side of the barrier may be controlled. The follow-

ing tabulation illustrates the action under different conditions. Dis
charge from the pool is controlled by the baffles and does not vary i
accordance with the difference in head shown in the table.

Elevation water surface—				
Upstream	6.0	2.5	2.5	—3.
In pool	2.8	2.3	6.2	—3.
Downstream	—3.5	—3.5	6.0	—4.
Flow in second-feet—				
From salt water pipe	0	25	31	23
From fresh water side	35*	5	0	2.
From salt water side	0	0	0	0
Into fresh water side	0	0	18	0
Into salt water side	35	30	13	25.

*Fresh water not conserved during flood.

From the above it will be seen that the losses of fresh water ar very little. The only water which enters the basin comes from th salt water conduit and is only partially saline.

When the water surface is higher downstream than upstream th water flows in both directions from the pool, and from this point t the basin the fish would be travelling in the direction of flow. If thei instincts oppose this course the function of the fish ladder would not b realized at such times and unless further study reveals ways of over coming the objection it may be periodically inoperative.

The estimates provide for a feed pipe leading directly from the fres water basin to be used instead of that from the salt water conduit i desired. (See Plate 4-12.)

Guide Walls.

The usual functions of guide walls are exceeded at the barrier by reason of the protection they afford vessels from the high velocities of the flood channel when the latter is adjacent to the locks. The general layouts show their importance in this respect.

Three distinct types of guide walls for the 80-foot and 110-foot locks have been adopted to meet the conditions and are shown on Plate 4-13 No drawings of guide walls for the 40-foot lock have been prepared The latter are solid walls of concrete except for the limited use of piling in some schemes where the location of the cofferdam interferes with concrete construction. Gravity walls are necessary at some loca tions on account of unbalanced pressure, while others require only a wall with vertical faces, strengthened against shocks from vessels by buttresses on a wide base.

Of the three types designed for the larger locks the concrete wal requires a cofferdam and the other two are, to some degree, inter changeable. The caisson type wall was contemplated, however, wher mud overlies rock in depths too shallow to support piling subjected t shocks from large vessels. The general layouts show the type adopted for each case.

No description of the timber and concrete walls is necessary to sup plement the drawings. The caisson type is not shown in detail bu has been worked out as required to insure reasonable quantities in th estimates. The pressure of silt was computed with the same assump tions discussed in connection with substructure caissons for contro works at the Dillon Point site. The estimates provides for excavation and concreting without unwatering.

EMBANKMENT

Requirements.

Except for differences shown on Plate 4-3 to meet alternative requirements, the rock embankment is essentially the same in all schemes. Where the rock would have to be deposited in water characterized by tidal currents, which is the prevailing condition, slopes of 1 on 3 were adopted for most of the height below water surface. At higher elevations, and when the embankment is to be constructed within a cofferdam, or around a corewall that would retard the current, slopes of 1 on 1½ were deemed adequate. The change in slope before riprap is placed was assumed to mark the highest elevation that could be attained in depositing material from bottom dump barges. Above elevation —7.5 the use of derrick barges and skips is contemplated. It is believed that above elevation —7.5 the 1 on 1½ slope can be maintained since the depth of water flowing over the fill at that time will have become relatively small.

Material for the embankment is available in sufficient quantity from excavation in all schemes except those presented in Estimates 6, 14 and 15, which provide for borrowing to make up the deficiency. The contingent necessity of rehandling during the transition of the material from its original state to final disposition in the embankment was discussed at the beginning of this chapter. Materials for construction of the embankment are discussed in the Geological Report included as Exhibit 11 which is summarized in Chapter III. It will be recalled that it was Mr. Bryan's belief that the rocks found at the various sites, when deposited underwater in an embankment, would form a tight and relatively stable structure. To insure watertightness, however, the estimates provide for pumping mud from the bottom of the channel to fill the interstices of the rock, the necessary quantity being determined from the assumption that if concentrated at the surface of the fill it would cover both slopes below water level to a depth of 6 feet.

Unfortunately, the drawings of the cross-sections of the embankment, with the exception of those shown on Plate 4-3, are misleading in that the relative size of the rock in the fill and that used for riprapping above elevation —7.5 are reversed. Neither is drawn to scale and the method of illustrating the two kinds of rock must be considered symbolic only.

Settlement.

The subject of settlement at locations where firm material is overlain by silt in a semi-fluid state has received considerable attention. Data on similar structures in the Bay region were secured and it was found that extensive displacement of the mud in some cases has occurred under the weight of superimposed rock. Data on the character of the channel filling and examples of settlement were presented in considerable detail in Chapter III. No attempt will be made here to enlarge upon the discussion.

It is generally agreed that quantities should include a liberal allowance for settlement although the disposition of the material below mud line, after equilibrium has been reached, cannot be predicted with any degree of certainty. It seemed likely that the mud would be displaced for its entire depth where the weight is greatest, and that quantities based on more optimistic assumptions would not satisfy conservative opinion. To expedite the work of computing, it was assumed that the amount of settlement would be equivalent to a prism defined by a rectangle, or trapezoid, of width equal to the width of embankment at the surface of mud and height equal to the mean depth of rock, or other firm material such as sand and gravel, below top of mud. A few exceptions to the foregoing method were introduced where the water is shallow and the depth of mud comparatively great. The relative height and width of the resulting sections approached absurdity and practical considerations were satisfied by extending the 1 on 3 slopes below the surface of mud. The necessary treatment involved more or less extreme modification of the foregoing rule but such cases were rare and had no appreciable effect on the quantities.

Swell, Shrinkage and Waste.

It was assumed for estimating purposes that a cubic yard of solid rock would be equivalent to 1.35 cubic yards after excavation which means 26 per cent voids. It is probably that a high percentage of fine particles would be present after blasting and subsequently carried away if the material were deposited in running water. It was assumed that this loss below elevation —7.5, combined with shrinkage, would amount to 35 per cent of the quantity as measured in place in the embankment, or in other words, that a cubic yard in situ would make a cubic yard of fill. Above elevation —7.5 a large part of the material would not be subjected to the action of the current and 10 per cent is considered a fair allowance while shrinkage alone, assumed at 5 per cent, was estimated for embankment placed on unwatered areas.

Highways.

The inevitable settlement of the embankment through a long period of time would be destructive in its effect on a paved road and, to avoid heavy maintenance disbursements, the estimates provide for macadam with a surface of oiled screenings. It is reported that it is necessary to add from 2 to 3 inches to the Southern Pacific road bed across Suisun Marsh about every 4 to 6 months to maintain the elevation of grade.

APPROACHES

Requirements.

To provide easy grades (1 per cent maximum for railroad) the approaches to the main structures are generally of considerable length as shown on the general layouts and involve large items of expense. The limit of curvative is the same as for the bridge, which has been discussed, and the width of highway is the same.

Rock Fill and Open Cut.

Rock is available with the same exceptions that were noted in the discussion of embankment. Except for the absence of riprap and differences in top widths when adjacent locations for the railroad and highway were not selected, the rock fill, in section, is the same as embankment placed on unwatered areas. Slopes of 1 on ½ were provided in open cut as previously stated.

Tunnels.

The schemes presented in estimates 6, 13, 13-A, 14 and 16 (Plates 4-25, 4-47, 4-51 and 4-57) include tunnels. In all but the last named, which provides separate tunnels for railroad and highway, they are for the exclusive use of the railroad. Timbering has been generously estimated in anticipation of needed protection against disintegrating rock throughout the length during construction.

CONSTRUCTION

Cofferdams.

Construction of cofferdams, perhaps the most difficult feature of the work, was discussed in considerable detail under "Unwatering" and will not be repeated here.

Construction Materials.

There are a number of Portland cement mills in the region, the nearest at present being located at Tolenas and one near Mount Diablo.

The largest local source of sand and gravel suitable for concrete is located on Alameda Creek, at Niles. Another deposit is found on the delta of Walnut Creek a short distance south of Concord. Excellent sand and gravel may be obtained from Marysville by railroad but can not be barged down the Sacramento without rehandling for the reason that the Yuba River or the American River are, at preesnt, not navigable at the sand and gravel plants. River sand used to a large extent in the bay region is obtained by pumping from the Sacramento River bottom near Clarksburg and barged down the river. The river sand is the least expensive but is rather fine for use in concrete. In the preliminary estimates of the barrier it has been assumed that river sand would be mixed with Marysville or Niles sand in equal parts.

It is estimated that there are 75,000 cubic yards of slag suitable for concrete aggregate available at the Mountain Copper Company smelter on Suisun Point. The slag dump is shown on Plate 3-3. This slag can be purchased at the rate of 25 cents per cubic yard on the dump.

As stated in the Geological Report, Exhibit 11, excellent material for riprap and for crushed concrete aggregate is found in the quartzite quarries on Points San Pablo and San Pedro, particularly the latter.

The suitability of the rock at the damsites for building the embankment portion of the barrier as discussed in Exhibit 11 is summarized in Chapter III. Suffice it to say that it is considered suitable for constructing a stable, tight dam.

Clay for cofferdam work may be obtained from the delta slopes of Alameda, San Pablo and Walnut creeks. There are many places on the salt marshes around the bays where good clay may be secured by dredging. Other clay deposits are located near Bryant, Glorietta, Orinda and Lafayette.

Excavation.

The character of material to be excavated and the methods suggested for handling it were discussed in Chapter III. The operation will be hindered somewhat by the oscillations of the tides, which reach maximum of about 10 feet, and by tidal currents up to about 6 fe per second.

If it becomes necessary to waste solid material, other than on adj cent marshes, it may be dumped shoreward of the bulkhead line esta lished by the War Department but, generally, it must be retained suitable structures to preevnt its finding its way back into the chann A permit must be secured from the District Army Engineer to dur material bayward of the bulkhead line, or at any place where harb lines are not established. Dredged material may also be dumped water over 50 feet deep, under permit, in selected spots approved the district engineer. Harbor lines are shown on the topographic ma of each of the sites investigated. There are no established harbor lin at Point San Pedro or anywhere on that side of either San Francis or San Pablo bays, nor in San Pablo Bay just upstream from Poi San Pablo.

Time Required for Completion.

The matter of time required for construction of the barrier is on to which little consideration has been given. The undertaking is large one and while construction should be pushed to completion expeditiously as possible there is no apparent reason for purchasin a large amount of plant for the purpose of rushing the work in ord to make a record. It seems that a construction program covering period of from 5 to 7 years, depending upon the site chosen, would reasonable. Excavation could be under way throughout the whol period.

Right of Way.

Information secured from the U. S. Land Office at San Francis indicates that there are no vacant public lands in the vicinity of th sites investigated for the barrier. These lands are covered by Spanis grants, swamps or overflowed lands. The lands within the grants we deeded by the Spanish Government before California became a pa of the United States, and the state claims all swamp or overflowed lan under the act of September 28, 1850. However, the state has sold mu of the land to private interests.

In some cases construction of the barrier will require the acquisiti of lands now occupied by various types of plants and buildings. A attempt has been made to reduce interference with present constructi to the practicable minimum. Right of way required is indicated various layouts. Ownerships, as nearly as it has been practicable secure the information, are shown on Plates 3-3, 3-7 and 3-10.

Unit Costs.

In considering unit prices it must be noted that the location of t barrier, at any site investigated, is one that favors low costs. Constr tion materials can be brought directly to the site by water or r There are excellent quarries, sand and gravel pits, clay deposits a Portland cement mills within short hauling distance. Large manuf turing plants, foundries and machine shops are located nearby, a any one of the sites investigated is convenient to the homes of a lar working population of mechanics and laborers. San Francisco and Oakland are headquarters of numerous contracting firms.

The unit prices used in the preliminary estimates of cost are the result of an intensive study of the subject. While it is very difficult to estimate the cost of items like Class III, subaqueous excavation on account of lack of precedent, it is believed that, in general, the estimates are conservative. They are, of course, based upon present prices of material and labor and must, in the future, be adjusted as required to take into consideration the then current prices. The preliminary estimates which accompany the report are in great detail so that a further discussion of unit prices would be superfluous. The unit prices assigned to the principal items of cost are, for convenience, summarized in the following list. They are field costs, exclusive of engineering, administration and contingencies and, as indicated at the end, include no allowance for interest during construction.

LIST OF PRINCIPAL UNIT COSTS

Item		*Field cost*
Open caisson excavation, Class I		\$0 75 per cubic yard
Open caisson excavation, Class III		15 00 per cubic yard
Subaqueous excavation, Class I—mud pumped average of 1 mile		0 12 per cubic yard
Subaqueous excavation, Classes I and II—Removing rock-fill cofferdams	0 85 to	1 05 per cubic yard
Subaqueous excavation, Class III (maximum depth 50 feet)		3 25 per cubic yard
Subaqueous excavation, Class III (maximum depth 70 feet)		4 50 per cubic yard
Dry excavation, Class III—Quarrying in deep cuts		1 25 per cubic yard
Dry excavation, Class III—Stripping and cut-off trenches		5 00 per cubic yard
Tunnel excavation, Class III (timbered)		6 50 per cubic yard
Rockfill in cofferdams		0 90 per cubic yard
Rockfill in barrier below elevation —7.5 (bottom dump barge)		1 10 per cubic yard
Rockfill in barrier above elevation —7.5 (dumped by derrick)		1 40 per cubic yard
Rockfill between lock walls		0 90 per cubic yard
Rock riprap		3 00 per cubic yard
Grouted paving		7 50 per cubic yard
Cement delivered to bins		2 50 per cubic yard
Sand for concrete (50% river sand and 50% Niles sand)		1 80 per cubic yard
Crushed rock for concrete, Army Point and Dillon Point sites		2 00 per cubic yard
Crushed rock for concrete, Point San Pablo site		1 60 per cubic yard
Plain concrete in lock walls	\$10 25 to	12 00 per cubic yard
Plain concrete in lock sills	8 25 to	8 75 per cubic yard
Plain concrete in guide walls	10 25 to	10 75 per cubic yard
Plain concrete in sea walls (1:2½:5)	9 75 to	10 25 per cubic yard
Plain concrete in abutments (1:2½:5)	9 75 to	10 25 per cubic yard
Plain concrete filling under floors (1:3:6)	7 75 to	8 25 per cubic yard
Plain concrete in tunnel lining (1:2½:5)	15 25 to	15 75 per cubic yard
Reinforced concrete in flood gate piers (1:2½:5)	15 50 to	16 00 per cubic yard
Reinforced concrete in bridge piers above elevations 12 and 10	22 00 to	22 50 per cubic yard
Reinforced concrete in floodgate footings (1:2½:5)	16 00 to	16 50 per cubic yard
Reinforced concrete in floodgate floors (1:2½:5)	10 50 to	11 00 per cubic yard
Plain concrete in flood gate piers and curtain walls placed in open caissons by tremie	9 50 to	10 00 per cubic yard
Plain concrete in flood gate counterweights	20 75 to	21 25 per cubic yard
Reinforced concrete in deck of guidewalls (1:2½:5)	26 50 to	27 00 per cubic yard
Reinforced concrete in guidewalls placed in open caissons by tremie (1:2½:5)	10 75 to	11 25 per cubic yard
Reinforcing steel in place		0 05 per pound
Steel sheet piling in place	0 05 to	0 055 per pound
Lock gate leaves, structural steel, in place		0 10 per pound
Stoney gate leaves structural steel in place		0 095 per pound
Stoney gate towers, structural steel in place		0 08 per pound
Railroad bridge, plate girders in place		0 065 per pound
Highway bridge, pony trusses in place		0 075 per pound
Open caissons, structural steel in place		0 12 per pound
Gate hoisting machinery, exclusive of motors, in place		0 40 per pound
Lumber in sea wall trench braces in place		90 00 per M B.M.
Creosoted piles in guide walls in place		1 05 per lineal foot
Engineering, administration and contingencies		25%

No allowance made for interest during construction

CHAPTER V

TIDES AND FLOODS

Purpose of Study.

The primary object sought has been a determination of the gate area that must be provided in the barrier for the passage of flood waters from the Sacramento and San Joaquin rivers. A determination of the volume of water in the tidal prism of the bay at present and the effect of a barrier on the size of these prisms, and on the strength of the tidal currents, were other objects sought. A closely related subject is the effect of the barrier on the deposition of silt in the bay, which will be discussed in a separate chapter.

It should be stated in the beginning that the results of the studies made can, in no wise, be considered final. The work done opened up a vast field for investigation which, if undertaken, would have required more time and funds than were available. It is realized that the studies presented are more or less superficial. They have, however, made it possible to design the barrier with considerable confidence as to its capacity for passing floods and as to its probable effect upon the water surface elevation in the delta region during flood. In reading what follows the need of additional study will be evident.

Data Available from Other Sources.

Tidal measurements around San Francisco Bay were begun as early as 1852 and continuous records have been kept at Golden Gate since that time. Continuous observations have also been made at Mare Island by naval authorities since the early fifties. Most of the data at the Golden Gate, made by the United States Coast and Geodetic Survey, and those at Mare Island, have been recorded by automatic tide gages. Many observations have been made at other points throughout the bay region, some by the United States Army Engineers, but principally by the Coast and Geodetic Survey.

The results of the work of the U. S. Coast and Geodetic Survey have been collected in a pamphlet recently issued by the Survey under the title "Tides and Currents in San Francisco Bay," a copy of which will be found in the envelope at the back of Volume II of this report as Exhibit 15.

Flood flow studies in connection with flood control works along the Sacramento and San Joaquin rivers have been carried on for many years by the California Debris Commission and by the Flood Control Department of the California State Division of Engineering. All of these data have been freely made available for the investigation and have been invaluable in the preparation of this report.

New Data Collected.

Owing to the fact that the tidal data heretofore gathered have been mainly for the service of navigation and the general study of tidal phenomena, they were not in such shape that they would serve for all phases of the proposed studies and it was found necessary to do some additional work along this line. Advantage was taken of the presence of the drill barge to make current meter measurements throughout a tidal cycle at each of the three barrier sites investigated. One cycle was observed at Point San Pablo, one at Dillon Point, and three at Army Point, the last one being made during the high water of February, 1925. While the current meter measurements were being made, readings at 10 to 15 minute intervals were also made of a tide staff at the site.

On July 6 and 7, 1925, during a cycle of the greatest range occurring during the year, a series of simultaneous tidal gage readings was obtained for various points extending from the Presidio to Sacramento on the Sacramento River and to the Southern Pacific Railroad bridge near Lathrop on the San Joaquin. Automatic tide gage records were available for the Presidio, Mare Island, Sacramento, Stockton and Lathrop bridge. These were supplemented by 15-minute readings on tide staffs established at Point San Pablo, Dillon Point, Suisun Point, Collinsville and the highway bridge at Rio Vista. Mr. Wm. Pierce also established an automatic gage in the slough at Suisun; the curve could not be plotted, however, because while the high and low points were recorded, the clock mechanism was out of order so that the time interval was incorrect. All other records have been plotted in superimposed position on Plate 5-6. The combined river discharge into Suisun Bay varied approximately from 13,000 second-feet on July 1 to 10,500 on July 7.

Current Meter Measurements.

Measurements were made to ascertain the velocities that might be expected during construction, and to furnish additional data in connection with tidal studies. The first observation was made at Army Point at hole 2500 (Plates 3-3 and 3-4) from 5.10 p.m. September 19, to 6.35 p.m. September 20, 1924. The maximum range during this period was only 4.5 feet, or 55 per cent of the range that was found on July 6-7, 1925, which is close to the normal maximum range at this point. The second observation was made at hole 3550 at Army Point, from 8.40 a.m. October 1, to 5.55 a.m. October 2, 1924. The greatest range was 5.5 feet, or 67 per cent of the July 6-7 range. The third observation was made at hole 1900, Dillon Point site (Plates 3-7 and 3-8), from 9.25 a.m. October 30, to 10.10 a.m. October 31, 1924. The greatest range was found to be 7.28 feet, or 85 per cent of the July 6-7 range. The fourth series of measurements was made at hole 4500, San Pablo site (Plates 3-10 and 3-13), from 5.30 p.m. November 25, to 6.40 p.m. November 26, 1924. Here the greatest range was 8.03 feet, or 93 per cent of the July 6-7 range. The last current meter measurement was made at Hole 3550 at Army Point from 11.45 a.m. February 7, to 9 p.m. February 8, 1925, at a time when the rivers were discharging flood waters into Suisun Bay at the rate of about 150,000 second-feet.

Elevations of the water surface were determined during the first two observations by reading a staff gage attached to the drill column of the barge. For the balance of the observations a staff was established at the nearest convenient dock and readings made every 10 or 15 minutes.

The results of the observations are shown on Plates 5-1 to 5-5 inclusive, and are discussed in memoranda accompanying this report as Exhibit 20.

Bench Marks, Datum Planes, and Location and Tide Staffs.

Tide staffs in all cases were referred to mean seal level as determined from the nearest U. S. G. S. B. M., where available. The staff at Point San Pablo, however, is referred directly to the U. S. C. and G. S. B. M. at that point. This is a standard tablet set in the wall feet north of the southwest corner of a brick house located at the edge of the water, about 1000 feet north of Point Orient. The elevation of the B. M. is given as 7.62 feet above mean lower low water at this point. Level shots were taken in each direction across the straits to targets tied to this B. M. and to the one at McNear Landing, whose elevation is given as 11.44. These levels checked within 0.02 feet. By taking shots in each direction, curvature and instrumental errors were eliminated. A line of levels was run from the San Rafael U. S. G. S. B. M. (described on page 136, Bulletin 342, U. S. Geological Survey Results of Spirit Leveling in California), but there is too much discrepancy—4.376 feet—between the elevation above mean sea level as published and that given for the Coast Survey elevation above mean lower low water to place much reliance on any check from this B. M.

When the tide staff readings for July 6-7, 1925, were plotted over the record from the Presidio, the San Pablo graph appeared to be referred to a plane that was too high. The tide staff at Point San Pablo was checked and found to be set 0.13 feet too low, resulting in readings that would place the graph too high. Furthermore, it was estimated that the true plane of reference—standard sea level—is 0.12 feet higher than the plane of mean tide level to which this bench is referred (determined from only two high and two low waters) or, in other words, the elevation of this B. M. above standard sea level is 4.25 feet. The result of these two changes was to reduce the reading of this staff by 0.25 feet, and to lower the plotted graph to a position which appears to bear a more correct relation to that of the Presidio graph. The San Pablo staff is located on the shore side of the landward "L" of the Standard Oil Co. dock at Point Orient, just south of Point San Pablo. This staff, as well as all others used in this work, was made of an unpainted 2-inch by 3-inch plank, with knife cut to mark the feet and tenths. The "0" of all staffs was supposed to be set 6 feet below standard sea level.

After making the correction of 0.25 feet to the Point San Pablo readings, the elevation of the mean tidal plane during the cycle was found to be 0.155 feet above standard sea level, while that for the Presidio gage was 0.152 feet.

The tide staff for the Dillon Point site is located on a pile in the approach to the burned warehouse dock of the Balfour Guthrie Co. near Eckley. The "0" mark is set six feet below mean sea level as determined by a closed level line run from the U. S. G. S. B. M. at Port Costa, elevation 16.787. This B. M. is described in bulletin 342, page 128, as being a bronze tablet stamped "17" in a concrete column of the Carquinez Market, now the post office.

The gage set at Suisun Point has been destroyed, but its "0" was set 6 feet below mean sea level as determined by a closed level line from the bench mark at the Court House in Martinez, elevation 23.04. The original U. S. G. S. B. M. was a bronze tablet stamped "27" in the front wall of the County Building, elevation 27.082. When the building was replaced, the B. M. was set in a granite block at bottom of steps at the left side of the west entrance of the building. In 1923, County Surveyor R. R. Arnold determined the new elevation to be 23.04 by levels from the Port Costa and Concord bench marks.

The permanent gage at Suisun Point is a painted staff, probably set by the Army Engineers, located at the intersection of the curved and straight portion of the outer end of the Mountain Copper Co. dock at Suisun Point. This gage was compared with the gage used in the observations of July 6 and 7 and found to read 3.65 when the Reclamation Service gage read 6.0. In other words, the reading for mean sea level, as determined above, on the present gage is 3.65 feet.

The Collinsville gage, made like the others, is nailed to a pile just west of the inclined landing platform at the main dock. The elevation of the "0" of this gage is also 6 feet below mean sea level as determined by a closed line of levels run from the U. S. G. S. B. M. at the southwest corner of the school house grounds, one-half mile north of Collinsville. The B. M. is marked "5B," and its elevation, given on page 140 of Bulletin 342, is 4.927.

At Rio Vista, permission was granted by the Army Engineers to move one of their gage boards, painted white with black tenth marks, from the timber bulkhead near the highway bridge to one of the piles on the west side of the west guard piles, near the bridge tender's house, where it could be conveniently read by the bridge tender. The datum of this gage was not changed, "0" on the gage being 3.6 feet below mean sea level. This was checked to a known elevation on the southwest corner of the west pier and found to be 0.08 feet low, but this adjustment was not made in plotting, as uncertainties in the gage readings and levels did not warrant it. This elevation was run by the Army Engineers from the bench mark at the southeast corner of the Rio Vista Bank Building (now the stage station), a bronze tablet set in the brick wall 2 feet above the ground, stamped "23B," elevation 22.425, as described on page 141, Bulletin 342. The U. S. G. S. elevation of this B. M., as furnished by the Army Engineers, was 22.404.

U. S. G. S. Bulletin 342 was published in 1908. In 1925 a new Bulletin of Spirit Leveling in California, No. 766, was published, but a copy was not available until the work in connection with tidal studies had been completed. Below are given the elevations of bench marks upon which the plotting of graphs of the simultaneous tidal readings depends, as given in Bulletins 342 and 766, respectively.

Location	[1] *Bulletin 342*		*Bulletin 766*	
	Page	*Elevation*	*Page*	*Elevation*
Port Costa, Carquinez Market	128	16.787	----	-----
Collinsville, School Grounds	140	4.927	590	5.509
Rio Vista, Bank Building	141	22.425	591	22.985
Stockton Cool Corner	120	15.633	538	16.033
Fairfield, Court House	[2]129	15.170	----	-----
Sacramento, Post Office	142	30.527	601	31.086
Martinez Court House	129	[3]27.082 [3]23.04	----	-----
Benicia, U. S. C. & G. S.	13 & 128	5.980	----	-----

[1] Used in studies reported herein.
[2] B. M. 2.7 miles east of Fairfield Court House is given in Bulletin 342 as elevation 14.704 and in No. 766 as 15.183.
[3] See text above.

The datum planes for Presidio, the standard for all bench mar work, is best set forth in correspondence with the U. S. Coast an Geodetic Survey, included as Exhibit 16.

In plotting the simultaneous gage readings, that for the Presidio referred to the latest standard sea level datum, 2.97 feet above th plane of standard lower low water. The datum for the Point Sa Pablo curve, already described, is also compared with this latest stan ard sea level plane. All the other curves were referred to elevations bench marks as given in Bulletin 342.

As will be explained under the discussion of tidal prisms, any sma change in the adjustment of bench marks would not affect the result the study of volumes in tidal prisms. It would, however, affect th relative positions of the tide graphs and the slopes of water surfa as shown on Plate 5-6. Since the change in elevations given in Bull tin 766 is greater than the change in datum at the Presidio, and sin it is impractical to go into the adjustment of levels used in obtaini the new bench mark elevations, it has been deemed best in this pr liminary study to plot the curves in accordance with the datum plan explained above. Before final studies of the Salt Water Barrier a completed, however, careful levels should be run from the Presidio connect up all the bench marks involved in order that all elevatio may be tied to one plane of reference.

Distances, Area and Volume Curves.

The distances used in connection with the tidal studies were scal from the Coast and Geodetic Survey charts of San Francisco Bay alo the average flow line of the tidal currents, and are shown in Table 5 The areas in Suisun and San Pablo bays are shown in Table 5-2, a the volume curves for the delta channels have been plotted on Pl 5-7. For convenience and accuracy in computing the volumes in t tidal prisms, the areas in the bays are tabulated for every two mil in distance from the lower end of each bay. In the delta, the volum for the prism between elevations —3.6 and +6.4 (0.0 and 10.0 U. S. D. datum) have been computed and the results shown by curves N 1 and No. 2, Plate 5-7, for every two miles in distance from the low end of Chain Island, near Collinsville, to the point where these ele tions run out above Sacramento and Stockton. The volume curve f the entire prism is also shown by curve No. 3. In order to use t volume curves in connection with the tidal prisms, the rates of accum lation for the different elevations on the volume curve were determin Assuming that the total accumulation of this curve is 1 acre-foot, rates for the different elevations, expressed as a fractional part of acre-foot, have been plotted on the rate of accumulation of Curve No It may be assumed that the abscissae of the rate curve represent fractional part of the whole which is included in a section 1 f deep at the elevation shown on the scale of ordinates. The method using this curve is explained under "Tidal prism graphs and comp tion of volumes."

Because of lack of detail information as to elevations in the ba between low water and high water, it has been assumed that there straight line variation of areas between these elevations, and no capa curves were plotted for the tidal studies, as they were not required this work.

Tidal Prism Graphs and Computation of Volumes.

The volume of water in the tidal prism above any cross-section of the channel, which in this report will be designated the "home section," is represented by the volume that passes the home section between two successive slack water periods, corrected for river flow and opposite tide. Slack waters are not coincident with high and low water, but usually occur one to two hours later. True slack water is very difficult to determine. If the definition is assumed as being that period when the total passage of water by the section is zero, then it is entirely possible to conceive that there may be no place in the cross-section where the current is zero; but that the algebraic sum of the up and down stream velocities is zero. There is an old belief, partially borne out by data shown on plates 5-1 to 5-5, and also substantiated by studies by John R. Freeman in Boston Harbor (See Report of Committee on Charles River Dam, 1903, pages 398 to 403), that the flood current starts first at the bottom. At times this may be neutralized by a surface current in the opposite direction, so that true slack water occurs with appreciable currents flowing. This condition will be very noticeable if there is a heavy flow of fresh water from the rivers.

This phenomenon of flood current first existing on the bottom, accompanied by a second phenomenon, that the fresh water does not immediately mix with the salt but floats on top, can readily be studied at the mouth of the Klamath River, or any similar stream, when flow conditions are right. During the summer the Klamath empties through a narrow channel, restricted by sand bars, directly into the ocean, but has a small bay above of such size that the tidal prism can not be fully supplied by the flow of fresh water. Within the straits, and not more than 200 to 300 feet from the ocean, during flood tides, a very distinct line exists on the surface, marking the division between fresh and salt water. For three or four hours during the strength of the tide, this line maintains a position varying not much more than 100 feet up and down stream. For some distance from this line, on the fresh water side, there is practically no surface current, but below the surface a very strong flood current of salt water will be found moving upstream.

Unless the discharge of fresh water is considerable in proportion to the volume of the tidal prism, the period of slack water for purposes of study of the tidal prism can be determined fairly closely. Even if there should be considerable error in time, the error in the volume of water that passes will be much smaller in proportion, because the rate of passage of water at this time is much less than the average rate for the cycle.

When the gages were read on July 6 and 7, 1925, the time of occurrence of slack water was also determined so far as this could be done by observations from shore. In addition to shore observations, salt water samples were taken at the slack after higher high and lower low tides on the morning of the seventh at Point San Pablo from a boat 1000 feet out in the channel, and 200 feet out at Collinsville, while at Suisun Point, samples were taken from the Mountain Copper Company dock. As these were taken at 10-foot intervals between top and bottom, a better determination of the time of slack could be obtained by observing the inclination of the line to the sampler, than from surface indications.

The estimated time of slack water, after adjustment for consistency among the various observations, are shown on the tide graphs, Plate 5-6. Slack water data for the observations recorded on Plates 5-1 to 5-5 are shown in Table 5-3.

The graphs of the tidal prisms, shown on Plates 5-8, 5-9 and 5-10 for Presidio, Point San Pablo and Army Point, represent, for July 6 and 7, 1925, the elevations of the water surface throughout the extent of the tidal area above the home section for the instant of slack water at the beginning and end of the tidal interval, and also for each intervening hour. In case of the tidal prism above the Presidio, however, no graph has been shown for the tidal prism in south San Francisco Bay because of the fact that no tide gage readings were available. The water surface elevations shown were determined from the tidal graphs on Plate 5-6. Whenever interpolations were made, straight line variations of water surface and velocity of the tidal wave were assumed.

For Point San Pablo and Army Point, the volume was computed by breaking the hourly strata into sections two miles long and determining the number of acre-feet in each of these blocks. For example: For the flood tide beginning at 8.50 p.m., July 6, at Army Point, between 11 p.m. and midnight, for the block, 4 miles to 6 miles above Army Point, the rise of water surface for the hour is 1.06 feet, and the average elevation is 2.65 feet. Assuming the marsh line to be at elevation 3.2 (See Table 5-2), and the minimum area at low water to be at

elevation —3.2, the area at elevation $2.65 = 4480 + \left(\frac{5.85}{6.4 \times 170}\right) = 4635$

acres. The volume $= 1.06 \times 4635 = 4910$ acre-feet. Considering the block, at this same hour, from 6 miles to 8 miles above Collinsville, the rise of the surface is 1.08 feet and the average elevation is 1.25. From the table on Plate 5-7, the volume of storage for 10 feet of depth at this distance is 18,500 acre-feet. From Curve No. 5, the rate of increase at elevation 1.25 is 0.1006. The total volume of storage in this 2-mile block is equal to $0.1006 \times 18{,}500 \times 1.08 = 2110$ acre-feet.

The results of these computations are given in Tables 5-4, 5-5 and 5-6 for Army Point, Point San Pablo and Presidio, respectively. Flood flows have been given the plus sign and ebb flows the minus. Since the fresh water flow is in the same direction as the ebb, it also takes the minus sign. The sign of the "opposite" tides, explained below, will always be opposite to that of the main tide.

Inspection of Plates 5-6, 5-8, 5-9 and 5-10 shows that there is a fairly uniform progression of the tide phases from the Presidio to the head of tidewater. This is further brought out in Table 5-7. Since the average time interval from high water to low water is only 6 hours and 12 minutes, it follows that at points approximately 85 miles apart the tides must be in opposite phases, that is, if it is high at one place it is low at the other. Between these points is a third where the graph of the tidal prism appears to have a node. This is not a permanent nodal point, for the nodal points, like all other phases of the tide, progress. They are the points where the tidal surface has the same elevation at the beginning and end of a period of time during which the tide is passing from one phase to the opposite phase at some other point. If, at the beginning and end of any six-hour period, there are nodal points at B with respect to A, then for a period beginning three hours later, there will be a node at, or near A with respect to B. The word "appears" has been used above to distinguish this type of node from the usual conception of a nodal point with respect to vibrations, where the node is a point about which oscillations occur. In case of a true nodal point the elevation remains constant, but at B the elevation of the water surface will have risen to high, or dropped to low, after the lapse of three hours; and at the end of the six-hour period it has returned to its midtide elevation.

In the following discussion of "opposite" tides, it will first be assumed that there is no inflow of fresh water. Then, if the main tide is rising, the opposite tide must be falling. If there is only one tidal node, due to the defined limits of the length of the estuary, the water comprising the prism of the opposite tide must pass by the nodal point into the prism of the main tide, thus decreasing by this amount the amount of water which must pass the home section in order to produce the full volume in the main tidal prism. The opposite condition occurs when the tide in the main prism is falling.

If there is a flow of fresh water, its effect is to help supply the water in the tide prism when it is rising, thus cutting down the quantity of water that passes the home section during the flood tide, while on the ebb, not only the water in the tidal prism must pass the home section, but also the fresh water flow during that period. Thus, the sign of the flow of water in the opposite tide prism is always opposite to that at the home section, while the sign of the fresh water flow is the same as the ebb, but opposite to that of the flood.

If, for any particular tide, the flow of fresh water is sufficient to raise the surface of a basin as rapidly as the tide would raise it, there would be no flow in the upstream direction during the flood tide past the home section, although the tide would be rising; but at points below there would be an upstream flow, necessary to fill the tidal prism below the section of no flow. This neutral section will always exist at some point within tidal influence if there is an appreciable flow of fresh water, the neutral section moving downstream as the flow increases, and receding as the flow decreases. The position and character of this neutral point will be influenced by the presence of salt water, as previously mentioned, but usually the plane of neutral flow will be a considerable distance upstream from the point where the saline content is high, so that the flows in opposite directions in the vertical section are not so likely to be found here. When the flow of fresh water is very large, however, and the neutral section is well downstream, say at Carquinez Strait, it is very probable that at points farther downstream there will be found a condition of upstream flow of salt water along the bottom, and ebb flow of fresh water on top.

Discussion of Tidal Prisms.

The volumes of the tidal prisms, as calculated from measurements made on July 6 and 7, 1925, have been summarized in Table 5-8. It will be noted that for Point San Pablo and Army Point the sums of the flood and ebb check very closely. It is not probable, however, that this is an exact measure of the accuracy of the volume determinations for the reason that the quantity in the tide covering the marshes is uncertain. An error in this quantity, however, could not affect the check, because the same quantity of over-marsh water appears in both flood and ebb. Moreover, the volume of the marsh overflow is only a small percentage of the total tidal prism; therefore the total volume would be affected very little, even with considerable error in the marsh overflow. No graph could be constructed for south San Francisco Bay for the reason that no gage readings were available for the period July 6-7. It, therefore, appeared to be a useless refinement to attempt a close computation of that portion for which there were records, so the areas in this prism were divided into districts, and the total depth of each portion was computed at one operation; consequently the volumes in the four prisms do not check as closely as the prisms at the other two points, but check sufficiently close for all practical purposes.

To check the volume of flood against ebb flow, it is necessary to deduct from the ebb the total volume of fresh water that has flowed throughout the period of both the flood and ebb tides, or else to eliminate the fresh water flow from the volume of both the flood and ebb tide prisms. Allowance must also be made for the difference in elevation of the water surface at the beginning and end of the period of measurement.

Inspection of Plates 5-8, 5-9 and 5-10 shows that if a barrier were placed at Army Point, the reduction of the tidal prism at the Golden Gate would not be equal to the tidal prism above Army Point, but would be that portion of the Presidio prism lying above Army Point less the opposite tide, the latter being eliminated if the barrier existed at any point below what is now a node.

The effect of the construction of a barrier on the volume of the tidal prism above the Golden Gate is summarized in Tables 5-9 and 5-10. Tides of July 6 and 7, 1925, are used. River flow is not included, because the assumption is that, except in flood times, this will not pass the barrier.

The volume of the four tides at Army Point is 13.8 per cent of the volume at Golden Gate, while the reduction in the Golden Gate tides by a barrier at Army Point is 7.5 per cent. The San Pablo tides are 35.8 per cent of the volume of those at Presidio, while the barrier at Point San Pablo would reduce the Golden Gate tides by 35.3 per cent. From the above, the conclusion can safely be drawn: As the barrier is located farther from the Golden Gate the influence of the elimination of the tide above the barrier on the volume of the tidal prism above the Golden Gate decreases, till the reduction is zero; and if the barrier is placed at the nodal points, the Presidio tides will actually be increased by an amount nearly as great as the volume of the opposite tides.

The elevation of the water surface, or of the center of gravity of the tidal prism, as well as the range of the tide, has an influence on the volume of the tidal prisms, because of the fact that the higher the elevation of the surface, the greater the area to be flooded. Table 5-11 gives the ranges of tide and volumes in the four tidal prisms at Presidio, Point San Pablo and Army Point on July 6 and 7, 1925. The volumes in Table 5-11 are not the same as those in Tables 5-4, 5-5 and 5-6, for in the latter, the volumes given are those which pass the home section during the phase of the tide while in Table 5-11 the quantity of water in the main tide between the upper surface and the lower surface at the beginning and end of the tidal period is given. From the quantities in this table it is possible to arrive at the volume in any tide above any of the given home sections when the range and elevation of half tide is given.

The U. S. C. & G. S. Bulletin, "Tides and Currents in San Francisco Bay" (Exhibit 15), gives the mean range for the Presidio as 3.93 feet, for Point San Pablo, 4.42 feet, and for Army Point, an average of about 4.7 feet. The San Pablo record is for only one day and appears large compared with other stations in the vicinity with longer records. As indicated in Table 5-11 for the July, 1925, series of measurements, the mean Presidio range was 5.37 feet and the Point San Pablo range 5.65 feet. Comparing these with the mean range at Presidio of 3.93 feet gives a mean range for Point San Pablo of 4.14 feet, which compares favorably with the range of other points near Point San Pablo.

Using the respective ranges 3.93, 4.14 and 4.7 feet, the approximate volumes of the tidal prisms of mean range above the different stations are: Presidio, 1,173,000 acre-feet; Point San Pablo, 414,000 acre-feet; Army Point, 157,500 acre-feet. The volume of South San Francisco Bay (south of Goat Island), computed from mean tide range, is 625,000 acre-feet. The volumes were arrived at by plotting the values shown in the last column of Table 5-11 as abscissa and the half tide elevations shown in column 4 of the same table as ordinates. From the resulting curve the probable value for the volume per foot, for a tide with mean elevation at zero, was deduced, and this value, multiplied by the mean ranges, gives the volume in the average tidal prism. The determination of exact volumes is difficult for the reason that the plotted curves are irregular, the iregularity being due to the fluctuation in the position of the nodes, to the effect of the over-marsh tide and to various other factors.

On page 82, Professional Paper 105, Geological Survey, "Hydraulic Mining Debris in the Sierra Nevada," the volume of the mean tidal prism above the Presidio is given as 1,205,000 acre-feet, which checks within 2.6 per cent the value given above.

To arrive at the quantity flowing past the home section, it would be necessary to correct for the opposite tides, whose volumes can be taken from Tables 5-4, 5-5 and 5-6, and also for river flow.

It is evident that if the flow of fresh water at a section is equal to the upstream flow producing a certain flood tide, then the flow during the flood tide will be practically zero, while the ebb flow will be approximately twice its normal quantity. At the same time the volume in the tidal prism may be practically the same as if there were no fresh water flow.

Under the heading "Bench marks, datum planes, and location of tide staffs," it was stated that any small change in the adjustment of bench marks would not affect the result of the study of volumes in tidal prisms. These volumes are determined from elevations of water surface recorded on tide gages, and the depth of water in a prism is definitely fixed from these readings, irrespective of the correct elevation of the gage. An adjustment of bench marks might affect the areas of water surface slightly, due to the variation of the area of successive elevations, but any bench mark adjustment would be so slight that the correction in area could not be determined from any existing data.

Height of Tide Below the Barrier.

When flood tidal flow starts at the Golden Gate, the mass of water comprising the tidal prism receives its energy from the head that is built up through the approach of the ocean tide wave to the shore. As shown on pages 102 to 106 of Exhibit 15, the velocity of the current in this rising tide is small compared with that through the Gate. If we conceive of a barrier at the Golden Gate, we have a condition of a continuous shore line, and no heavy currents would be likely to be found. With conditions as they are, there exists a large area in the bays to be supplied with water through a restricted opening, with a constantly increasing head outside. A column of water, whose cross-sectional area is that of the Golden Gate, is thus set in motion, with a velocity equal to that due to the head of the tide plus the head of the velocity of approach of the ocean current, minus the decrease in head due to the rising water in the bay. Just inside the gate this stream divides, one portion flowing south and the other north. These flowing streams are of large cross-sectional area and several miles long. To the south the bay tapers almost to a point, with gradually shallowing depth. The area to be flooded is insufficient in size to absorb all the water that has been set in motion in the channel to the north, with the result that the energy, and volume of flow of the moving column, must be absorbed in filling up the south end of the bay to a level nearly twice as great as that at the Presidio, thus neutralizing the energy of flow of the moving column by creating a counter head and by absorbing an extra portion of the volume of flow. To the north this condition exists to only a minor degree.

The width of water surface at sea level, the cross-sectional area of the channels at the various control sections below mean sea level, and the values of the hydraulic radii are given in Table 5-12.

The mean velocity at these control sections, in feet per second, computed from mean tidal prisms and areas of waterways are: Golden Gate, 2.4; Point San Pablo, 1.66; Army Point, 1.51; Goat Island, 1.78. Since velocity varies as the square root of the hydraulic radius, the velocities should be divided by this quantity if it is desired to compare the conditions of flow at the various sections. For the various sections, V, the square root of r gives: Golden Gate, 0.178; Point San Pablo, 0.232; Army Point, 0.234; Goat Island, 0.230.

This would indicate that the energy of the moving column of water at each station, compared with the tidal prism beyond that station, is equal in all cases except through the Gate. On page 121, Professional Paper 105, Geological Survey, "Hydraulic Mining Debris in the Sierra Nevada," Mr. Gilbert states that the bed of Golden Gate is very rough, due to the presence of many ledges. This condition would account, in part, for the low value of the factor of flow at this point, for much of the energy would be absorbed in overcoming resistance to flow. There is evidently a flatter slope through the Gate than at other points, because the tide tables give a lag of only 10 minutes to Alcatraz Light, which calls for a higher velocity of the tidal phase than at other points in the bay with a corresponding flatter slope of the water surface. The presence of the flatter slope has been demonstrated in the investigations, as indicated by the slope curves on Plate 5-11. This flatter slope would also reduce the value of the flow factor

This relative area south of Goat Island to be flooded is smaller than that beyond Point San Pablo or Army Point; therefore, in order that the energy of the column of moving water may be absorbed or in other words, that storage room may be provided for the water that is crowding in, it is necessary that the depth of storage be increased, which can be done only through raising the water surface. This is what actually occurs, for the tide range gradually increases with the distance from Fort Point, till at the south end the range is 1.9 times that at the Presidio.

For the bays north of the Golden Gate, the area, in general, is sufficient to allow the spreading of the water that passes the various straits so that no such large ranges are found as at the south end. The greatest range to the north is found at Carquinez Strait. A probable explanation of this is the fact that the cross sectional area compared with the surface area is large, allowing a large amount of water to enter, with the resulting tendency to a rapidly rising surface. This tendency is mainly neutralized by the fact that the greater portion of the entering water can pass on into Suisun Bay, but before a complete transfer has taken place, a reversal of current causes the excess water to pass back into San Pablo Bay.

Neglecting sediment brought down each year by the rivers, it is safe to assume that the areas of the channels in the bays, and through the straits, have practically reached a stage of equilibrium so that the velocities necessary to pass the water in the tidal prisms is such that no further progressive erosion is taking place, and furthermore, so that these channels are of sufficient size to permit the interior tides to rise as high, or higher, than those at the Golden Gate. If these channels were not of sufficient size, the range at interior points would be less than at the entrance but the velocities through the straits would be greater because of greater differential head.

This condition is analagous to that in two tanks A and B, separated by a diaphragm with a small opening. If the water in tank A were made to fluctuate by means of suitable inlets and outlets in a manner similar to tide movement, then, after its surface has risen above that in tank B, water will start flowing to the latter and continue till after A has reached its peak and then recede until it is below the surface in B, when the direction of flow would reverse. If the connecting pipe is relatively small, the water surface in B will not rise as high as in A, nor will it drop as low, but its mean elevation will be the same as that in A. The smaller the relative size of the opening, however, the greater would be the velocity, for the fluctuation in B would vary directly as its size and, consequently, the maximum heads would vary inversely.

The construction of a barrier at any point in the bay would disturb this condition of equilibrium and have an effect on the tides below. If placed at Point San Pablo, the area north of the Golden Gate would be so reduced that it would fill rapidly with the large channels supplying it. The velocity in these channels would, therefore, be reduced because the differential head would be cut down. This reduction in the velocity would reduce the tendency of a piling up below the barrier, which might be expected under other conditions. The time interval of high or low water between this point and Presidio would also be reduced. The earlier filling of North San Francisco Bay would also advance the time of the tide phases in South San Francisco Bay, but otherwise would have little effect.

With the barrier at Army Point, the reduction of the Presidio tidal prism would be comparatively small, and consequently the velocity of the current in the San Pablo Channel would not be greatly reduced. It has previously been shown that the volume of the tidal prism above Army Point is 13.8 per cent of that above Presidio; while the portion of the Presidio prism above Army Point is 7.5 per cent of the Presidio prism. It follows, then, that that part of the Army Point prism equal to 6.3 per cent of the Presidio prism is supplied from points inside the bay. In terms of the Army Point prism, these percentages are 100, 54.4 and 45.6. Two and one-tenth per cent of the latter comes from the opposite tide, so that 43.5 per cent of the Army Point tide is supplied from that portion of the bay lying between the Golden Gate and Army Point. The area to the north of Point San Pablo is considerably in excess of that to the south, and, likewise, the tide phases are later, so that probably 75 per cent of the 43.5 per cent, or about 33 per cent of the water in the Army Point tidal prism, is supplied from San Pablo Bay. The above figures are from the average of the four tides of July 6 and 7, 1925, but the percentage would be practically the same for mean tides.

In South San Francisco Bay, the piling up of the tide varies approximately as the distance from Golden Gate. Table 5-9 shows the volume of reduction of the tidal prism at Golden Gate through the construction of a barrier at Army Point. The area of water surface at the high tide, north of the Gate, is 144,100 acres. If it is assumed that the energy of flow is sufficient to sweep into the bay the same amount of water as at present, and that this piles up at a constantly increasing rate from the Presidio to the barrier, there would be an increase in the rise at the barrier and vicinity, in amount equal to twice the water formerly flowing to Suisun Bay, divided by the area. For the two July, 1925, tides this increase would amount to 1.36 feet and 1.74 feet, respectively. Owing to the crooked channel, and to the fact that the piling up of the head neutralizes a part of the energy of flow, it is not probable that the piling up would be as great as that shown. Further light is thrown on this subject in a letter from Mr. R. L. Faris of the U. S. C. and G. Survey dated December 18, 1925, quoted on page 228. The subject is one requiring further consideration if construction of the barrier is decided upon.

Velocity and Slope Curves.

Plate 5-11 shows the velocities and slopes at Army Point and Point San Pablo for the tides of July 6 and 7, 1925. The velocities are the mean for the section and were obtained by dividing the discharge per hour, as determined from the volumes of the tidal prisms (Tables 5-4 and 5-5), by the cross sectional area of the respective sections, the area being corrected for the mean elevation of water surface for each hour. The ordinates between the curve and the zero line represent the velocity at the time indicated by the abscissa.

The slopes were obtained by moving a tracing of the Army Point tide curve horizontally to the left an amount equal to the time interval of corresponding tide phases between Army Point and Dillon Point, which is equivalent to replacing the Dillon Point curve by the Army Point curve. The quotient, obtained by dividing the vertical ordinates between the two curves by the distance between the two points, is the slope of the water surface at Army Point. These slopes were obtained for each half hour and the points joined by a curve. The ordinate between the curve and the zero line represents the slope of the water surface at the time indicated by the abscissa. For Point San Pablo, the San Pablo tide curve and the time interval and distance between that point and the Presidio were used. This method of determining the slope eliminates errors in determining the true elevation of the gage staff, but gives the true slope for only that stretch of channel through which the shape of the tide graph is identical.

It will be noted that the phases of the slope curve precede those of the velocity curve by from $1\frac{1}{2}$ to 2 hours, which well illustrates the surging action of the waters in the bay. Attention is also called to the relative steepness of the early part of each phase of both the slope and velocity curves compared with the later part of the phase. This is especially noticeable in the large tides, and is somewhat more pronounced in the curves for Army Point than for those at Point San Pablo. The same general characteristics of the velocity curves may be noted on Plates 5-1 to 5-5, inclusive.

Two possible explanations of this phenomenon are suggested. One of these is the more rapid filling, or emptying, of the portion of the respective tidal prisms near the observing stations, with a relative tardiness of the passage of the water comprising the tidal prism in the more remote and shallow portions of the two tide prisms, and, especially, of the water that floods the marshes. In the case of each of these stations the remote portion of the prism comprises a large part of the total volume.

A second possible reason is that it is a manifestation of the law governing the proper design of Venturi meters and transitions in flow channels, namely, that acceleration of velocity of flow is accomplished, without undue loss of head, through a shorter space or in a shorter time than deceleration.

Comparing the velocities of the tide phases given in Table 5-7 with the average velocity of the water given on page 201 and with that shown on Plate 5-11, it will be seen that the tidal phases travel from six to seven times as fast as the water itself moves. This is a function of the relative areas of the channels of flow—including the values of "r" and "n" of these channels—and of the volume of the tidal prism. The action of the water in the bays is in accordance with a surging motion, due to momentum of the column of moving water which receives its energy from the tidal action in the ocean. This is illustrated in the graph of simultaneous water surface elevations, Plate 5-6, and also on Plate 5-11.

Record Floods.

The largest flood of record is quite generally assumed to be that of December, 1861, and January, 1862. The most serious flood in the

Sacramento River, of which there are fairly complete and reliable records, occurred in March, 1907, and January, 1909. Floods from the Sacramento are effective on the lower San Joaquin by reason of the many interconnecting channels throughout the delta. The largest recent flood of record on the San Joaquin is said to be that of January 31 to February 3, 1911.

The 1907 Flood.

The flood of March, 1907, is of particular interest because it is generally believed to have been larger than that of January, 1909, and resulted in materially higher water against the levees in the heart of the delta. See Mr. Atherton's letter of June 27, 1925, contained in Exhibit 19. It is reported that the 1909 flood was better sustained for a period of four consecutive days, but that the flood of 1907 was better sustained over a week or 10 days, and crested higher. (House Document No. 81, 62d Congress, 1st session, p. 17.)

During the 1907 flood the U. S. Geological Survey, in cooperation with the State of California, made a study of the runoff from the Sacramento and San Joaquin valleys. A very complete article entitled "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California," prepared by Messrs. W. B. Clapp, E. C. Murphy and W. F. Martin of the U. S. Geological Survey, together with discussions, is found in Volume LXI, *Transactions of the American Society of Civil Engineers.*

It is stated in the article that the flood was preceded by a period of heavy precipitation, and consequent flood stages in all streams, a condition which had prevailed intermittently for several preceding weeks. The precipitation in March was nearly three times the normal for the month and about one-third of it occurred in the three days, March 17th to 19th, accompanied by comparatively high temperature and consequent rapid melting of snow in the higher altitudes. During the flood the flow from 83 per cent of the mountains and foothills in the Sacramento Basin was measured at 11 gaging stations, while the flow from 41 per cent of the mountains and foothills in the San Joaquin Basin was measured at 6 gaging stations. Unfortunately, no gagings were made of the San Joaquin itself. Where data were lacking estimates were made upon the basis of runoff per square mile. As a result of the study it was estimated that had the levees not broken, permitting storage of flood water in the flood basins, the mean runoff into Suisun Bay for the four day period, March 18th to 21st, 1907, expressed in cubic feet per second, would have been as follows:

From Sacramento Basin	554,700
From San Joaquin Basin	226,960
Combined mean discharge	781,660

It is estimated that the maximum flow in the Sacramento would have occurred below the mouth of Cache Slough at 8 p.m., March 19th, if the water had been confined in the channels, and would have amounted to about 640,000 second feet. Likewise, it was estimated that the maximum flow in the San Joaquin occurred on March 19th, at the rate of approximately 313,000 second-feet. The hour of the peak is not stated but it is not probable that the peak discharge from the two rivers coincided.

The authors state that:

> It is doubtful if any combination of causes or conditions will ever produce a larger rate of delivery of water to this valley for a four-day period than occurred during the flood of March, 1907.

In discussing the above quotation, Mr. Luther Wagoner says:

> The writer believes that it would be unsafe to accept this statement as a basis for planning reclamation and flood prevention, unless it is qualified by a large factor of safety. It is generally believed that the flood of 1862 was greater in volume of water discharged into the basins and bay. * * *
>
> While it may be true that a flow of 782,000 cubic feet per second for four days may not be exceeded, there are two points to be considered. The flow from the San Joaquin region might occur as in 1862, and in combination with a 1907 flood on the Sacramento, in which case the quantity would be greatly exceeded. Again, suppose the rivers were leveed in accordance with the plans of the Engineering Commission of 1904, it would not require a four-days sustained flood to overtop the levees, and the probabilities are always in favor of the shorter but perhaps more intense run-off.

It was the opinion of the same gentlemen who discussed the article that the discharge had been overestimated. For example, Mr. C. E. Grunsky says:

> By the mass-curve method, already described, it can now be shown that the maximum discharge of the Sacramento River below its lowest tributary would have been about 540,000 cubic feet per second, and that this would have occurred late on March 19th, or on March 20th. * * *
>
> It is believed that 540,000 cubic feet per second as an approximation of the maximum discharge that would have resulted in Sacramento River below Cache Slough if water had been delivered into the valley as estimated by the authors and if it had all been confined to adequate channels, is nearer the correct value than the 640,000 cubic feet per second noted in the paper. * * *
>
> The same criticism relating to overestimates that has just been made with reference to the regulated flow of the Sacramento River applies in the case of the San Joaquin. * * *

In refuting the arguments presented in the discussions of their paper the authors state in part:

> It is believed that the estimates (of flood flow) are quite conservative, and rather inclined to be too low than too high. * * *
>
> The simultaneous occurrence of a very large flood on both the Sacramento and San Joaquin rivers, is possible, but its probability is very small, on account of the great length of these two basins. Storms of great intensity seldom extend over very large areas. The maximum rate of flow of nearly all the tributaries of the San Joaquin River was greater in 1862 than in March, 1907, but this latter is the greatest recorded flood on the lower San Joaquin that has occurred simultaneously with a very heavy flood discharge of the Sacramento River.

The 1862 Flood.

The flood of January, 1862, which followed a previous one in December, 1861, is generally conceded to be the greatest of record. Extracts from the Journal of the California State Senate for 1863, relative to this flood, accompany this report as Exhibit 17. It will be noted by inspection of the exhibit that the impressions of some of those reporting were apparently more vivid than those of the others. There is a lack of positive information as to the actual amount of run-off, but it probably was not as great as some of the published reports would indicate. Below is a quotation from Bancroft's Hand-book Almanac for the Pacific States, 1863, page 85-86.

> The great floods of 1861-62 were the most overwhelming and disastrous that have visited this state since its occupation by Americans. The first flood submerged the Sacramento Valley about the 10th of December, the water rising higher than in either of the memorable floods of 1849 and 1852. For six weeks thereafter an unusual amount of rain descended; and during that time the deluge but partially subsided, the streams still carried torrents, and the lowlands were overflowed. On the 24th of January the second flood attained its greatest height, and the Sacramento and San Joaquin valleys were transformed into a broad inland sea, stretching from the foothills of the Sierras to the Coast Range, and somewhat similar in extent and shape to Lake Michigan.
>
> The raging mountain torrents swept away bridges, fences, houses, mills, and the most durable improvements in their reach; not infrequently ploughing new channels through the country, and depositing the debris of sand and rock upon large sections of cultivated land.
>
> But the flood was not attended with unmixed evil. The streams that had been choked by tailings for years were suddenly cleared of their obstructions, and extensive river beds were again opened to the enterprise of the miner. The work of rebuilding bridges and mills, and of repairing other damages, called into profitable employment a large number of persons; and trade and commerce and actual improvement suffered less interruption than might naturally have been expected, after so great a blow to our prosperity; and such are the wonderful energies and resources of our people, that in a few months the ravages of the flood had disappeared, and losses estimated at millions had been retrieved.

Likewise extracts from an article in the same publication by Thomas Rowlandson, F. G. S. L., entitled "Notabilia of the Floods of 1861-62."

> * * * Dr. Logan remarks that, on the occasion of the first inundation at Sacramento on December 7, 1861, "It commenced raining at 12 m., and ended at 9 a.m on the 9th; amount in inches, 2.570; the flood commenced at 10 a.m. of the 9th of December and at 10 p.m. had reached 2 feet 6 inches in my office; by daylight it had all subsided. At the second inundation, on January 5, 1862, rain commenced at 10 a.m. and ended at 1.30 a.m. on the 6th; during that interval there fell 2.690 inches. On January 8th, rain commenced at 11 a.m. and ended at 7 a.m on the 10th; between which periods there fell 2.840 inches. On January 10th the flood reached my floor at 2 p.m. and at 8 p.m. came to a stand of 3 feet 11 inches above my floor. The Sacramento River rose during this night to 24 feet above low water mark. On the 14th the water had receded from my floor. * * * "
>
> Assuming the entire watershed drained through the Straits of Carquinez as occupying an area equal to 50,000 square miles, and that the rainfall averaged over the entire area a depth equal to four inches in twenty-four hours—and for some days in January last it certainly must have exceeded that amount—it would be equal to 5,377,785 cubic feet per second, or four times the highest gage ever made of the Mississippi at its highest floods. The whole of this immense volume has no outlet excepting a passage not greater than 300,000 feet sectional area, with the further disadvantage that this outlet is subjected to tidal influence. Under such circumstances, that the low-lying country to the east of Carquinez should become inundated, and that for a long period, is not surprising. The inundation thus caused, extended over probably more than 6,000,000 acres. * * * Most singular of all, however, was the fact that the bay fishermen frequently caught fresh water fish in the bay; for from two to three months, the surface portion of the entire waters of the bay of San Francisco consisted of fresh water, to the depth of from eighteen to twenty-four inches. * * * At the Golden Gate, for nearly a fortnight, the stream on the surface was continuously flowing toward the Pacific, composed

entirely of fresh water, the tide not affecting the surface flow, and the water was brackish at the Farallone Islands.

Facts and fancy are strangely blended in this last quotation, and the exaggerated accounts undoubtedly have had much to do with magnifying the probable height of the flood.

Attention is called to the statement of the County Surveyor of Yolo County, in Exhibit 17, that "a barn floated two miles upstream and landed on the other side," indicating that the velocities were very low. Undoubtedly the restricted condition of the lower reaches of the Sacramento had much to do with cauing general inundation. In recent years this has been greatly enlarged to permit the passage of floods. Another agent assisting in the general inundation was the choked condition of the streams brought about by hydraulic mining, as indicated in the first quotation from Bancrofts Almanac, and from the following quotation from page 11, Hydraulic Mining Debris in the Sierra Nevada by Gilbert.

In the early days of gold mining in the Sierra Nevada only a moderate amount of earth was disturbed. An army of men were engaged, but they worked as laborers, with pick, shovel and rocker. It was only gradually that more efficient methods were developed; but finally the resources of the engineer were brought to bear, water power was substituted for man power, and vast quantities of earth were handled. At the height of the hydraulic mining, when hundreds of large jets of water were turned on the auriferous deposits, the material annually overturned was reckoned in scores of millions of cubic yards.

The material thus washed from the hillsides consisted chiefly of sand and the finer detritus called "slickens," but included also much gravel and many cobbles and boulders. The slickens was taken in suspension by the water used in mining and went with it to the creeks and rivers. Much of it escaped from the mountains altogether and found eventual lodgment in the Great Valley of California or in the tidal waters of San Francisco Bay and its dependencies. The coarse stuff tarried by the way, building up alluvial deposits on the lower hill slopes, in the flatter creek valleys, and in the river canyons. When rains and floods came the sands and gravels were moved forward toward the lowlands, and in 1862 a great flood washed so large a quantity into the lower reaches of the Sierra rivers and into the rivers of the Great Valley that the holders of riparian lands became alarmed. The mining-debris question, then for the first time generally recognized, assumed greater and greater importance and prominence in subsequent years and led to protest and litigation which in 1884 culminated in a series of injunctions whereby the miners were restrained from casting their tailings into the streams. The petitioners were valley dwellers, and the evils cited by them included the burial of alluvial farming lands by the flood of debris, the obstruction to navigation from shoaling of Sacramento and Feather rivers, and the raising of the flood levels of the valley streams whereby the area of periodic inundation was increased and protection against inundation became more difficult and expensive.

Mr. Rowlandson gives the impression that the floods were caused in great part by the restriction at Carquinez Strait. This is well refuted by statements of the county surveyors appearing in Exhibit 17. The report from Solano County stated that the water stood about $2\frac{1}{2}$ feet deep over the marshes at Suisun. The present elevation of these marshes above mean sea level was found in the investigation just completed, to be about 3.5, making maximum water surface elevation about 6.0 if the elevation of the marshes has not changed. Other extracts from these same quotations also report that the flood conditions on the marshes around Suisun Bay were not unusual.

In March, 1907, the water reached an elevation, as measured by the U. S. Army Engineers, of 11.0 at the head of Seven-mile Slough, 3 miles below Rio Vista. Mention was made in the items quoted in Exhibit 17 that there was a depth of about 8 feet over the marshes at the latter place. The elevation of these marshes varies from 0 to 3.5 as shown on the maps of the War Department Survey of the Sacramento River. If the depth given is correct, the elevation of water surface at Rio Vista during the great flood could not have exceeded 11.5, which would have been less than the elevation in 1907, for the drop in three miles above Seven-mile Slough during the latter flood would undoubtedly have been more than 0.5 of a foot.

The statement from Dr. Logan of Sacramento, given in the quotation from Mr. Rowlandson, places the height of high water at Sacramento at 24 feet above low water. So far as known, this gage was the predecessor of the present weather bureau gage with the same datum plane and was established in 1849. The flood of 1909 reached 29.6 on this gage. The project flood planes are shown on Plate 5-20.

The American River appears to have been one of the worst offenders in the 1862 flood, as indicated by the marks of extreme high water along its course, marks that have been definitely identified as made at that time. Likewise, the evidence of the county surveyor of San Joaquin County, quoted in Exhibit 17, and the following quotation from page 95 of the "Economic Aspects of a Sacramento Ship Canal" by C. E. Grunsky and L. M. Cox strengthen this evidence.

> There are those still living who may remember the course which the waters of the American River took across the eastern portion of Sacramento in the great flood of 1862. The small levee that had been provided to keep out the American River proved inadequate. It was easily breached by the river and the water followed a natural depression southwesterly into the City of Sacramento and thence southerly toward Sutterville and into the Sacramento Flood Basin.

It is probable that the flood of 1862 was greater than any that has occurred since, but the evidence does not seem to support the belief of many that it was greatly in excess of the floods of 1907 and 1909.

Flood to be Passed by the Salt Water Barrier.

In determing the maximum flood for which the flood gates in the Salt Water Barrier must be designed information was sought relative to the magnitude of floods for which other important works are now being designed and built. The following quotations are from what are believed to be the best authorities.

House Document No. 81, 62d Congress, 1st session, "Reports on the Control of Floods in the River Systems of the Sacramento Valley and the Adjacent San Joaqin Valley, California." Transmitted on June 27, 1911, by the Secretary of War.

Report of California Debris Commission.

> Page 5—All projects prior to this one, however, have been based on a maximum flood discharge (in the Sacramento River) of about 250,000 cubic feet per second at Collinsville, while the floods of March, 1907, and January, 1909, showed that it will not be safe to provide for less than 600,000 cubic feet per second. It is evident that when the maximum flood discharge considered was less than one-half of what it is known to have been at a later date, grave modifications must be made in the projects that have been advanced.

Page 16—* * * It is considered that this flood (1907) was the greatest experienced since the flood of 1862, and while a discharge of any one tributary may occur that will exceed that of the flood of 1907, the possibility of a greater discharge than that of 1907 simultaneously in several important tributaries is so remote that it is not considered advisable to provide for a greater flood over the entire river system. * * *

Page 19—* * * The floods of 1907 and 1909 have proved conclusively that a a flood in this (Sacramento) river may continue for several days at almost the point of maximum discharge. Failure to provide for a discharge such as is shown by these floods of 1907 and 1909 would leave open the way for damage by the occurrence of a similar flood.

Page 20—It is considered advisable, therefore, by this commission to provide capacity for a flood of the extent and duration of that of March, 1907, or January, 1909, and that provision for anything less would be not only unwise but unjustifiable.

Letter of November 12, 1925, from Mr. E. A. Bailey, Flood Control Engineer, State Department of Public Works, to the writer of this report:

Our estimate of the total discharge which would probably have occurred at Collinsville from the combined floods of the Sacramento and San Joaquin rivers in 1907, if the flood control projects had been completed during that flood, was 750,000 second-feet, about 530,000 of which would have come from the Sacramento River. Some of this, however, would have reached the San Joaquin through Georgiana and Three-Mile Sloughs.

As to the discharge which actually did pass through Suisun Bay in 1907, with both Sacramento and San Joaquin Valleys flooded, it is probable that not much over one-half of the 750,000 second-feet actually reached the bay but we have never had occasion to make any detailed analysis of that flood with the conditions existing in 1907.

U. S. Geological Survey, Professional Paper 105, "Hydraulic-Mining Debris in the Sierra Nevada" by Mr. Grove K. Gilbert:

Page 120—* * * It is impracticable to gage the flow of Sacramento and San Joaquin rivers at their mouths, because there the rivers are tidal. The best available data on their discharge are derived from gagings on numerous branches, made for the most part where they issue from the uplands. * * *

Page 89—* * * All authorities agreed, however, that such a rate of delivery (782,000 cubic feet per second estimated by Clapp, Murphy and Martin) has not been realized in the past, and before the construction of levees it was not even approached. So much flood water was stored in the lateral basins of Sacramento Valley and on the delta marshes that the delivery to the bays was regulated as by a reservoir. Its rate may never have exceeded 300,000 cubic feet per second, and 400,000 cubic feet can be accepted as an outside estimate.

House Document No. 123, 69th Congress, 1st. session. "Sacramento and San Joaquin Rivers, California." Transmitted on December 7, 1925, by the Secretary of War.

Page 30 Table H—Existing Conditions, Sacramento River. Flood discharge from Suisun Bay to Steamboat Slough 600,000 cubic feet per second. The figure is for the flow in the river channel, assuming the by-pass system of the Sacramento River flood-control project complete.

Page 46 Table M—Existing conditions, San Joaquin River: Flood discharge, Suisun Bay to Stockton Channel, 280,000 cubic feet per second. The flow exceeds the channel capacity.

Page 53—By section 2 of the act approved March 1, 1917, Congress adopted a complete flood-control project for the Sacramento River, from which considerable benefits will result also for the lands lying along the lower San Joaquin River. This project outlined and recommended by the California Debris Commission (published in H. Doc. No. 81, 62d Cong., 1st sess., and Committee on Rivers and Harbors, H. Doc. No. 5, 63rd Cong., 1st sess.), provides * * *

(5) for the enlargement and straightening of the river channel below the mouth of Cache Slough to safely carry the full flood run-off of the watershed, estimated at approximately 600,000 second-feet. * * *

Transactions American Society of Civil Engineers Vol. LXXXIV (1921).

In discussing an article upon the "Control of Flood and Tidal Flow in the Sacramento and San Joaquin Rivers, California," by Capt. C. S. Jarvis, in which the construction of a Salt Water Barrier is proposed, Maj. H. H. Wadsworth, who made detail studies of the floods from the two rivers, says:

Page 474—The project for the control of floods on the Sacramento River now being carried out under the direction of the California Debris Commission, with funds contributed by the Federal and State Governments, provides channel capacity for 600,000 second-feet of water, with a mean water surface elevation at the mouth of the river of 7.0 feet, U. S. Engineer Department datum (which is 3.6 feet below mean sea level and about 3.4 feet below half tide level at this place) and calls for levees of heights sufficient to protect the lands against tides 3 feet above this mean flood elevation.

The tentative flood-control project for the San Joaquin River which serves as a temporary guide to the state and federal authorities in passing on reclamation projects on the San Joaquin River is planned to provide for the discharge of that stream, at its mouth, of 260,000 second-feet, with the same water surface elevation at the common mouth of the two rivers. The maximum simultaneous combined discharge of the two rivers is estimated at 750,000 second-feet.

Letter of February 19, 1926, from C. S. Ridley, Major, Corps of Engineers, U. S. A., and District Engineer, to the writer of this report. Referring to the above quotation from Mr. Wadsworth, Major Ridley states:

The Sacramento River Flood Control Project has not been changed since this was written, although there is now a report before Congress for a revision this project. If this revision is adopted the mean water surface at the mouth of the river at extreme flood will be considered to be 10.7 and the extreme high tide elevation will be taken as 12.1. Otherwise, the proposed revision will not change the plans or policy as outlined in this quotation.

Referred to mean sea level datum, the elevations given by Major Ridley are 7.1 and 8.5 respectively. The data are shown on Plate 5-21.

As a result of the analysis made of data pertaining to past floods, and in view of the above quotations setting out the view of those considered best qualified to discuss the subject, 750,000 cubic feet per second has been assumed as the maximum combined flow of the two rivers which is likely occur at Collinsville. If such a flood should occur, it is probable that some of the levees would be overtopped and fail as they have in the past, permitting storage of a part of the flood in the lateral basins, and on some of the delta area, with the result that the rate of discharge into Suisun Bay would be decreased. However, provision for a smaller rate of discharge past the barrier would be attended by considerable risk in view of the fact that coincidence of the peaks of the 1907 flood in the Sacramento and the 1911 flood in the San Joaquin would result in a combined maximum discharge of nearly one million second-feet, if the estimates of Clapp, Murphy and Martin may be assumed as correct, and furthermore, since it is possible, although not probable, that such a flood might occur simultaneously with extreme high tides occasioned by a storm such as that of January, 1914, which is discussed in the following paragraphs.

Extremely High Tides.

Mention has previously been made of an elevation of approximately 6 feet for high water at Suisun during the 1862 flood. The quotations also stated that the highest tide at Benicia occurred several days before the January flood of 1862. The actual elevation of this high tide is not known. The highest elevation recorded at Army Point is 5.8 at 1 p.m., January 21, 1909, when the Army Engineers had an automatic gage in operation at this point. The pencil at this time ran off the paper, however, so the actual height may have been a little greater. An automatic gage in operation at the same time at Collinsville produced a complete record, with a maximum height at 1 p.m., January 21, of 6.1 feet. A copy of these two records is shown on Plate 5-12.

Letters from Mr. F. N. Chaplin to Mr. Wm. Pierce, and from W. T. Richards, construction engineer of the San Francisco-Sacramento Railroad (the O. A. and E. R. R. referred to by Mr. Chaplin) are here quoted to show the elevations that have been reached in recent years.

F. N. CHAPLIN.

506 First National Bank Building

Miami Florida, September 10, 1924.

Mr. William Pierce,
Suisun, California.

Dear Sir:—

My sister, Mrs. Wilson of Grisly Island, wrote me that you desired information regarding the floods on Van Sickle Island; that you are gathering data, relative to conditions that would be affected by the Carquinez Dam.

I moved to Van Sickle in 1913. The first flood came on January 25, 1914. The water covered most of the levees surrounding Van Sickle. There was a flood on the river, and a terrific storm on the ocean. At the drawbridge of the O. A. and E. R. R. across the Montezuma Slough, the water arose to a line two-thirds the width of the wheels on which the bridge turns. The diameter of the wheels is about 16 inches. The water rose up on those wheels above the center of the wheels. The flood on the river did not greatly increase the height of the tide (water at high tide). Several days before, the scheduled tide was higher, and the flood on the river higher. The storm drove the water up from the ocean.

The second flood came on February 25, 1917. There was only a 5.4 tide marked in the tide book, and no flood on the river. Water was low in the river. Not much rain that winter. But a terrific storm blew from the southwest. The water rose at the same railroad bridge about 2 inches higher than during the storm of 1914.

The flood took out, in one tide, about one mile of levee, on the bay side, opposite Pittsburg. So the water rose about as high inside the levee as outside.

When I left Van Sickle, about 18 months ago, the marks of the 1917 flood were still on the building around the house, near where the railroad crosses the Montezuma. The water was 21 inches deep in the dwellinghouse, at the door between the dining room and the bedroom at the time of the highest flood.

At other times we had breaks in the levees, during storms, but the island would be flooded only in small parts. The breaks always came during storms at high tide.

F. N. CHAPLIN.

SAN FRANCISCO-SACRAMENTO RAILROAD CO.

Oakland, California, October 11, 1924.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
Berkeley, California.

Dear Sir:—

In reply to your letter of October 10th relative to flood planes on Suisun Bay. The information in the letter which you quote from F. N. Chaplin is verified by our own employees who were at the drawbridge during the periods mentioned. It is undoubtedly true that the sweep of the wind across the bay is often as damaging as any extremely high tide, provided, of course, that conditions are generally favorable for high water.

The elevation of the bottom of the rollers referred to is 5.94 U. S. G. S. Datum. The rollers are 16 inches in diameter so that as the water rose approximately to about two-thirds the height of the rollers above their bottom, and later two inches higher still, the high water mark could be considered at an elevation of 7.00 U. S. G. S. Datum. This is the most accurate reference we have to high waters in that vicinity.

Yours very truly,
SAN FRANCISCO-SACRAMENTO RAILROAD CO.

W. T. RICHARDS,
Construction Engineer.

These data are set forth in the following table:

Jan. 25, 1914		*Feb. 25, 1917*	
Dia. rollers=16"	=1.33'	2" higher than	1914
$\frac{2}{3}$ x 1.33 =	0.89	In 1914	6.83
		2"=	.17
El. W. S.	=5.94+.89=6.83 U. S. G. S.	El. W. S.	7.00 U. S. G. S.

By reference to the map of Suisun Bay, Plate 2-4, it will be noted that Van Sickle Island is a little below Collinsville, and the crossing referred to is about 2 miles below that point. Except as protected by levees, this, as well as all the other islands, is covered by the higher tides, and probably is one of the islands referred to in the previous quotations stating that live stock was not injured by the flood in 1862 in this region.

While there was high water in the river during 1914, it was by no means of record proportions, and there was no flood of moment in 1917. The following is quoted from a letter of March 26, 1925, from Mr. W. T. Richards:

> In reply to your letter of February 18th, 1925, regarding high water in Suisun Bay during February of this year. The highest water recorded at our drawbridge over Montezuma Creek during this high period, was on February 20th, when it rose to an elevation of 5.6 U. S. G. S. Datum. * * *

Weather Bureau records indicate that the February flood peaked at Sacramento on the 6th, the gage on that date reading 26.5 feet. This flood was probably the highest in the Sacramento River since 1909. The maximum combined flow in the rivers occurred on February 8th, at which time approximately 153,000 second feet were being discharged into Suisun Bay.

High Tide of 1914.

The highest water recorded at the city of Suisun in recent years stood at elevation 5.34 on January 25, 1914, as noted by a depth of three-quarters inch on the floor of Hoxie's boathouse near the head of Suisun Slough. The elevation has been determined by a line of check levels from the U. S. G. S. B. M. at the Fairfield courthouse. The elevation attained at Suisun by the high tide of January 21, 1909, is not known.

The high water of January, 1914, in the upper bay region, resulted from the coincidence of a severe storm on the ocean, seasonal high water in the rivers, heavy rains over the region and a spring tide. There was a new moon on the 25th of the month. It had reached its maximum southern declination only two days earlier. Weather bureau reports for San Francisco Station show that a southwest gale prevailed all along the coast, continuing from January 23d to 25th. On January 24th, a maximum velocity of 43 miles per hour was reached at 4.54 a.m. At Point Reyes (Plate 3-1) a velocity of 72 miles per hour was reported. On the following day the maximum wind velocity at San Francisco Station was 37 miles per hour at 7.41 a.m. and again at 5.30 p.m. The 24-hour precipitation at San Francisco was 0.52 inch on the 24th and 0.86 inch on the 25th. The rainfall at Sacramento, Suisun Point and the city of Suisun, and the Sacramento River gage readings at Sacramento for January, 1914, are shown on Exhibit 18.

By reference to the exhibit it will be noted that the river was at a higher stage on January 1st than on the 25th, and that the maximum for the month occurred two days after the highest water at Suisun. The effect of the storm upon the elevation of the surface of the water against the delta levees, and the comparative elevations attained during other recent periods of high water, are discussed by Mr. Geo. A. Atherton in the two letters attached as Exhibit 19.

Plate 5-22 was prepared to show the relation between certain characteristics of the tides of 1914 and those of the past three years. It will be noted that the period of winter high tides includes the months in which large river floods have usually occurred in the past. It will also be noted that the highest water at Suisun did not occur at the time of maximum predicted tide at Presidio which was 0.3 foot higher on the 11th and 12th of the month than on the 25th. The combined effect of the river discharge and storm on the ocean was to raise the water surface at Presidio 1.4 feet above the predicted higher high tide and over 0.8 feet above the predicted lower low tide. Had the same storm and river discharge coincided with the high tide of December, 1914, it is possible that even higher water would have been experienced in the upper bay region. As shown on Plate 5-22, the predicted maximum tide for that month was 0.6 feet higher than in January, but the effect of this higher tide upon the discharge through the flood gates would be counteracted by the lower elevation of the corresponding low tide indicated on the same drawing.

It is difficult to predict the result of discharging a flood from the rivers, such as occurred in 1907 and 1909, into Suisun Bay under conditions as they were in 1914. These were severe as indicated by the following quotation from page 9 of Exhibit 15:

> During the 26 years of observation (at Presidio, 1898 to 1923 inclusive) sea level was lowest in 1898 with a value of 8.30 feet, and highest in 1914 with a height of 8.81 feet. The value for 1914 is principally affected by

the extreme height of 9.16 feet for December of that year (0.6 foot above mean sea level). It is recorded that during that month the tides were unusually high and that the Key Route Ferry steamers between San Francisco and Oakland were obliged to shorten their flag poles in order to avoid striking the sheds in their slips on the Oakland side.

In the above, the heights are yearly or monthly means, as the case may be, and are referred to the 1897 staff. Mean lower low water, adopted as the datum plane by the U. S. Coast and Geodetic Survey, reads 5.55 on this staff. ("Tides and Currents in San Francisco Bay." Special Publication No. 115, p. 16. Included in this report as Exhibit 15.)

Comparison of Extremely High Tides.

In the design of the Salt Water Barrier it was important to learn whether maximum requirements would be satisfied by assuming the tides of January 25, 1914. The letters quoted in Exhibit 21 give some interesting data relative to extremely high tides.

Following is a comparison of some of the important features of the high tides used as a basis of design in this report (1914); the highest of record in Golden Gate (1918); and the tides during the river flood generally conceded to be the greatest of record (1861-62):

Feature	*Jan. 1914*	*Nov. 1918*	*Dec. 1861-Jan. 1862*
Elevation of sea level during the month in which the high tide occurred	+0.5	+0.4	+0.6 ft., Jan., 1862
Maximum velocity in miles per hour and direction of wind at San Francisco	43 Southwest	45 Southerly	
Elevation of maximum tide above mean sea level	+4.5 ft.	+5.2 ft.	+4.6 ft. No record. See Ex. 21(d)
Raise in water surface above predicted high tide in Golden Gate due to storm and flood	1.4 ft.	1.4 ft.	1.8, Dec. 31, 1861 1.5, Jan. 1, 1862
River stage	Ordinary seasonal high water	Low flow	Extreme flood

That the high tide of November 18, 1918, can in nowise be attributed to high river discharge is demonstrated by the following table giving the discharge of the important tributaries of the Sacramento and San Joaquin drainage basins for November 17 and 18, as furnished by the District Engineer, Geological Survey:

Stream	*Discharge in second-feet* Nov. 17, 1918	Nov. 18, 1918
Sacramento River at Red Bluff	5,600	5 600
Feather River at Oroville	2,250	2,560
Yuba River at Smartsville	935	760
Bear River at Van Trent	200	200
American River at Fair Oaks	1,040	1,040
Cache Creek at Yolo	5.5	5.5
Putah Creek at Winters	1.8	2.1
San Joaquin River at Newman	630	755
Tuolumne River at La Grange	570	583
Stanislaus River at Knights Ferry	378	325
Mokelumne River at Clements	246	149
Cosumnes River at Michigan Bar	89	64

Effect of Discharge of Fresh Water from Rivers upon the Elevation of Tides.

That a large flow of fresh water has an effect on the general elevation of the tidal prism is brought out in the following letter from Mr. R. L. Faris of the U. S. Coast and Geodetic Survey. Questions 1 and 2 referred to were:

(1) "If the barrier should be constructed at any one of the three points indicated upon the map (the three sites investigated for this report) what would be its effect upon the height of the tides below the structure?"

(2) "What is the effect in raising the surface of the bays caused by the inflow of a large quantity of fresh water from floods in the rivers?"

DEPARTMENT OF COMMERCE

U. S. Coast and Geodetic Survey

Washington, D. C., December 18, 1925.

Mr. Walker R. Young,
U. S. Reclamation Service,
Department of the Interior,
Berkeley, California.

Dear Sir:—

In reply to your letter of December 3, 1925, receipt of which was previously acknowledged, relative to the effect of the construction of a barrier at some point in San Francisco Bay to prevent the encroachment of salt water into Sacramento and San Joaquin rivers during periods of low flow, upon the heights of the tide, the following information is submitted:

In connection with question (1), it is reasonable to assume that a barrier constructed at the Army Point site, or the Dillon Point site, would increase the range of the tide below the barrier in the vicinity of Carquinez Strait and Mare Island Strait. The eastern part of San Pablo Bay shows a contraction in width with extensive flats and narrowing channel. As the tidal wave advances up this narrow funnel-like body with shallowing bottom toward Carquinez Strait, the confinement of the energy of the moving mass of water into narrow limits causes it to be raised to a higher level. This is manifested in the large range of tide in Carquinez Strait, and it appears reasonable to conclude that if the tide were entirely blocked in Carquinez Strait the range in the converging part of San Pablo Bay and in Carquinez Strait would be increased, but it is doubtful that the range of the tide would be materially affected in San Francisco Bay proper. With regard to the effect of constructing a barrier at Point San Pablo site, it would appear that the range of the tide would probably be increased slightly in North San Francisco Bay below the barrier.

In general large ranges of tide may be ascribed either to the configuration and hydrographic features of the locality or to the character of the tidal movement, such as that resulting from the stationary wave type. In the Bay of Fundy both causes cooperate to produce the very great range of tide found there. These matters are discussed in an article entitled "Tides in the Bay of Fundy" published in the Geographical Review for April, 1922.

In connection with question (2) there is enclosed herewith a set of curves which represent the monthly heights or annual variation in sea level in San Francisco Bay and tributaries. The first curve shows the annual variation at Presidio averaged over a period of 26 years from 1898-1923. The second curve gives the variation at Presidio for the period March, 1908–March, 1909. The third curve gives the variation at Collinsville for the same period, and the last curve gives the variation in river discharge at a station near Red Bluff on the Sacramento River during the period March, 1908–March, 1909. The data used in plotting this curve were obtained from the U. S. Geological Survey Water Supply Paper No. 298. The variations in river discharge from the San Joaquin River during this period were small compared to the Sacramento River, and would not appreciably affect the curve given for the Sacramento River.

From these curves it appears that the variation in sea level at Presidio and Collinsville for the period March, 1908–March, 1909, except for the short break in January, 1909, has the same general form as the mean curve at Presidio. It is also apparent that the large river discharge in the Sacramento River during January, 1909, was reflected in a considerable elevation of sea level at Collinsville, but to a much lesser extent at Presidio. The curves also indicate that, in general, sea level at Presidio and Collinsville are influenced mostly by causes other than river discharge except when this discharge is considerably above the average. At such times the discharge of fresh water into the bays may be sufficient to mask the effects of other influences and materially affect sea level, especially in the eastern tributaries of San Francisco Bay.

With regard to the question in the seventh paragraph of your letter pertaining to the drop of the low water plane below sea level as compared with the rise of the high water in the case of excessive tides mentioned in your fifth paragraph, this survey does not have sufficient records of continuous observations in the Bay of Fundy or the Gulf of California to furnish the information desired. From a publication by the Department of the Naval Service, Ottawa, Canada, entitled "Tidal Levels and Datum Planes in Eastern Canada," high water in Cumberland Basin is approximately 17 feet above mean sea level, while low water is approximately 20 feet below mean sea level. In connection with these elevations it is noted that the results are based upon day tides only, and, therefore, can be considered as approximate only. At Dumbarton Point 45 days of observations in 1923 gave mean high water as 3.10 feet above mean sea level, and mean low water as 3.20 feet below mean sea level.

There is being forwarded to you, under separate cover, Special Publication No. 115, Tides and Currents in San Francisco Bay. (See Exhibit 15.) This publication contains the tabulated results from various tidal and current observations made in San Francisco Bay and tributaries, and may be of service to you in connection with your investigations.

Very truly yours,
R. L. FARIS,
Acting Director.

The curves referred to by Mr. Faris are reproduced as Plate 5-13. Plate 5-14 shows the predicted and actual high and low waters at the Presidio, and the actual at Mare Island, for the flood periods of March, 1907, January, 1909, and January, 1914. As only a comparison between predicted and actual tidal heights were desired for this study, the true tidal graph was not plotted, the high and low points being connected by straight lines. It will be noted that the actual mean tide, in practically all cases shown, stands considerably above the predicted elevation. Winds and other meteorological conditions undoubtedly have much to do with the extra height of the tidal elevation, but it seems probable that excessive flow of fresh water has the major effect, especially when the super elevation of the plane lasts for several days or even weeks. This condition may be ascribed to the less density of the fresh water which requires a higher elevation of water surface to balance the greater pressure of the salt water in the lower reaches of the bay, or in the ocean. As the salinity increases gradually toward the ocean, the superelevation of the water surface gradually decreases. Another condition enters, however. When the point is reached where the flow of fresh water is insufficient to supply the storage in the tidal prism as rapidly as the tide rises, there must be an influx of water from lower reaches of the bay, and this influx, being more dense on account of its greater salinity, will flow along the bottom. This action tends to retard the mixing of the fresh and salt water. The fresh is riding upon the salt, thus tending to increase the elevation of the water surface.

This influence of the fresh water probably is not perceptible in the lower reaches of the bay at times of ordinary river flow. The volume of the mean tidal prism above Army Point has been shown on page

199 to be 157,500 acre-feet, equivalent to an average flow during each turn of the tide of 300,000 c. f. s., or a constant outflow of 150,000 c. f. s., since the tide is ebbing only half of the time. This is nearly four times the average combined river discharge, so it is evident that the point where the influence of the fresh water inflow on the elevation of the tidal surface of the bay is perceptible, must, for the greater part of the time, be some distance above Army Point.

Study of Discharge.

In calculating the discharge through the flood gates of the barrier, consideration must be given to the fluctuating water surface below. The discharge will vary from a minimum at high tide to a maximum at low tide, the bay above the barrier serving as a reservoir to equalize the discharge from the rivers and that through the flood gates. The water surface above the barrier will also fluctuate but to a less degree than below. To be conservative, the flood gates should be designed to pass the probable maximum flood occurring during a period of high tides, without injury to the levees in the delta region. In order to determine the most critical conditions, continuous tide graphs should be available for each barrier site investigated. Unfortunately, the water stage recorder at Army Point was out of commission during the greater part of the occurrence of the high tides of 1909 and it was necessary to study other tide graphs which may be considered comparable. Since the tidal conditions at Mare Island are more nearly representative of those at Army Point than are those at the Presidio, a study was made of the Mare Island tide graphs to determine the most unfavorable tidal conditions for a 24-hour period. While the high water of January 25, 1914, was not as high as that of January 21, 1909, the mean elevation for the tidal cycle was considerably above that of 1909. For this reason, the 1914 tide graph was adopted, and applied directly to the study of a barrier at Army Point. The tide at Army Point was known to be higher than at Mare Island but to arrive at the maximum probable elevation at Collinsville, it is safe to add to the computed elevation at Collinsville the difference in the height of the Mare Island graph that was used and the height that actually was reached at Army Point.

No tide graphs were available for the study with the barrier at Point San Pablo. To supply the deficiency, a graph was interpolated (Plate 5-17), by adding to the tide graph at the Presidio, for the period January 24-25, 1914, 0.3 of the difference between the Presidio and Mare Island graphs, and assuming the time 42 minutes later than at the Presidio. The January, 1914, tide was not the maximum tide that has been recorded at the Presidio. As indicated on Plate 5-22, the maximum was 5.2 feet above standard sea level on November 18, 1918, 0.7 feet higher than the one used, but for purposes of comparison with studies at Army Point, it was believed that the same tidal period should be used.

The assumptions were made that all the islands in Suisun Bay were reclaimed against high water; that no channel improvements had been made below Collinsville; and flow through Montezuma Slough was neglected. These assumptions confined the flow to the present main channels, the cross-sections of which were taken from the U. S. C. and G. Survey chart for Suisun Bay (Plate 2-4). No allowance was made for surge above the barrier, although this might have a minor effect on the elevations. As there is no reversal of current, the surge effect would not be large, although the alternate decreasing and increasing of the flow below Collinsville would undoubtedly cause some surge or reflex tidal action.

In all of the final studies 30 flood gates, 50 feet wide and with sill 50 feet below mean sea level, were assumed. For different tide phases, the water surface elevation below the barrier was used to determine the area of the opening. Table 5-13 shows the discharge capacity of the 30 gates, with elevation of tail water at mean sea level, for various heads. For any depth, d, other than 50 feet over the sill, $Q' = d \div 50 \times Q$, where $Q =$ discharge with tail water at elevation O. The assumed effective area of opening, with tail water at elev. $O = 30 \times 50 \times 50 \times 95\% = 71{,}250$ sq. ft. An entrance loss of 10 per cent of the velocity head was used, which is equivalent to using an effective area opening of 95 per cent of the total area. The discharges in the table are based on a correction for velocity of approach in an approach channel of 200,000 square feet assumed area. The velocities shown are those for the static head plus head of velocity of approach. These values of discharge for various heads were also plotted as a curve and are shown on Plate 5-15.

For a flow of 750,000 c. f. s., it was assumed that with the structure located at Army Point it would be possible to keep all the ship locks open, thus increasing the discharge capacity by 8 per cent. For the study at Point San Pablo, however, it was assumed that the regulations of the War and Navy Departments would not permit the opening of the ship locks to the passage of flood waters, as this procedure would temporarily prevent their use for shipping.

In calculation of flow through the bays a value of "n" in Kutter's formula of 0.020 was used. This is lower than is ordinarily used for earth channels, but consideration of all the conditions appears to warrant its use. Wherever the flats are exposed, at low tide, they have a very smooth, "slick" surface, indicating very little resistance to flow. Flow has been in both directions, due to tidal action, and this would have had a tendency to prevent the formation of abrupt bars and other obstructions to easy flow.

In Volume CCXVI, 1922-23, part 2, of the Minutes of the Proceedings of the Institution of Civil Engineers (British) is a paper by Arthur Burton Buckley, Jr., associate member, discussing his work in connection with the gaging of the Nile. His paper indicates clearly that the value of "n" in Kutter's formula varies for the same section, being smaller when the water is charged with silt and tending to deposit, and larger when the silt content is low and erosion of the bed is taking place. On page 246, Mr. Buckley, in his discussion, quotes E. S. Bellasis: "Hydraulics": "* * * over a hundred discharges observed near the head of a large canal in India show the average value of "n" to be 0.025 when there is no silt, but 0.013 when the depth of silt is 0.5 foot upwards * * *" (See R. B. Buckley's Irrigation Pocket Book.)

Mr. Buckley goes on to say that he found in his work along the Nile values of Kutter's "n" varying from 0.009, when the water was charged with silt, to 0.039 when the water was clear.

An effort was made to determine the value of "n" from slopes and discharges through the bays but an inspection of the curves on Plate 5-11 will show that little reliance can be placed in the ordinary methods of determining this factor. There is, theoretically, only one point in time, during a turn of the tide when slope and velocity are in equilibrium, and this point can not be determined without a previous knowledge of "n." A further proof that the friction factor is low may be deduced from the facts that at interior points, far distant from the Golden Gate, the tide range (exclusive of storm tides) is greater than at Presidio; and that mean tide level coincides very closely with mean sea level. If the frictional resistance were large, the range of the inland tides would not be likely to be as great as that at the Presidio. This point was brought out previously in the discussion of "Height of tide below barrier."

The soft mud that everywhere rests on the bottom of the bays could not offer the resistance called for by a high value of "n," with the high velocities that exist during the tropic tides. The chemical and mechanical analysis of samples of mud taken from the bottom are given in Chapter VIII. The particles are extremely fine and the mud is slippery.

If conditions affecting flow in the Nile can be compared to those in the upper San Francisco Bay system a relatively low value of Kutter's "n" is applicable to the latter for the reason that the water contains considerable silt, especially during periods of large discharge from the rivers and during wind storms which agitate the shallow water of the upper bays. As will be shown in Chapter VIII, the silt content increases with depth. In taking numerous samples of water it was noticeable that the bottom sample always contained a relatively large amount of silt, although an effort was made not to disturb the bottom with the sampler.

Storage over marshes was not considered, as these were assumed to be leveed. Storage in the tidal prism above Collinsville was not considered as it is not known how far back the tidal effect reaches during great floods. It is probable, however, that the tidal effect is so small that it can be neglected—an assumption which is on the side of safety. In determining flow, allowance for the change in elevation of water surface was made in determining the hydraulic functions of the various channels.

When computing the hydraulic functions, the channels were subdivided, according to the different values of "r," and the flow determined for the individual sections. This will always result in a higher discharge than will be obtained if the whole channel is considered as a unit, and is more in accordance with actual flow conditions, for the velocity in the deeper portions of a section are always greater than in the more shallow portions.

Flood Planes.

Using the value of "n" = .020 previously mentioned, the slopes for a discharge of 750,000 c. f. s. and 480,000 c. f. s. were computed from Collinsville to Army Point with elevation of water surface 6.0 feet above mean sea level at Collinsville. The results are shown on Plate 5-16. Curves Nos. 7 and 8 on this plate were obtained by plotting the cross-sectional areas as ordinates and slopes as abscissae with area of sections corrected for new water surface elevations. Using values from this curve, the curves of water surface elevation between Collinsville and Army Point were deduced for elevations of + 4 feet and of + 8 feet at Collinsville. As the purpose of the study is to determine probable flood elevations at Collinsville, with a barrier at Army Point or Point San Pablo, the total difference of elevation between Collinsville and the barrier site is the information desired. Curve No. 9 was constructed by interpolating values for drop among values of $Q = 0$, $Q = 480{,}000$ c. f. s. and $Q = 750{,}000$ c. f. s., and exterpolating values beyond this point. By computation the following relation was found, where $F =$ difference of elevation between Army Point and Collinsville:

$$480{,}000^{3.66} : 750{,}000^{3.66} = 0.75 : 3.85$$

Then for any other value of Q_1, we have:

$$Q_1^{3.66} : 750{,}000 = F : 3.85$$

Curve No. 10 was plotted directly from values from curves Nos. 2, 4 and 6, and curve No. 11 was derived from 10 by assuming that when 750,000 c. f. s. are flowing, with water surface at Collinsville at elevation + 4.0 or + 0.15 at Army Point, conditions are average. For any other elevation of water surface, points for curve No. 11 were obtained by dividing the slope for the given elevation at Army Point by the slope when the water surface is at + 0.15. When computing the flood planes above Army Point, curves No. 9 and No. 11 are the ones actually used. Having given a definite flow with a definite elevation of water surface at Army Point just above the barrier, to determine the elevation at Collinsville: from curve No. 9 is taken the drop for the given flow between the two points; from curve No. 11 is read the multiplier for the given water surface elevation at Army Point; then, applying the multiplier to the value read from curve No. 9, the result is the difference in elevation between the two points. This is all based on the assumption, not absolutely true but very closely so, that if the drop between the two points, for a certain value of Q, follows a certain law of variation, expressed by curve No. 11, for different elevations of water surface, then for any other value of Q this same law of variation holds good.

Investigations of flow and slopes were made also for Carquinez Strait and Pinole Shoal. The results of the study for Carquinez Strait are given in Table 5-14. As the slopes through the Strait are very small, they are neglected in the final studies. The results of studies across Pinole Shoal are shown on Plate 5-16, by curves Nos. 12, 13 and 14. The derivation of these was the same as for the other curves on this plate, already explained.

Attention is called to the rapid increase in the rate of change of slope in curve No. 9 at a rate of flow of 20,000 acre-feet per half hour or approximately 500,000 c. f. s. This would indicate that the channel has been eroded to accommodate flows not greatly in excess of this quantity, and that the natural limit of capacity of the channel is rapidly approached beyond this point.

The results of the flood discharge studies through a barrier located at Point San Pablo and at Army Point are shown on Plates 5-17, 5-18 and 5-19, and in Tables 5-15, 5-16 and 5-17.

It was necessary to assume that flow across the stretches over which slope was considered as uniform, although this is not strictly true, for very seldom is the flow actually uniform. Inspection of the flood discharge curves shows that this is practically always affected by storage action, and that this action is seldom the same at the two ends of the bay. Storage, or release, will generally be acting at a different rate, and frequently at one end storage will be taking place while at the other there is release from storage. Surge effect was also neglected. These two features could be taken into consideration, but limitations on time available did not permit it; and it is questionable whether this refinement, in view of the many uncertainties in the whole problem, is warranted. It is doubtful whether the final results would be appreciably changed by consideration of them. The slopes between Collinsville and Army Point, and across Pinole Shoal, were assumed to be those necessary to carry the estimated average amount of water, determined by consideration of storage conditions, flowing at any time with water surface as shown by the plotted elevations. These slopes were determined from the curves on Plate 5-16.

At the beginning of each study, the assumption was made that all slopes and discharges were balanced; that is, the head above the barrier was assumed at the proper height to discharge the incoming fresh water flow, no change in storage conditions was taking place, and the slopes across the various control sections was correct to carry the uniform flow. While this might not have been found to be the actual condition if the study had been carried through the previous tide, the adjustment to the probable true condition would have been made before the peak of the higher high tide was reached. If the elevations were assumed too high, the discharge through the gates would have been greater, so that the accumulation of storage would have been at a slower rate. On the other hand, if elevations were assumed too low, discharge through the gates would be less and the accumulation of storage more rapid. Thus incorrect assumptions of elevations at the beginning of the study soon automatically correct themselves.

It will be noted that in case of a 750,000 c. f. s. flood, with the barrier at Point San Pablo (Plate 5-17), the tide rises more rapidly than the bays are filled by the incoming fresh water from the rivers. Consequently, to prevent inflow from the downstream side, it would be necessary to close the gates for a period of about four hours during the rise of the lower high tide. With the barrier at Army Point, and a flow of 750,000 c. f. s., there would always be an outflow through the barrier. With 500,000 c. f. s., the outflow is almost, but not quite, checked. The condition of no flow through the barrier depends upon the rapidity with which a particular tide rises, the quantity of fresh water flow, and the capacity of the storage reservoir back of the barrier. Incidentally, referring to conditions during great floods, they do not differ materially from conditions as found with the barrier constructed.

The studies made indicate that the effect of a barrier at Army Point, would be to increase the rise in water surface immediately behind the barrier by 0.7 feet with a flow of 750,000 c. f. s. Owing to the resulting increase in depth in the channels, the slope to Collinsville is flattened a little, so that the increase in height of tide at the latter point above the height it would reach under natural conditions without the barrier would be a little less than the increase at Army Point.

As shown on Plate 5-18, the study of a 750,000 c. f. s. flood through a barrier at Army Point, the top elevation of levees recommended by the Flood Control Office, State Department of Public Works, at Collinsville is 13.52 feet above mean sea level. The probable extreme height of water under the assumed maximum flood conditions has been computed by the flood control bodies of the State to be elevation 8.5. The maximum recorded elevation at Collinsville is 6.1 on January 21, 1909.

The maximum computed elevation found in the three flood plane studies embraced in this report is 7.75, shown on Plate 5-18. The maximum tidal elevation recorded at Army Point is 5.8, 0.7 feet higher than the height used in the studies. It has been shown that the full amount of this addition should not be assumed at Collinsville. Assuming that with this tide of 5.8, the elevation would be increased 0.55 feet at Collinsville, the maximum height at that point would be 8.30, which is well within the limit of the height of water surface for which recommended heights of levees have been fixed.

Mention has previously been made of the surging action above the barrier, analogous to tidal action, but differing from the latter in that there is no reversal of flow. The curves on Plate 5-11, and the graphs of simultaneous water surface elevations on Plate 5-6, illustrate the action of the moving stream of water against the adverse grade that is set up by the alternating tidal movements. In these flood studies there is no reversal of slope, and no allowance has been made for the absorption of the average energy of flow when the discharge has been checked by the rising tide below the barrier. The probable effect of the energy of flow would be to carry the water to the lower end of the storage basin nearer the barrier, where a greater head to produce discharge would be maintained, thus cutting down the amount of water required to be taken into storage. This reduction in storage would result in a lowering of the water surface at Collinsville, at the peak period. Consideration of storage above Collinsville would have the same effect.

Summary.

Due consideration of all the factors entering into the problem would show a tendency toward a general averaging of the elevation of the water surface at Collinsville during a tidal cycle.

The study on Plate 5-19, which is for a flood of 500,000 c. f. s. through a barrier at Army Point, shows the maximum elevation reached at Collinsville to be 6.1, which is well below the safe line, so that discussion of this assumption is unnecessary.

It has been shown that in case of a 750,000 c. f. s. flood, the gates in a barrier located at Point San Pablo would have to be closed during certain periods to prevent an upstream flow. Because of this, the theory has been advanced that the construction of a barrier at Point San Pablo would reduce the elevation of the water surface, during floods, at Collinsville below the height it would reach under natural conditions. This contention is not borne out by the results of the study, nor is the argument believed to be logical, unless an excessively large gate area be provided. The study shows that the height of water surface immediately above the barrier would be 0.35 feet above that of the water surface below the barrier. The elevation of water surface at Collinsville would not be as high as that shown on Plate 5-18, due, in part, to the fact that the height of tide used was not as great as that used at Army Point, and, partly, to the fact that the large storage basin appears to have a tendency to smooth out the water surface at Collinsville, or to partially eliminate the tidal action.

The fact that the inflow of water from below the barrier is assumed to be prevented by the closing of the gates has less effect than might at first seem probable. To illustrate, assume the same flood and tide conditions shown on Plate 5-17, but without a barrier. The lapse of time of the first flood tide is 7.8 hours. The elevation of mean tide is —0.4 and the range of the tide 5.8 feet. From Table 5-11, the volume of this tide per foot would be 96,900 acre-feet, or a total volume of 561,000 acre-feet. During this same period, the inflow from the river would be 483,000 acre-feet. The back flow from the tide then would be 78,000 acre-feet. The period of the next rise is 6.3 hours, the range is 3.25 feet, and the volume per foot is assumed to be 120,000 acre-feet, giving a total volume of 390,000 acre-feet. The inflow during the same period is equal to this quantity. The total period between the two points considered is 18 hours, during which the total inflow was 1,114,000 acre-feet, so the back flow represents only 7 per cent of the total discharge through the straits. It is difficult to conceive how any structure could be designed for any of the sites, whose cost would not be prohibitive, that would not retard the discharge of flood waters by more than 7 per cent.

The maximum elevation of water surface immediately above the barrier, according to the studies, would be 0.35 feet at Point San Pablo and 0.7 feet at Army Point, higher than that below the barrier due to the fact that at the lower site the larger storage basin prevents the water from rising as rapidly. On the other hand, this same fact delays the acquiring of head for maximum discharge, but maintains it for a longer period during the ebb tide. It is also this fact that tends to smooth out the tidal effect at Collinsville.

The reason for the excessive height of tide at Army Point on January 21, 1909 (5.8 + ft.), compared with that at Mare Island (5.25), and at Presidio (4.5), is not known. It previously has been stated that the tides may rise higher just below the barrier, if constructed, than they do under present conditions. It is probable, however, that during periods of excessive floods, the great outflow of fresh water would neutralize this, due to the fact that the momentum of the flood tidal flow from the ocean does not exist in that locality under these conditions.

The construction of a barrier at Army Point would reduce the tidal volume passing through Golden Gate by less than 8 per cent. Under normal conditions, the height of tides below the barrier would probably be increased somewhat at high water and decreased at low water, with possibly a maximum increment or decrement of two feet; but during periods of excessive flood flow the change from present conditions would not be nearly as much. The increase in height of water at Collinsville, with a flood of 750,000 c. f. s. would not exceed 0.7 feet above that under natural conditions without the barrier.

The effects from a barrier at Dillon Point would be practically the same as though it were located at Army Point.

A barrier located at Point San Pablo would reduce the volume of tidal water passing through Golden Gate by about 35 per cent. The elevation of tides below the barrier probably would not be increased as much as at Army Point, although there is nothing certain on this point. The increase in water surface immediately above the barrier over that below would be about 0.35 feet but the increase at Collinsville would not be as much as this unless an unlooked for piling up of the tide below the barrier should develop. If a height of tide of 5.2, the maximum for the Presidio, had been used, it is probable that the maximum elevation attained at Collinsville would have been a few tenths higher than shown in the study.

The designs, to be in conformity with the studies outlined in this chapter, must provide a flood gate area of approximately 75,000 square feet. At the Army Point site the additional sectional area in the ship locks should be considered effective. The lock area at the Point San Pablo site should not be considered available for discharging floods because of the necessity of keeping the locks at that site open to navigation, even during extreme river floods. It is believed that in the preliminary designs and estimates the area of the flood gates should be made the same at all sites investigated. If the 0.7 feet raise in water surface (possibly 0.55 feet at Collinsville) caused by a barrier at the Army Point site is considered reasonable, it might be assumed that the gate area provided at the Point San Pablo site could be reduced. Whether this should be done to effect economy would depend upon the type of structure adopted, because, in some instances, closure of the present waterway can be effected by the construction of gates and piers as cheaply as by some other means. In arriving at a decision in the matter it should be recalled that extreme tides in the Golden Gate are apparently more effective in the lower bays than in the upper bays as evidenced by the records for January, 1914, and November 1918. It can not be said at this time that the effect of such extreme tides upon the discharge of floods through the gates would be detrimental over a period of 24 hours, but it seems likely that such would be the case. It appears, therefore, that until additional studies are made it would be unwise to estimate a smaller gate area at the Point San Pablo site than at the Army Point site. In any event, a large gate area is considered good insurance, and if a smaller raise in water surface at Collinsville will result through construction of the barrier at the San Pablo site with a gate area equal to that at the Army Point site, this should be considered as an advantage of the lower site.

CHAPTER VI

NAVIGATION AND BRIDGE TRAFFIC

GENERAL DISCUSSION

San Francisco Bay is considered one of the finest harbors of the world, being accessible through Golden Gate to the largest ships afloat.

By reference to the general map, Plate 2-1, it will be seen that the bay system is made up of San Francisco Bay proper, San Pablo Bay and Suisun Bay. The total length of the system is approximately 80 miles while the width varies up to about 12 miles. Both the Sacramento and San Joaquin rivers, which discharge into Suisun Bay at its easterly end, are navigable streams of importance. The accessibility of the upper bays, as well as the Sacramento and San Joaquin rivers, is limited at present only by the depth of channels which are maintained. It is evident that any plan proposed for the control of salinity in the Sacramento-San Joaquin delta should, if practicable, be coordinated with the requirements of navigation.

In the study of a Salt Water Barrier located at any point between the Golden Gate and Collinsville the volume of traffic, both present and future, and the size of vessels used in that traffic, become considerations of vital importance. It appears that it is only a matter of time until the city of Sacramento or Stockton, possibly both, will be made accessible to ocean going vessels. Future industrial development, to be expected along the shores of any body of practically fresh water which may be created through construction of the barrier, makes it imperative that the ship locks be made sufficient in size to accommodate the largest commercial vessels which enter San Francisco Bay and with capacity to permit of considerable growth in traffic. With these two points in mind data have been assembled in an effort to determine the requirements.

Volume of Traffic.

An idea of the commercial importance of San Francisco Harbor may be gained from a study of traffic figures shown in Tables 6-1 to 6-11. The data shown are extracted from the 1924 Annual Report of the Chief of Engineers, U. S. Army, and are for the calendar year 1923. As the barrier site located at the lower end of San Pablo Bay, between Points San Pablo and San Pedro, is the most westerly site considered in this report, figures for traffic on the navigable waterways east of that point only are included.

Type of Vessels.

Vessels enter San Francisco Bay from all parts of the world, including the largest battleships with large beam and draft, airplane carriers of great length, sailing vessels with tall masts and ocean liners with high deck structure and funnels. Boats navigating the bay system include those of almost all conceivable types. There are commercial freight carriers, large and small. There are fast passenger steamers operating on regular schedule between San Francisco and upstream points. There are many river boats of light draft but large beam, usually propelled by means of a stern wheel. There are motor driven barges of various types, sea going tugs, harbor tugs, towed barges, pile-drivers, dredges, derrick-barges, yachts, fishermen's boats and miscellaneous other craft.

All of the vessels could be handled in ship locks as at many places throughout the world. Some classes are more troublesome than others. For example, barges laden with crops from the Great Central Valley are towed downstream by one transportation company and returned with freight from San Francisco for distribution in the valley. They are towed in tandem in strings said at times to include as many as eight or ten barges. The barge ordinarily in use is about 46 feet wide and 235 feet long having capacity of around 800 tons. "Strings" of five and six barges are quite common. A string of five barges is shown in Photograph 6-1.*

As the length of these tows ranges from 1200 feet to one-half mile, it is obviously not practicable to construct locks which would pass the "string" as a unit. Long rafts of logs would be difficult to handle at the locks but it is believed that they need not be considered in the designs for the Salt Water Barrier. No rafts have been observed during the two years occupied in the investigations although piles are occasionally towed in the water.

Size and Number of Vessels.

Considering the probable industrial growth in the Bay region as a result of the creation of a practically fresh water lake, and the development of commerce expected to follow the construction of a deep water channel either to Sacramento or Stockton, it is believed that provision should be made at all barrier sites under consideration for passing the largest commercial vessels. Even under present conditions of channel improvement boats having a length considerably in excess of 400 feet navigate Suisun Bay, above all of the sites under investigation. Incomplete lists and dimensions of vessels greater than 400 feet in length, which pass Army Point and Point San Pablo dam sites, are given in Tables 6-12 and 6-13. The dimensions of vessels which pass Dillon Point site are not available except as may be assumed from the above tabulations.

The number of vessels of various lengths calling annually at wharves of some of the more important industrial plants in the Bay region above the Point San Pablo dam site under present conditions of development is given in Tables 6-14, 6-15 and 6-16 in which data furnished by the companies named are tabulated.

Continuous records of the number of vessels passing various points of interest, during the periods given below, appear in Tables and plates as follows:

Table 6-17: Rio Vista bridge, July 6 and 7, 1925.
Table 6-18: Collinsville, July 6 and 7, 1925.
Table 6-19: Pittsburg, May 14 to 20, 1925.
Table 6-20: Avon, May 14 to 21, 1925.
Table 6-21: Oleum, May 19 to 26, 1925.

* Not included in printed report. Films on file in office of U. S. Bureau of Reclamation, Denver, Colorado.

Plate 6-1: Rio Vista bridge, April, 1924, to October, 1925.

Plate 6-2: San Pablo Strait (discontinuous), May 12 to June 23, 1925.

Four of the largest commercial vessels which at present enter San Francisco harbor are listed below:

Name	*Length, feet*	*Beam feet*	*Draft, feet*	*Owner*
America	669	74	34	U. S. Shipping Board
Minnesota	622	74	32	Panama-Pacific Line
Manchuria	620	65	31	Panama-Pacific Line
President Taft	517	72	31	Dollar Steamship Co.

At the present time there are two-stern-wheel boats being built at Stockton for use on the rivers which are reported to be 286 feet long and of 58-foot beam.

As will appear later, locks are proposed at each of the barrier sites which are sufficient in size to pass a boat considerably larger than the "America." As the very large boat is the exception, rather than the rule, other and smaller locks are proposed for reasons which will be discussed.

Draft of Vessels.

Quantities of data relative to the draft of vessels serving San Francisco harbor have been assembled by the War Department by reason of its jurisdiction over navigable waters and by others who have been interested in developing transportation facilities. Data that are of particular interest in the study of locks for the Salt Water Barrier were gathered in connection with the investigation of the proposed deep water channels to Sacramento and Stockton. The subject has been so thoroughly covered that no attempt has been made in the investigations of the barrier to do more than summarize the data. Portions of various reports will be quoted which bear directly upon the lockage requirements at the barrier.

[1] "The question of draft is less easily settled, the draft of ships varying according to weight of cargo and salinity of the water, and there being no obtainable compilation of the average or maximum drafts of vessels operating on the Pacific Coast. To determine the relative proportion of ships now entering the port of San Francisco that could use either a 24 or a 30 foot channel the pilot records have been gone over and summarized in the following Table B (6-22). In this table actual draft at the time of entry into port has been considered, and the record is thought to be trustworthy as the pilots' remuneration varies with the draft of the ship when docked. To eliminate, as far as practicable, any eccentricity resulting from war conditions, the table has been prepared to comprise a six months' period before the war and the last six months for which complete records were available. The * * * investigation shows that 24-foot channel will be ample for 73 to 88 per cent of the vessels normally entering San Francisco during a year."

[2] "Following are excerpts from a letter by Capt. John W. Wallace, port agent, San Francisco Bar Pilots:

'We are pleased to advise you that the average draft covering vessels entering this harbor under our control for the period of six months ending September 24, 1924, is 20 feet 3 inches, the number of vessels involved being 854.'

'In computing this average we have taken the give-and-take system; that is, on vessels drawing less than 6 inches, we dropped the inches, and in those drawing over 6 inches, we called it another foot.'"

[1] Report on San Joaquin River and Stockton Channel, California; House Document No. 554, 68th Congress, Second Session, p. 35.
[2] House Document No. 554, p. 82.

Table 6-23 is a summary of the work sheet kept in the office of Captain Wallace. Inspection of the details indicates that the maximum draft by any vessel entering the harbor under San Francisco Bar Pilot's control was 30 feet.

[1] "Grain is now mostly shipped from the east side of San Francisco Bay and from Port Costa. In both cases a depth of 32 feet or more is available; it is therefore to be expected that the ships now engaged in the carriage of grain would usually have, as they do, a draft approximating 26 to 28 feet. The accompanying Table R shows the draft of the ships that actually went out of San Francisco Harbor with barley cargoes during the calendar year 1923."

Table R, referred to above, shows that in the calendar year 1923 there were 97 large ships that left San Francisco Harbor carrying barley as a part of the cargo. The average draft of all of the vessels when leaving San Francisco was 26.5 feet. The minimum was 17 feet 7 inches while the maximum was 34 feet. The "Tenyo Maru" was the largest vessel, having the following dimensions: Length 558.0 feet, width 61.9 feet, depth 35.5 feet, draft on leaving the port 30 feet 10 inches. There were 4 vessels 500 feet or over; 10 with length 485 feet or over; 29 with length 450 feet or over; and only 23 less than 400 feet in length. The minimum length was 337.7 feet. The "President Cleveland" had the greatest width and depth, 72.2 feet and 36.8 feet respectively. Its length is 517.0 feet. The draft when leaving port was 29.5 feet.

[2] "This concern (Luckenbach Steamship Co.) is reputed to operate the 'largest and fastest' vessels in the intercoastal service. The cargo capacities of the vessels range around 11,500 tons and the exact full-cargo drafts of 10 of them are as follows: 31 feet 8½ inches, 31 feet 8¼ inches, 31 feet ½ inch, 30 feet 6 7/16 inches, 30 feet 6 3/16 inches, 30 feet 6 7/16 inches, 31 feet 1 inch, 30 feet 4¼ inches, 29 feet 4¾ inches, and 29 feet. Their lengths between perpendiculars vary from 445 feet to 496 feet, and when they arrive at San Francisco from the northwest their drafts range around 25 and 26 feet."

In the design of the ship locks the fact that a vessel has a greater draft in fresh water than in salt water must not be overlooked. It has been estimated[3] that in passing from salt water to fresh water a vessel of the size suitable for navigation of the upper bays and deep water river channels, if built, will increase its draft at the maximum about 8 to 10 inches.

In Tables 6-2 to 6-11 data are presented which indicate the number of vessels of various drafts in use on the bays and lower rivers, many of which, under present conditions, would have to pass through the ship locks at a Salt Water Barrier.

Vertical Clearance.

The following quotation is taken from Military Engineer for July-August, 1920, to indicate the seriousness of the problem encountered in an attempt to build structures across important navigable waterways sufficient in height to clear all vessels.

Height of Vessels and Clearance of Bridges.

An investigation has recently been conducted by the Port Facilities Commission, United States Shipping Board, to ascertain the maximum height

[1] House Document No. 554, p. 57.
[2] House Document No. 554, p. 79.
[3] House Document No. 554, p. 22.

of seagoing vessels above light and load water line, the results of which are of interest in connection with the vertical clearance of bridges, and cable lines across navigable waters.

Data were received as to 53 vessels ranging in gross tonnage from 4170 to 54,281 and in height above water line from 96.8 to 217 feet.

Fifteen of the 53 vessels have a maximum height above light-water line greater than 150 feet, as follows:

FIFTEEN VESSELS OF MAXIMUM HEIGHT (In Feet)

Name	*Built*	*Gross tonnage*	*Height* Light	*Height* Loaded
Aquitania	1914	45,647	217.0	205.0
Leviathan	1914	54,281	192.8	186.5
Stavangerfjord	1917	13,600	191.0	183.0
Carmania	1905	19,524	181.0	173.0
Caronia	1905	19,687	181.0	173.0
Mauretania	1907	30,704	173.0	170.0
Nestor	1913	14,501	168.5	153.0
Henderson	1917	7,493	164.4	157.0
Rotterdam	1908	24,149	162.3	149.0
Geo. Washington	1908	25,569	159.7	154.0
Von Steuben	1901	14,908	154.8	151.0
Noordam	1902	12,531	153.5	135.8
Ryndam	1901	12,527	152.5	135.8
Aeneas	1910	10,049	151.0	136.0
Ascanius	1910	10,048	151.0	136.0
Average	1909	21,014	170.0	159.9

The following table contains data on the more important bridges under which ocean-going vessels pass:

CLEARANCES OF IMPORTANT BRIDGES

Name of bridge	*Type*	*Waterway*	*Maximum horizontal span in feet*	*Vertical clearance in feet*
Poughkeepsie	Cantilever	Hudson River	547	160
Firth of Forth	Cantilever	Firth of Forth	1,700	157
Quebec	Cantilever	St. Lawrence River	1,800	150
Vancouver	Vertical lift	Columbia River	250	150
Glison street, Portland, Oregon	Vertical lift	Willamette River	205	144
Tower Bridge, London	Double bascule with overhead footway	Thames River	280	141
Brooklyn	Cable suspension	East River	1,546	135
Manhattan	Cable suspension	East River	1,470	135
Williamsburg	Cable suspension	East River	1,536	139
Hell Gate	Fixed arch	East River	1,017	135
Queensboro	Cantilever	East River { East span	947	135.6
		East River { West span	1,153	133.6

Of the 53 vessels reported on, 32 have a height above light-water line greater than 135 feet and are therefore unable to pass under the East River bridges.

Of 19 vessels whose gross tonnage ranges from 12,527 to 54,281, 12 exceed 150 feet and 16 exceed 135 feet in height.

Of 18 vessels whose gross tonnage ranges from 10,048 to 11,850, 2 exceed 150 feet and 9 exceed 135 feet in height.

Of 16 vessels whose gross tonnage ranges from 4170 to 9996, 1 exceeds 150 feet and 7 exceed 135 feet in height.

Of the 53 vessels, only one, the Powhatan, gross tonnage 10,531, is less than 100 feet in height. Its height above light-water line is 96.8 feet.

The vessels built during the war for the Emergency Fleet Corporation, ranging in gross tonnage from 2020 to 7898, all have heights less than 100 feet. This is due, however, to the fact that the height of these vessels was, prior to the signing of the armistice, kept as low as possible. Restrictions upon the allowable height of vessels of the Emergency Fleet Corporation have now been removed.

In view of the constant tendency to give deep water access from the sea to important cities at moderate and even considerable distances from the ocean, the restricted heights of bridges are a serious problem.

There seems to be no relation between the size of boat and the height of masts or permanent deck structures. Small schooners have tall masts. The *Matsonio* and *Maru,* owned by the Matson Navigation Company of San Francisco, ships 501 feet in length, with beams of 58 feet, are reported as having masts 123½ feet above light load line. This company, however, has plans for building a steamer requiring a vertical clearance of 180 feet.

The highway bridge recently completed over San Joaquin River near the town of Antioch, was built under a permit issued on December 20, 1923, by the War Department which specified a vertical clearance above high water of 70 feet under fixed spans and 135 feet under the lift span when raised.

The original permit for the construction of the high level highway bridge erected across Carquinez Strait, near Crockett, provided for a vertical clearance of 135 feet above mean high water. The plan was revised to include a roadway built on a grade and on January 17, 1924, permit was issued providing for a vertical clearance above mean high water of 135 feet at the south pier and 158 feet at the north pier.

No definite information has been obtained relative to the clearance required by the ordinary smaller vessels in the vicinity of San Francisco Bay, but data obtained in the operation of the Lake Washington locks at Seattle, Washington, show that gas schooners of only 26 tons have 39-foot masts; 60-ton tugs have 40-foot masts; 100-ton tugs have 38-foot masts; 200-ton tugs have 40-foot masts and 400-ton boats have 55-foot masts. The height of deck houses of these tugs above water line vary from 20 feet for tugs up to about 150 tons to 30 feet, and over, for the larger tugs. If it may be assumed that the smaller boats in use on the San Francisco Bay system are similar to those on Puget Sound, which appears reasonable, the determination of the clearance necessary to pass the bulk of the smaller vessels without lifting the bridge is difficult.

Harbor regulations require all craft navigating ocean or inland waters to show range lights, but as far as has been learned no definite minimum height of the uppermost light has been established for San Francisco harbor. Establishment of uniform bridge clearance is now under consideration by the War Department, but no conclusions have been reached to date.

One of the controlling considerations in the construction of the new Central Railroad of New Jersey bridge over Newark Bay, was to provide sufficient vertical clearance to permit all low vessels to pass without raising the lift span. The clearance above mean high water is 35 feet with the lift span in lowest position and 135 feet when raised.

Data obtained relative to the operation of the Lake Washington canal are of value in indicating the vertical clearance required to pass ordinary small boats. The lowest city bridge across the canal has a vertical clearance of 30 feet. This bridge carries more street traffic than any of the others and is required to be opened oftener. The District Engineer states that a vertical clearance of 45 feet would have been much better, as it would have allowed practically all of the small craft, which use the small ship lock, to pass under the closed bridge thus avoiding interference with vehicular traffic.

As the smaller lock of those proposed at the Salt Water Barrier is longer than the small Lake Washington lock (40′ x 200′ in comparison with 30′ x 150′), it is probable that the vertical clearance required will be greater than found advantageous at Seattle. In the design of the barrier to which principal consideration is given in this report, provision is made for a minimum clearance of 56 feet above mean sea level, or 50 feet above the highest observed tide. It is assumed that any vessel requiring a vertical clearance of more than 50 feet would be too large, otherwise, to use the small lock and the bridge span over that lock is made a fixed span although it could be made movable at very little added expense. If deck houses of the smaller craft will clear a bridge it is not a difficult matter to arrange the masts and stacks to be lowered to avoid opening or lifting the movable part of the bridge.

Movable bridge spans are provided over the larger locks proposed for the barrier. Two types have been considered—the bascule and the vertical lift. In case of an open bascule bridge the sky is the limit of vertical clearance. In case of the vertical lift the clearance has been made 141 feet above mean sea level or 135 feet above the highest observed tide.

A minimum clearance of about 70 feet would be advantageous in that practically all, if not all, regular river boats could pass under the closed spans, thus avoiding interference with trains or vehicular traffic, and although the increased cost of the barrier to provide the additional 20-foot clearance has not been considered warranted by those responsible in the investigation just completed, it is possible that further consideration would alter this point of view. Since most of the river boats are too large to be accommodated by the small lock there would be no object in providing a greater minimum vertical clearance other than to minimize interference with vehicular or railroad traffic. Delays to overhead traffic are discussed later.

Navigation Projects.

The depths of water below mean lower low water in the San Francisco Bay system are shown on Plates 2-2, 2-3 and 2-4, respectively.

Entrance to Harbor.

The following quotations are from House Document No. 124, 67th Congress, 1st Session, which contains reports upon the "Entrance to San Francisco Harbor, California," transmitted by the Secretary of War on November 17, 1921:

> [1] The entrance to San Francisco Harbor is through the Golden Gate, where there is ample depth and width. Five to six miles outside there is a semicircular bar through or around which are three channels, two of which —the main ship channel directly opposite the entrance and Bonita or North Channel along the shore—are now used. The controlling depth and width of the former are 36 feet and 1600 feet, respectively, and the latter 54 feet and 730 feet. In Bonita Channel there are some rock obstructions and for some distance it runs approximately parallel with the rock-bound coast, rendering navigation somewhat hazardous. The main ship channel is the usually travelled route, but the depth is not sufficient in times of heavy swells to prevent large vessels from striking the bottom. The mean tidal

[1] House Document No. 124, p. 2.

range on the bar is 3.8 feet. The improvement desired is a channel which will permit deep-draft vessels to enter the harbor safely in all kinds of weather. A study of the draft of vessels using San Francisco Harbor shows that to comply with this requirement the depth should be 40 feet at mean lower low water. * * *

After due consideration, * * * I (Major General Lansing H. Beach) concur in the views of the District Engineer and the Board of Engineers for Rivers and Harbors, and therefore report that the improvement of the entrance to San Francisco Harbor by the United States is deemed advisable to the extent of dredging a channel through the outer bar on line of the main ship channel, 40 feet deep at mean lower low water and 2000 feet wide, at an estimated cost of $530,000 for original work and $100,000 annually for maintenance. * * *

[1]* * * During the calendar year 1920, 176 foreign and 371 American vessels entered the port. The largest of these had a draft of 32 feet. The largest vessels of the Navy are reported to draw 33 feet. Experience has shown that in rough weather there should be at least 7 feet between the keel and the bottom to insure safety. This indicates a depth of about 40 feet.

[2]* * * The maximum draft of commercial craft likely to use this harbor at present is 32 feet, and of naval vessels 33 feet. It has been noted that there are large transatlantic vessels of much greater draft than this, but it is not expected that these vessels will trade in San Francisco in the near future. * * *

[3]* * * In the Annual Report of the Chief of Engineers for 1920, p. 274, it is noted that a ship with a reported draft of 42 feet, 10 inches navigated Ambrose Channel, New York Harbor, in 1919.

San Pablo Bay.

The authorized project for San Pablo Bay and Mare Island Strait provides for dredging a channel 44,000 feet long, 500 feet wide, and 35 feet deep at mean lower low water, thence through Mare Island Strait, a channel 16,000 feet long, 500 feet wide and 35 feet deep, with a turning basin 1000 feet wide in front of the quay wall at the Navy Yard.

Suisun Bay.

The authorized project for Sunsun Bay from Martinez to Antioch provides for a channel 300 feet wide, 24 feet deep across the lower shoal near Bullshead Point, thence 18 feet deep across Point Edith and Middle Ground Shoals, thence 18 feet deep through New York Slough. In addition, an existing project for Suisun Channel (commonly known as Suisun Creek) provides for dredging a channel 125 feet wide and 6 feet deep up to the head of navigation at the town of Suisun, with a harbor of the same depth, 1400 feet long and 150 feet wide. All depths are referred to mean lower low water.

Sacramento River.

[4] The State of California has, by statutory enactment, declared that navigable waters and all streams of sufficient capacity to transport the produce of the country are public ways, for the purpose of navigation and of such transportation. Among the streams denominated as navigable is the Sacramento River, between its mouth and the mouth of

[1] House Document No. 124, p. 3.
[2] House Document No. 124, p. 20.
[3] House Document No. 124, p. 18.
[4] Report on the Economic Aspects of a Sacramento Deep Water Ship Canal by C. E. Grunsky and Leonard M. Cox, p. 96.

Middle Creek. This river is thus declared to be a public way to a point in Shasta County.

The Sacramento River has been under improvement from its mouth, at Collinsville, to the city of Red Bluff, a distance of approximately 250 miles. The existing project provides a low water depth of 7 feet from the mouth of the river to Sacramento, 60.7 miles; 4 feet from Sacramento to Colusa, 86.2 miles; 3 feet deep from Colusa to Chico Landing, 51.3 miles, and such depths as practicable from Chico Landing to Red Bluff, 52.4 miles. Below Sacramento the results are obtained by means of wing dams at the shoals, supplemented by dredging when necessary. Above Sacramento the results are obtained by the removal of snags and concentration of the channel by temporary works.

Under present conditions it is probable that Sidds Landing, east of Willows and about 120 miles upstream by river from Sacramento, is the practicable head of navigation. Diversions for irrigation purposes affect the navigability of the upper river at low stage and it is the belief of some that ultimately Colusa must necessarily be regarded as the head of navigation during the low water season.

In the study of the Salt Water Barrier the requirements of navigation on the Sacramento River below Sacramento are important considerations. The project depth of 7 feet has, in recent years, been maintained without great difficulty. A project which proposes to provide a depth of 10 feet at mean lower low water up to Sacramento has been approved by the War Department and is now before congress. Any lock proposed for handling river boats should therefore provide a depth over the gate sills of at least 12 feet at mean low water.

Navigation below Sacramento is not dependent upon river discharge to the same extent as above. On July 7, 1925, the range of the spring tide under approximately normal conditions of summer river flow, was 2.12 feet. The following figures are taken from the curves shown on Plate 5-6:

COMPARATIVE TIDAL FLUCTUATIONS AT COLLINSVILLE AND SACRAMENTO ON JULY 7, 1925

Tide	*Elevation of water surface U. S. G. S. datum* — *Collinsville*	*Sacramento*
Higher high	+3.80	+4.83
Lower low	—2.28	+2.71
Range	6.08 feet	2.12 feet

The curves referred to show that the maximum instantaneous drop in water surface from Sacramento to Collinsville was 6.28 feet in 60.7 miles while the greatest slope in the opposite direction was 0.74 feet. The corresponding slopes are 0.1034 and 0.0122 feet per mile, both very flat.

In 1924 the flow past Sacramento dropped to 705 cubic feet per second, allowing for the draft and American River flow between the measuring section and Sacramento. [1] In spite of this the largest river steamers maintained their regular schedules between San Francisco

[1] Proceedings of the Second Sacramento-San Joaquin River Problems Conference, p. 107.

and Sacramento and it appears that requirements at the locks for the Salt Water Barrier are independent of any action that might be taken relative to the division of water between navigation and irrigation interests.

The Army Engineers have investigated various schemes whereby irrigationists might be allowed to take a maximum amount of water from the Sacramento River without impairing the navigability of the river during the low water period. One plan investigated contemplates canalization of the river by a system of four dams which would provide slack water navigation during the low water period to the vicinity of Butte City. Each dam would be provided with a ship lock 76 feet wide by 450 feet long. [2] The dams proposed would be located as follows:

No. 1. Near Freeport, about 13 miles below Sacramento.

No. 2. Near Collins Eddy, about 13 miles above Knights Landing.

No. 3. At Kent, about 6 miles below Colusa.

No. 4. At Comptons, about $12\frac{1}{2}$ miles above Colusa.

It is said that the scheme, supplemented with some dredging just below each dam, would provide a minimum depth at low water of 9 feet to Sacramento and 6 feet from there to Butte City. It appeared to those who made the study that the project might be operated with not more than 500 second-feet of water and perhaps much less. The argument is advanced that the amount of water required for operation of the system would be well under the amount which must of necessity be allowed to pass on down the river for the use of irrigationists in the delta region. This is no doubt true, but the system of dams would not solve the salt water problem in the delta, as none of the dams proposed are downstream far enough to be of any use in stopping the encroachment of salt water. No claims have been made in this direction. Upon the other hand, if, in the future, slack water of the depths indicated were provided, the effect of increased commerce on the river would probably be to increase the number of lockages at the Salt Water Barrier and this should not be lost sight of in considering the number of locks required.

San Joaquin River.

The existing project for the maintenance of navigation on the San Joaquin River provides for a channel 9 feet deep and 200 feet wide from the mouth of the river to the mouth of Stockton Channel and in Stockton Channel to its head at Stockton, a total distance of 45 miles; and for snagging, removing overhanging trees and constructing brush wing dams to facilitate light draft navigation from the mouth of Stockton Channel to Hills Ferry, a distance of 86 miles.

A large amount of commerce is handled on the lower San Joaquin and on the many navigable channels of the delta. Navigation is not dependent upon the discharge of the river. During the low water season the entire river is diverted for use in irrigation and the flow through the delta is return flow only. The slope of the river through the delta is even flatter than that of the Sacramento River. Under present conditions tidal fluctuations extend well above the Southern Pacific bridge near Lathrop but are not noticeable at the Vernalis

[2] Proceedings of the First Sacramento River Problems Conference, p. 139.

gaging station. The figures appearing in the following table are taken from the curves on Plate 5-6. They may be of interest in comparison with figures given previously for the Sacramento River.

COMPARATIVE TIDAL FLUCTUATIONS AT COLLINSVILLE AND STOCKTON, JULY 7, 1925

	Elevation of water surface U. S. G. S. Datum		
Tide	*Collinsville*	*Stockton*	*Lathrop Bridge (Southern Pacific R. R.)*
Higher high	+3.80	+4.31	+5.54
Lower low	—2.28	0.00	+4.12
Range	6.08 feet	4.31 feet	1.42 feet

The curves on Plate 5-6 show that the maximum instantaneous drop in water surface from Stockton to Collinsville was 4.26 feet in a distance of about 42 miles while the greatest drop in the opposite direction was 2.13 feet. The corresponding slopes are 0.1014 and 0.0507 feet per mile respectively.

Future Requirements.

Under present conditions approximately 200 vessels visit Mare Island Navy Yard annually. In addition, a Yard tug makes two trips a week to San Francisco. At a time of emergency it is estimated that possibly as many as 800 to 1000 vessels would go to the Navy Yard in the course of a year. If a Salt Water Barrier were constructed at the lower end of San Pablo Bay, all boats going to the yard would be passed through the ship locks, while, if located above Mare Island Strait, the barrier would not affect navigation between the ocean and Mare Island Navy Yard, other than to reduce the velocity of tidal currents through a small reduction in the effective tidal prisms passing in and out through Golden Gate.

The largest dry dock now constructed at Mare Island Navy Yard is approximately 740 feet long from the inside of a caisson gate to the head of the dock, with an entrance width of 102 feet. These dimensions diminish toward the bottom so that the maximum theoretical ship which could be docked would have a length of 719 feet, a beam of about 90 feet and draft of 29 feet.

At present the largest battle cruisers have a length of approximately 875 feet, beam of 102 feet and maximum draft of 33 feet. The Washington Limitation of Armament Conference limits battleships to about 35,000 tons displacement which provides for a ship about 650 feet long, 100-foot beam and maximum draft of approximately 35 feet. The plan for the proposed development of a Naval Base at Alameda contemplates a dry dock which would accommodate a vessel of this size which might, when disabled, draw 40 feet of water.

If the barrier should be constructed at the Point San Pablo site at least one lock similar to those of the Panama Canal should be provided. They practically fix the limits of vessel dimensions for some time to come. The Panama lock chambers are approximately 1000 feet long, 110 feet wide and provide a depth of about 40 feet of water on the gate sill.

The ability to lay up vessels in a fresh water basin has its advantages in the retardation of marine growth and in arresting the corrosion of the steel hulls. It is not probable, however, that a considerable amount of money should be put into large locks having these benefits solely in view, as the majority of naval vessels of greatest value to the fleet are necessarily in active commission and would not be lying around in basins merely for the purpose of destroying marine growth and arresting deterioration of the hull. They have their periodic docking at least twice a year to remove the growth which retards their speed and to permit the hull otherwise to receive proper care. It therefore appears that locks to pass large war vessels may be dropped from consideration at sites located east of Mare Island Strait.

The population of the bay region is increasing at a rate which merits careful consideration of future traffic. Moreover, the presence of a fresh water basin may hasten the influx of industries that depend upon its use and if the water surface were maintained above present low tide level, shipping would be promoted by the greater depths.

Consideration must also be given to proposals which have been made to build deep waterways making both Sacramento and Stockton accessible to large ocean going vessels. Construction of either project would influence the growth of traffic through the ship locks at the barrier.

San Joaquin River and Stockton Channel.

In April, 1925, the city of Stockton voted a bond issue for the construction of deep waterway to Stockton with federal and state aid. The project was studied by the War Department, the results of the investigation being reported to congress by the Secretary of War in House Document No. 554, 68th Congress, 2d. session, from which the following extracts are taken:

> [1] The floor of the San Joaquin-Sacramento Valley is formed by some 17 counties having a total area of over 38,000 square miles. Tributary to the valley because of natural conditions, are 12 foothill and mountain counties covering about 30,000 square miles. Nearly half of the land in farms, within the State of California, is in these counties. Also tributary, in a more limited sense, are 12 counties of Nevada having an aggregate area of about 61,000 square miles and Klamath County (in Oregon) with an area of approximately 6000 square miles.
>
> [2] The principal navigable waterways serving parts of the area which bear on this study are the San Joaquin and Sacramento rivers. The San Joaquin River below the mouth of Stockton Channel serves a highly productive agricultural area and at present is tributary to Stockton and San Francisco commerce.
>
> [3] The board (of Engineers for Rivers and Harbors) has made a careful study of the case, has held several hearings, and has made an inspection on the ground through a committee of its members. It (the board) discusses in detail the economic aspects of the proposed improvement, basing its discussion primarily on a brief submitted by local interests. In this brief it is estimated, with certain assumptions as to present and future rail and water rates, and based on available figures of present commerce, that under existing conditions the potential traffic of a deepwater port at Stockton is 770,000 tons a year, with a corresponding annual saving of $694,000. For the year 1930 it is estimated that these figures would be increased to 1,000,000 tons and $900,000 annually. The board is of the opinion that the data in the brief have been carefully and conservatively gathered, and that the assumptions regarding rates are justifiable. Some reduction of the estimates

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[1] House Document No. 554, p. 85.
[2] House Document No. 554, p. 86.
[3] House Document No. 554, p. 3.

of tonnage and savings appears desirable, however, in view of the uncertainty of the movement of certain commodities, including a portion of the barley and much of the canned goods and vegetables which are included in the potential commerce. It concludes that, even with this correction, the probable saving would still be sufficient to justify federal participation in a deep-water project on suitable terms of cooperation.

The Chief of Engineers, on page 5 of the Document, reported: "That the further improvement of San Joaquin River and Stockton Channel is deemed advisable to the extent of providing for a channel from deep water in Suisun Bay to the city of Stockton, 26 feet deep at mean lower low water and 100 feet wide on the bottom, following the river route, in general as laid out by the district engineer, with levees set back 230 feet from the center of the channel, and having suitable passing places and a turning basin at Stockton; and for dredging in Mormon Slough from its mouth to Center street, to a depth of 9 feet at mean lower low water and a width of 100 feet; at a total estimated first cost of \$3,715,000 for excavation, levee work and dredging plant, and \$195,000 for maintenance the first year, and \$125,000 annually thereafter; subject to the provisions that local interests shall * * * submit plans for an ultimate terminal development capable of handling at least 1,000,000 tons per year. * * *

On page 57 of the Document the District Engineer states that 87 per cent of the vessels entering the port of San Francisco during the period April–September, 1924, could have gone to Stockton with a 26-foot project upon the assumption that it would accommodate a vessel drawing 24 feet or less.

Some difference of opinion exists among ship operators as to the dimensions of future vessels. The following is found on pages 36 and 37 of House Document 554:

> The charts (not printed) collated with similar more general studies[1] indicate that by 1951 a channel 37 feet deep, with bottom width 274 feet and low water surface width of about 550 feet will be required for navigation by the largest Pacific coast ships. * * * The possibility of their (these larger ships) going to Stockton can not now be foreseen. * * * Moreover, it is the consensus of opinion among operators that the 12,000 to 15,000 ton ships drawing not more than 32 feet are an economic maximum, which will persist as such until there is some radical change in trade conditions, in the costs of operation, or in the kind of motive power; such a change can not now be foreseen and can not, therefore, be provided for with any reasonable assurance of the provision being adequate when the changed conditions do occur. A 30-foot channel may then be considered as the limit for which provision at the present time is economical and practicable.

A 30-foot channel was the deepest for which estimates of cost were prepared for inclusion in the District Engineer's report. It cannot be concluded from this that locks providing a 30-foot depth over the gate sills would meet the requirements of navigation in the future. As noted in Chapter IV the preliminary designs for the Salt Water Barrier provide a mean depth of 40 feet over the sills in the lock which would most likely be used by the larger ships. The ship predicted for 1951, with a 37-foot draft, could pass over the gate sills at any stage of ordinary tides. It could not pass at extremely low tide.

Sacramento Deep Water Ship Canal.

Construction of a deep water canal from some point on the lower Sacramento or San Joaquin River to the city of Sacramento for the accommodation of ocean going vessels has been under consideration for

[1] Papers of the Twelfth International Congress of Navigation, Philadelphia, 1912.

some time. The physical aspects of the project were investigated by the State Department of Public Works in cooperation with the Sacramento Chamber of Commerce. The investigation was made under the direction of the late Major Paul M. Norboe. The results of the investigation were reported under date of October 7, 1922. The economic aspects of the project, including a terminal port at Sacramento, were investigated by the C. E. Grunsky Company, Engineers, who reported under date of February 28, 1925. The Grunsky Report includes the Norboe Report as an appendix. Both are drawn upon freely in the following discussion of the project:

> Of several plans studied[1] "Alternative IV, known as the Norboe plan, with such changes in alignment as may be indicated during the preparation of detail studies, appears to be the most logical and feasible plan for a ship canal to Sacramento.
>
> [2] The canal and port should ultimately provide facilities for the largest vessels which are likely to make use of such a canal. Construction may be progressive beginning with a canal and harbor 26 feet in depth, but looking to a canal with ultimate depth of 30 feet.
>
> [3] The project contemplates the continued maintenance of at least a 35-foot depth (M. L. L. W.) through San Pablo Bay; maintenance of the same depth through Suisun Bay and the San Joaquin or Sacramento rivers to the location of the southern end of a proposed canal." * * *

[4] In the report principal consideration is given to a canal 30 feet deep below mean low water, having a bottom width of 160 feet. Estimates were also prepared in less detail for a canal 26 feet deep with a bottom width of 100 feet. A summary of the estimated cost of the 30-foot project is as follows:

Ship canal	$13,180,150
Harbor at Sacramento	6,221,685
Belt Line Railroad	816,500
River connection and lock	316,250
Total	$20,534,585

> [5] The hinterland, or region which will contribute to the business of a Sacramento deep water port, if there be no competition of a second interior deep water port, is the Great Central Valley of California and adjacent mountain slopes. The dependable tributary district is the Sacramento Valley and adjacent counties, a region with a present population of about 300,000, and an assessed valuation of real estate and improvements of about $325,000,000.
>
> [6] While it is possible, or even probable, that with a port at Sacramento first in the field the already important shipping center of Stockton would become a lighterage tributary and load its shipments on ocean carriers at Sacramento wharves, a conclusion based upon such a contingency would not be justified. Your Commission should face facts at the very outset of your investigation and it is a fact that Stockton, already taking steps in that direction, can at any time with the improvement of an existing waterway somewhat shorter than the wholly artificial Sacramento ship canal become a competing port to which favorable differentials in freight rates would draw shipments south of the Mokelumne River.

In the economic study made by Mr. Grunsky, only the Sacramento Valley and adjacent counties north of the Mokelumne River were

[1] Report on the Economic Aspects of a Sacramento Deep Water Ship Canal by C. E. Grunsky and Leonard M. Cox, p. 111.
[2] Grunsky Report, p. 3.
[3] Grunsky Report, p. 39.
[4] Grunsky Report p. 55.
[5] Grunsky Report, p. 5.
[6] Grunsky Report, p. 6.

assumed to be tributary to the port at Sacramento. The total area of the 20 counties within this district is said to be 26,215,680 acres of which 8,148,827 acres are in farms valued at $577,428,862 according to the 1920 census.

[1] From computations made by the State Board of Public Works, Division of Engineering, the total cultivatable acreage comprised within the district appears at 5,295,600 acres.

[2] Of the freight which originates in the dependable tributary area about 450,000 tons per annum is of a character which could be handled through a Sacramento port. Of incoming freight the amount which could better reach this area through a Sacramento port than through any other water terminal is about 125,000 tons.

The above estimate of tonnage is based upon present conditions. Of the exports, probably grain would be the largest item, estimated at 230,000 tons annually.

[3] Assuming cargoes of from 5 to 10,000 tons, this total would annually bring to the port some 25 to 40 ships—peaked during the season of grain movement.

Any improvement, such as the proposed Sacramento Canal, will obviously contribute to general prosperity and growth of population, and increased activity. Industries will be attracted to Sacramento on account of the deep waterway.

The forecast of future outbound water-borne freight originating in the Great Central Valley is given on page 52 of the Grunsky Report as follows, in tons:

Origin	*1930*	*1940*	*1950*
Canal Hinterland (north of Mokelumne River)	650,000	850,000	1,050,000
San Joaquin Valley (South of Mokelumne River)	850,000	1,050,000	1,450,000
Totals	1,500,000	1,900,000	2,500,000

The figures for the "Canal Hinterland" are based upon business which would belong solely to the Sacramento Deep Water Canal, regardless of whether there be established an additional port in the Central Valley of California. The totals represent the tonnage to be expected upon the assumption that no other new port be established which would draw water-borne freight from the Great Central Valley.

It is probable that a deep waterway either to Stockton or Sacramento would serve the Great Central Valley. As previously stated, the War Department has approved construction of the Stockton Channel and the matter is now before Congress. The Sacramento Canal has not been made the subject of investigation by the War Department. Whether one or both deep waterways are built the tonnage to be handled through the locks at the proposed Salt Water Barrier would be about the same, estimated as above at from 1,000,000 to 1,500,000 tons in 1930 and increasing perhaps to 2,500,000 tons in 1950. Assuming that cargoes carried on the deep waterways average 5000 tons, an annual report of 2,500,000 tons would not tax the capacity of the ship locks proposed as they would be required to handle, on an average, only one or two large boats a day each way from that source. The

[1] Grunsky Report, p. 7.
[2] Grunsky Report, p. 5.
[3] Grunsky Report, p. 17.

navigation channels in either case would probably be built first to a depth of 26 feet below mean lower low water with the idea of increasing the depth as required. The depth over the sills at the ship locks need be no greater than in the channels above the barrier.

Dimensions of constructed canals are of interest in the study of ship locks as they indicate the present requirements of large vessels. Some of the more important canals are as follows:

Name[1]	*Bottom width*	*Depth of Water*
Suez	108 feet	36 feet
Manchester	104 feet	28 feet
Amsterdam (North Sea)	164 feet	32 feet
North Sea-Baltic (Kiel)	144 feet	35 feet

[2] The dredged channel below the ship locks in the Lake Washington Canal, at Seattle, has a bottom width of 150 feet and a depth of 30 feet at low water; from the locks to Lake Union a channel 100 feet wide on the bottom and 36 feet deep has been dredged; and between Lake Union and Lake Washington, the channel is 75 feet wide and 26 feet deep. These dimensions will be increased to meet the needs of commerce.

SALT WATER BARRIER LOCKS

General Features.

The number and size of the ship locks at the various sites for the proposed barrier are subject to the following considerations:

(a) Requirements of present and future water traffic.

(b) Loss of fresh water.

(c) Incursion of salt water.

It has been assumed that no serious interference with water traffic will be tolerated; consequently the time consumed in locking should be reduced to a minimum and the number of locks should be sufficient to preclude the liability of waiting for other vessels beyond a reasonable limit. A bridge with a lift span at the locks would not be an obstruction to navigation if water traffic were given precedence. Each lock probably would be unwatered for renovation during a period of a week or two annually. Delays at such times might be permissible but there should be facilities for passing all classes of traffic when one lock is inoperative.

Ship locks of the following dimensions were selected for study in various combinations:

Inside width	*Length between service gates*	*Depth on gate sills below mean sea level*
40 feet	200 feet	26 feet
60feet	500 feet	33 feet
80 feet	825 feet	40 feet
110 feet	1000 feet	44 feet

As shown on the drawings, intermediate lock gates are utilized which results in a greater variety of lock sizes than indicated above.

Loss of Fresh Water.

The loss of fresh water can be minimized with locks economically suited to the size of vessels. Intermediate lock gates allow adjustment

[1] Grunsky Report, p. 122.
[2] Military Engineer, July-August, 1920, p. 322.

in length; and in the final designs it may be practicable to provide economy in depth by dividing each gate leaf into two parts along a horizontal plane so that the upper section can be moved independently of the lower. No adjustment in width appears to be feasible, however, and a choice of different sized locks is the only recourse. The 110-foot lock should be reserved for warships so far as practicable. Empty lockages are a source of waste that can be largely avoided with locks in generous number, if the saving in water justifies the expense of their construction. The alternative of detaining a vessel until one has passed in the opposite direction is not consistent with locking provisions, as previously stated.

Incursion of Salt Water.

The remedy for excessive salt water incursions is similiar to that for saving the fresh water. Economic depth is probably of prime importance in this case, owing to the tendency of the heavier salt water to progress upstream along the bottom of the channels.

Analysis of Water Traffic.

Comprehensive records of traffic at Point San Pablo, Dillon Point and Army Point were obtained from continuous observations during a period of about 27 hours on July 6 and 7, 1925. Incidentally, the traffic for 24 hours of this period has been summarized in Table 6-24. The purpose of these observations, however, was mainly to secure data for analyzing the operations of several combinations of locks with traffic as it actually occurred. These analyses depend upon assumptions as to the time required for handling vessels. In Table 6-25 the time consumed in locking through the 40 feet and 80 feet locks has been estimated from experience gained at Lake Washington locks near Seattle which also furnish a good indication of what may be expected in operating the others. It is believed that the figures are conservative. No distinction, as to time of operation, has been made between the two divisions of a lock having intermediate gates and the lock as a unit. It is assumed that vessels will proceed through the locks under their own power. Officials at Lake Washington are of the opinion that towing locomotives would not expedite the lockages at that place although they are used at Panama.

The above mentioned analyses of lock operation, with respect to the traffic on July 6 and 7, are given in Tables 6-26 to 6-33 inclusive. It is assumed that advance information will allow all empty lockages to be completed before approaching vessels have arrived at the locks. River boats less than 150 feet in length could enter the 40-foot lock but a tug with tow might exceed its capacity unless the one were less than 60 feet in length and the other less than 150 feet. The summary (Table 6-33) shows that a reduction of time lost in waiting for passage can be accomplished only by sacrificing economy in the number of locks and lockages, and by introducing long periods of idleness when the traffic is not at the peak.

If vessels arrived at the locks in suitable order, or if long delays in passage were permissible, one or two locks at any of the sites considered would be ample. This will be evident by inspection of Table 6-33. With only two locks at the Army Point site one lock would have been in operation only 7 hours and 42 minutes out of 24 and the other 14 hours and 50 minutes, according to the assumptions made. With only three locks at the Point San Pablo site, the lock working over the longest period of time would have been in operation only 18 hours and 40 minutes out of 24.

By increasing the number of locks at Army Point to three, the calculated number of delays was reduced from 32 to 21; the total waiting time was cut from 7 hours and 52 minutes to 2 hours and 34 minutes; and the maximum single waiting was reduced from 1 hour and 10 minutes to 30 minutes. The total number of lockages was reduced from 100 to 98 but in all other cases the number of lockages, and therefore the tendency to feed salty water into the upper bay, increases as the number of locks is increased.

By increasing the number of locks at the Point San Pablo site from three to five the calculated number of delays was reduced from 71 to 45; the total waiting time was cut from 32 hours and 28 minutes to 5 hours and 8 minutes; and the maximum single waiting was reduced from 1 hour and 38 minutes to 13 minutes. The number of lockages was increased from 118 to 131. Some other use of the locks undoubtedly would have resulted differently. The man who made the analysis was placed in the position of the superintendent of the locks who would dictate the program of lockages.

The total time occupied by a boat in passing the barrier, including time required in the locking process and time lost in waiting to be admitted into the locks, is an important consideration and has much to do with the selection of the number of locks to be built at any site. With the locks clear, the time required to lock a single vessel past the barrier, according to Table 6-25, varies from 5 minutes for a small tug through the 40-foot x 200-foot lock to 55 minutes for a large ship through the 110-foot x 1000-foot lock. During peak periods, however, the locks must be operated to the best advantage, which requires that two or more vessels be passed at each lockage. This expedient results in better overall efficiency but introduces some delay to boats for which there is not room in the lock, or which arrive at the locks "just too late." The following summary has been prepared to show the relation between the maximum time required at locks, had they been in operation at the various sites on July 6 and 7, 1925, according to the assumptions shown in Table 6-25. In each case the period of waiting and locking which resulted in the *maximum* time at the locks is shown.

Site	*Combination of Locks*	*Time at locks—Minutes*		
		Waiting	*Locking*	*Total*
Army Point	1-40'x200' and 1-80'x825'	70	20	90
	1-40'x200', 1-60'x500', and 1-80'x825'	0	60	60
Dillon Point	1-40'x200', 1-60'x500', and 1-80'x825'	41	65	106
	1-40'x200', 2-60'x500', and 1-80'x825'	8	65	73
Point San Pablo	1-40'x200', 1-80'x825', and 1-110'x1000'	98	95	193
	1-40'x200', 2-80'x825', and 1-110x1000'	39	65	104
	1-40'x200', 1-60'x500', 2-80'x825' and 1-110'x1000'	10	90	100

The two days preceding the observations were holidays and the traffic was probably in excess of the average. From Plate 6-2 the maximum number of vessels passing San Pablo Strait in 24 hours, for the period shown, was 151, while the number was 145 on July 6 and 7. The latter probably may be taken as close to the peak for this time of year.

It is not unreasonable to assume a corresponding fluctuation at the other sites with the data contained in Table 6-24 representing their peaks.

Plate 6-1 indicates that the occurrence of the annual peak is not regular, but the spring months show more than average activity. A longer period of record might establish the seasonal fluctuation. The class of transportation which predominates at Rio Vista is subject to greater irregularity than that farther downstream and records for short periods at the proposed dam sites should be closer to the maximum. Seasonal uniformity is not sufficiently well assured, however, to justify the assumption that traffic shown in Table 6-24 is never exceeded and provisions for present traffic should recognize this contingency.

Table 6-34 gives the estimated number of vessels and lockages per year under present conditions in comparison with records at Lake Washington. The figures contemplate similar fluctuation at the three local sites with an average for each equal to 105/145 of that on July 6 and 7, shown in Table 6-33. The numerator of the ratio is the average for San Pablo Strait from Plate 6-2 and the denominator is the traffic at the same place on July 6 and 7.

Table 6-34 shows that the amount of traffic which passes through each of the locks at Lake Washington exceeds that contemplated for the locks at the Salt Water Barrier as discussed in the following paragraphs. The annual traffic at the barrier may, however, exceed the estimate and even if the latter be representative the greater capacity of the Lake Washington locks might be accounted for in a number of ways. There may be a larger percentage of small vessels at Lake Washington, requiring less time per lockage and the element of waiting may not be avoided to the degree deemed desirable at the barrier. Comparison is therefore dangerous without complete knowledge of the facts. Moreover, Lake Washington was not accessible from Seattle Harbor before the construction of the locks, hence as a hindrance to navigation the latter have not the same status as locks in a channel hitherto unobstructed.

Provisions for Ship Locks in Preliminary Estimates.

With the July 6 and 7 observations as a basis, it is evident that locking requirements can be satisfied with least expense at the Army Point site and conditions are most unfavorable at Point San Pablo. While it may be claimed with some justice that data are meager, they show a relation that might be expected, and there can be no reason to question their value for comparison. It is probable that any error introduced by using the records as an indication of traffic during longer periods is very nearly the same at all sites.

Table 6-33 indicates that a uniformly generous provision for traffic at the various sites is satisfied by locks in the combinations listed below which have been adopted in the preparation of the preliminary estimates presented in this report.

Site	Number of locks of indicated size *40'x200'*	*60'x500'*	*80'x825'*	*110'x1000'*	*Total*
Army Point	1	1	1	0	3
Dillon Point	1	2	1	0	4
Point San Pablo	1	1	2	1	5

It is believed that under present conditions there are no vessels passing Army Point and Dillon Point sites that could not be accommodated by the 60-foot lock. At Point San Pablo large vessels could use either of the 80-foot locks. Two 110-foot locks might be deemed necessary at this site in case one needed repair at a critical time, but in this report it is assumed that one would suffice.

Indirectly, the barrier will induce a more timely arrival of vessels at the locks, which will offset, in some degree, the future increase of traffic. Observations show a marked tendency of vessels to follow the tides as exemplified by the classification in Table 6-35. This characteristic of the July 6 and 7 observations is sufficiently well established to preclude the possibility of accidental coincidence. The tidal prism above the barrier will be eliminated and its volume, for some distance below, will not reach the quantity necessary to produce a strong current. Vessels should, therefore, arrive at more regular intervals and avoid the congestion to be expected intermittently under present tidal conditions. Since the peak of the traffic will determine the number of locks, if delays are to be avoided, it is evident that some advantage will result. Allowance for this condition can not be made with any degree of assurance, however, and it is safer to recognize it as a margin of safety rather than justification for modifying locking requirements.

Provision for ultimate traffic should not be necessary at the time the barrier is constructed since flood control on the upper rivers will doubtless improve to permit the replacement of flood gates by locks as the need for the latter develops. Consideration should, however, be given to the requirements of the immediate future.

BRIDGE TRAFFIC

Provisions in Preliminary Estimates.

Provision is made for a bridge across the barrier in all but four of the preliminary estimates. The vertical clearance, with movable spans in the lowered position, is 50 feet above high water with one exception where 135 feet is provided. The latter is, consequently, not subject to any objections arising from interference with water or bridge traffic, and is excluded from discussion in that connection. Bridges with 50-foot clearance have a fixed span over the 40-foot by 200-foot lock, as previously stated, and lift spans over all others.

The study of railroad and vehicular traffic has been correlated with the passage of vessels through locks which have been selected at the three sites for estimating purposes. The precedence of water traffic is thus assured since the analyses of lockages do not take the bridge into consideration as a source of delay. Bridge traffic is considered subject, at all times, to the convenience of navigation.

Under the foregoing conditions a determination of the interruptions to bridge traffic involves assumptions concerning the operation of the lift spans over the locks. Experience at the bridges across the Lake Washington ship canal and data on a number of other lift bridges together with some arbitrary assumptions, have contributed to the figures presented in Table 6-36, which is the basis of the study.

With a bridge located at the lock gates the period of interruption will depend upon the direction from which the vessel approaches

The period will be shorter when following a lockage than when preceding it. In the former case the vessel would be stationary in the lock a short distance from the bridge which need not be raised until the lock gates are opened to permit its departure. The interval between the raising of the bridge and arrival of the vessel is therefore very short even when the average speed of approach is assumed to be only one mile per hour. Coming from the opposite direction, however, safety would require a greater margin in time, because the vessel might not come to a stop before passing the bridge and its speed of approach would not be under such direct control by lock officials. At the Great Northern Railway bridge across the Lake Washington ship canal the lift span is raised when a vessel is about 1000 feet distant, and the speed of approach has been observed to average about two miles per hour. It is assumed that similar conditions and requirements will prevail at the barrier. The lock gates are deemed the most favorable location for a bridge by officials at Lake Washington.

With a vertical lift bridge at the barrier the span would be raised 85 feet from lowest to highest position. An assumption of one and one-quarter minutes for this operation is consistent with standard practice and would apply as well to a bascule bridge.

It is impracticable to allow for differences in the time required for vessels to pass the bridge. The interval has been made constant by assuming an average length of vessel of 300 feet and a speed of one and one-quarter miles per hour, to apply to all passages.

During the observations of July 6 and 7, 1925, vessels passed simultaneously. If they were destined to use the same lock, however, it would be necessary for one to have precedence over the other whether their directions were the same or opposite. If they arrived from opposite directions a lockage would occur between their times of arrival at the bridge and a lift span operation would be necessary for each vessel, but if their directions were the same there would be but one lift span operation which, however, would cover a longer period to include the passage of both vessels at the bridge.

It is assumed that the movable spans, in their lowest positions, will not interfere with the passage of fishing boats, yachts, tugs with or without tows, or river boats less than 150 feet in length, but must be raised for all other vessels.

The operation of the lift spans during a continuous period is analyzed in Tables 6-37 to 6-40, which show the effect on bridge traffic. It is obviously necessary to assume the location of the bridge before the interference of a vessel with overhead traffic can be expressed in a period of time. If the number and size of vessels proceeding in opposite directions were the same, which would be virtually the case over a long period, no ultimate inequality would be introduced by such an assumption, but in a limited period an advantage will be indicated by one or the other of the two locations (the upstream or downstream lock gates) which reflects the error due to the brevity of the observations.

In all estimates for a barrier at the Dillon Point and Point San Pablo sites which provide for a bridge, the upstream lock gates mark its location and it occupies a similar position in the best arrangement at the Army Point-Suisun Point site from the standpoint of cost

(Estimate No. 4). The operation of the lift spans has, accordingly, been analyzed for this location.

In the case of vessels approaching the bridge from the side away from the locks (proceeding downstream in the cases that have been studied) the time of arrival at the bridge and locks is practically the same and has been so assumed. The time at which the lockage is completed has been taken to represent arrival at the bridge when approaching from the locks. Owing to the fact that the time consumed in lockage provides for the passage of a vessel beyond the restricted waterway at either end where it could not pass another vessel approaching the same lock, the arrival at the bridge would actually occur within the lockage period. It is impracticable to estimate the exact time of arrival for each vessel and no advantage would accrue since all arrivals would be advanced a small fraction of time without altering the result.

The average length of vessel passing the barrier sites increases with proximity to San Francisco, hence the assumed average of 300 feet, which fixes the time consumed in passing the bridge, is on the safe side at Army Point and presents the situation somewhat too favorably at Point San Pablo if the assumption is correct for Dillon Point, the intermediate site. Further refinement is not warranted by the period of observation however.

Table 6-40 is a summary of bridge traffic interruptions at the three sites during a 24-hour period on July 6 and 7, 1925. In drawing conclusions the growth of navigation merits serious consideration but it is believed that the figures show a fair margin to provide for this contingency.

CHAPTER VII

STORAGE IN DELTA CHANNELS AND BAYS

Purpose of Study.

The principal object of the study was the determination of the amount of water which could be stored behind a barrier constructed at any one of the three sites investigated. A second object was the development of data for use in the studies of salinity and silting of the bays.

Storage behind the barrier will include not only that in the bay or bays, as the case might be, but also that in the lower river and delta channels to the point where the level of the pond intersects the slope of each river. In the following paragraphs the storage in the river and delta channels, and in each bay, will be considered separately.

Storage in the River and Delta Channels.

In determining the amount of storage in the lower river and delta channels above the confluence of the Sacramento and San Joaquin, approximately 400 typical cross-sections of the various channels were selected from maps on file in the U. S. Army Engineer office, 2d District, drawn to scales of 400 and 800 feet to the inch. Cross-section notes were prepared by scaling on the typical sections distances between soundings made by the Army Engineers. Distances between typical sections used in the calculation of volume were also scaled from the same maps. As the work progressed, the typical sections were located on smaller scale maps and numbered consecutively. These maps are included in this report as Plates 7-1, 7-2 and 7-3. As it was not possible to obtain information on soundings covering the entire delta region during a recent short period of time, it was necessary to use data obtained as of 1908, 1913 and 1920.

There are a few short sloughs east of the Mokelumne River, and drainage canals west of the Sacramento River, on which no soundings have been made. The volumes of the sloughs east of the Mokelumne were calculated by multiplying their approximate end area at the junction with the Mokelumne by one-half their scaled lengths. The storage in the drainage canals west of the Sacramento River was estimated by using sections which appeared to have the proper dimensions for excavation necessary to construct the dikes whose approximate dimensions were known. The quantities obtained from these two sources are very small in comparison with the whole and an error in either would not materially affect the result.

Results of the study of the lower river and delta channels are shown on Plate 7-4. The data are summarized on Curve No. 6. It will be noted that the area and volume curves do not extend below elevation -3.6 nor above elevation $+6.4$, referred to mean sea level (0 to 10 U. S. Engineer Datum), the former being the plane of mean lower low water at the mouth of the rivers, below which it is considered the water behind the barrier will never be drawn, and the latter being the extreme height to which it is believed water will ever be stored. Elevation + 6.4 is only 0.3 feet below the high water of the 1907 flood in the delta region. While storage to that elevation is not advocated herein, it is possible that at some future time the delta levees might be enlarged and strengthened to make this feasible. The only object in extending the curves downward would be to furnish data for comparison with earlier data in the study of the reduction of storage in the delta channels caused by silting. Since comprehensive earlier data are not available for the delta region, the comparison can not be made. The storage below elevation —3.6 U. S. G. S. (O, U. S. E. D.) is, however, indicated on each curve.

It was not determined whether the surveys of the delta region by the Army Engineers have ever been "tied in" by carrying levels to or from the U. S. G. S. Bench Mark (Elevation 5.98) at Benicia, but it was assumed that they are based upon the same datum. Should it be found in future studies that this is not the case, adjustments should be made since the studies of the area and volume of the bays, and of Carquinez Strait, are based on the elevation of that bench mark.

Storage in the Bays.

The results of the study are shown on Plate 7-5 and in Table 7-1. It will be noted in this case that the curves have been extended from the bottom of the bay to elevation + 6.4, U. S. G. S. (10, U. S. E. D.) the latter having been selected for reasons previously stated.

Points on the area curves were obtained by planimetering, on the most recent U. S. Coast and Geodetic Survey Charts (No. 5533 of June, 1925, and No. 5534 of March, 1925), the area enclosed within contours drawn at each fathom (6 feet) of depth below mean lower low water, the datum plane to which all soundings shown on the charts are referred. The charts are included with this report as Plates 2-3 and 2-4, respectively.

The depths shown on the charts are referred to mean lower low water at the nearest tide gage established by the Coast and Geodetic Survey. The datum plane is not at the same elevation at all localities. It is not a gradually sloping plane between points of change, but is a series of steps, the area of which are laid down arbitrarily from time to time as the need arises.

Since the elevation of the plane of mean lower low water is not the same at the various tide gages throughout the bays, it was necessary to determine the average elevation of this plane of reference for the three divisions of the bays for which curves are shown on Plate 7-5. Furthermore, it was necessary to determine the relation of this reference plane to mean sea level in order that the curves for the bays and those for the delta region, could be drawn upon the same basis. Data available in the San Francisco office of the U. S. Coast and Geodetic Survey, relative to tides at various points in the area under consideration, are shown in the following table:

TIDE DATA FOR SAN PABLO AND SUISUN BAYS

Location of gage	*Mean H. H. W.*	*Mean tide*	*Mean sea level*	*Mean L. L. W.*
Point San Pablo	+2.65	0.00	*—0.04	—3.25
Mare Island	+2.92	0.00	—0.04	—3.58
Crockett	+2.95	0.00	Not given	—3.55
Benicia	+2.92	0.00	—0.14	—3.55
Martinez	+2.92	0.00	—0.14	—3.55
Bay Point	+2.90	0.00	Not given	—3.40
Ryer Island	+2.78	0.00	Not given	—3.45
Collinsville	+2.60	0.00	+0.04	—2.91

* Relation to mean sea level assumed same as Mare Island.

The calculations made resulted in the establishment of the following relations:

Section	*Mean H. H. W.*	*Mean tide*	*Mean sea level*	*Mean L. L. W.*
San Pablo Bay	+2.80	0.00	—0.04	—3.40
Carquinez Strait	+2.95	0.00	—0.09	—3.55
Suisun Bay	+2.85	0.00	—0.05	—3.40

In determining the location of the average mean lower low water plane in San Pablo Bay from which soundings were taken, and its relation to mean sea level, it is assumed from the shape of the bay and tributaries that half of the soundings were referred to the Mare Island gage and half to the Point San Pablo gage; and that mean sea level at Point San Pablo is 0.04 foot below mean tide level at the same point.

For Carquinez Strait an average of the gages at Mare Island and Benicia was used for the relative positions of mean sea and mean tide levels and it was assumed that mean lower low water is — 3.55, gages at Benicia and Crockett being adjacent to the entire area.

For Suisun Bay, which is very irregular in shape, it was estimated that soundings over probably one-twelfth of the area were referred to the gage at Collinsville, two-twelfths to the gage at Benicia and nine-twelfths to the average of the gages at Bay Point and Ryer Island. An average of the relative positions of mean sea level was taken for the gages at Benicia and Collinsville.

From the above table it was found that the relative position of elevation + 6.40 U. S. G. S., above the average mean lower low water for the three sections, is as follows: San Pablo Bay, 9.76 feet; Carquinez Strait, 9.86 feet; and Suisun Bay, 9.75 feet.

The curves shown on Plate 7-6 were used in the early studies but are superseded by those on Plate 7-5 which are based on the latest charts. A comparison of the two sets of curves throws some light upon the deposition of silt in the upper bays.

Volume of Tidal Prism Above Barrier Sites.

As used in this chapter the term, "volume of the tidal prism," should not be confused with the same term as used in Chapter V. The tidal prism, as discussed in Chapter V, is the portion of the bay lying between the plane of mean lower low water and the surface of the bay at mean high tide, the bays' surface being curved vertically for the reason that no phase of the tide occurs simultaneously throughout the bay system. In this chapter it is assumed that tidal movements have been eliminated through construction of the Salt Water Barrier.

The water surface, therefore, would be a level plane and the volume of the tidal prism would be an altogether different amount than considered in Chapter V.

The calculated volume of the tidal prism upstream from each barrier site is shown on Plate 7-7. As before, the curves are drawn between Elevations — 3.6 and + 6.4, U. S. G. S. (0 and 10, U. S. E. D.). These curves are of particular interest in the study of water available for beneficial use and in the operation of the barrier. For convenient reference the data shown by the curves have been summarized in Table 7-2.

CHAPTER VIII

SILT

General.

As far as could be learned, no extensive study of silting of the San Francisco Bay System has been made other than that by Grove K. Gilbert, whose report was published in 1917 by the U. S. Geological Survey as Professional Paper 105. The Army Engineers have made various studies of shoaling in dredged areas, including those recently made of the dredged channels in Mare Island Strait and across Pinole Shoal.

In this chapter it is the intention to cover the subject in a general way, only, and in so doing an attempt will be made to summarize information obtained from other reports, adding data that have been secured during the progress of this investigation. Conclusions as to the effect of a Salt Water Barrier upon silting of the bays, and upon the Golden Gate Bar, can be drawn only after studies more comprehensive than it was possible to make with funds available for the present investigation have been made. Mr. Paul Bailey, on page 46 of his Supplemental Report on the Water Resources of California (Bulletin No. 9), states that studies of the effect of the barrier on silt deposits in Suisun Bay and San Pablo Bay, and on the flood heights in the lower river region, are being conducted by the Division of Engineering and Irrigation, but that additional money will be required to complete them.

Formation of the Bays.

In U. S. Geological Survey Folio 193, "Geologic Atlas of the United States," Mr. Andrew C. Lawson states that San Francisco Bay is a submerged valley and is a most notable example of a great harbor formed by the influx of the sea into the low parts of a subsiding coast. Before submergence, the river that drained the Great Central Valley probably flowed between Tiburon Peninsula and Angel Island and thence, through the gorge of the Golden Gate. Mr. Lawson states further that:

> Outside the Golden Gate, extending out to the Farallon Islands, there is a broad submerged embankment, which lies beneath an area of very shallow water. This embankment probably in part represents the delta of the ancient river that once flowed through the Golden Gate before the depression, but it has been also in part built up by deposits of fine silt, which in the flood season are carried through the bay of San Francisco and dropped outside the gate.

At the time the valley became submerged the seat of deposition of the sediments brought down by the rivers from the interior was transferred from a delta outside the Golden Gate to the bays which, as a consequence, are gradually filling up, the coarser and more pervious gravels and sands having been buried by silt, clay, or dark colored sandy mud, as indicated by the logs of the holes drilled.

According to Gilbert, there is some reason to believe that the areas in which the debris comes finally to rest are undergoing a slow downward movement, but after a review of the evidence, the possible economic subsidence seems to be limited to San Francisco Bay proper. In supporting this contention Mr. Gilbert gives as reference: (1) Lawson, A. C., The Post-Pliocene Diastrophism of the Coast of Southern California; California Univ. Dept. Geology Bull., Vol. 1, No. 4, pp. 115–160, 1893; The geomorphogeny of the coast of northern California; Idem., No. 8, pp. 241–272, 1894. (2) Trask, J. B., report on the geology of the Coast Mountains and part of the Sierra Nevada, p. 27, 1854. (3) Newberry, J. S., U. S. Pacific R. R. Ex. pl., Vol. 6, pt. 2, p. 14, 1857.

The bay region is divided into two areas, which are sharply separated by the Haywards fault extending along the southwestern face of the Berkeley Hills to Pinole Point, across San Pablo Bay in a northwesterly direction, and along the northern edge of Petaluma Valley. In the eastern area the latest recorded movement, according to Mr. Gilbert, was downward, but the changes have not been the same as for the western area. Since Sacramento River excavated the Carquinez gorge, there have been three distinct changes; first, a subsidence of more than 100 feet; second, an elevation of more than 50 feet; and third, a subsidence of about 30 feet. J. S. Newberry has noted that the uplift was not shared by San Francisco Bay. While the latest recorded movement in both areas is downward, it is indeterminate whether this movement is still in progress, but it is reasonably safe to assume that it is, since the development of deltas in the bays by streams from the neighboring hills is comparatively small. There are deltas being developed, but they are not being extended to the marsh plane. The marsh planes have been built up by the water. Had subsidence taken place rapidly and reached completion before the building of the marsh lands the waves would have made their records on the coastal slopes and that record would now be visible, but such is not the case. These facts would indicate that subsidence has continued so nearly to the present time as to establish the presumption that it is still in progress, and that the general rate of subsidence is no more rapid than the upward growth of the marsh lands.

On page 23 of his report, Mr. Gilbert says:

> The general fact appears to be that the delta deposits, including the peat marshes and their silt rims, rest on a pre-existent surface with alluvial slopes, and that the outlet of the earlier drainage, like that of the present, was westward to the Suisun Basin. In all probability these slopes record for the Great Valley an epoch in which the Sacramento and San Joaquin waters flowed as a river through the Carquinez and Golden Gate gorges to the ocean and the present bays did not exist. Since that epoch the delta region has subsided through a vertical distance equal to the maximum depth of the peat plus the fall of the ancient river between the passage at the Montezuma Hills and its mouth.
>
> This subsidence is the latest recognized vertical movement of the land in the delta region. It may have been slow and continuous. It may have been interrupted by period of rest or of elevation. It may have been completed long ago or it may be still in progress. If it was completed long ago, it created a bay in the Great Valley, a fourth bay of the San Francisco chain, and within this bay the delta plain was afterward built. If it occurred gradually and slowly and is still incomplete, the growth of the delta plain may have kept pace with it, preventing the formation of a bay.

If subsidence is accepted as the general character of crustal movement at the present time, alike in the bay region, the delta region, and the Sacramento Valley, it does not follow that the change has everywhere the same rate. Diversities such as have characterized the movements of the past in different areas may plausibly be ascribed to those of the present.

Changes in the Bays Due to Silting.

The following extracts from Mr. Gilbert's report indicate the changes that have taken place in the bays due to silting:

> The streams that discharge to the chain of bays (Suisun, San Pablo and San Francisco) deliver along with the water a quantity of fine detritus, consisting of mud and sand. Lodging on the bottom the detritus tends to shoal the bays, and combining with vegetation along the margins it tends to contract them. These tendencies are opposed by the slow subsidence of the land, and in the natural condition of the region there may have been an approximate balance between the opposed factors. If such a balance existed, it has been overthrown by the activities of the white man, which have so increased the detrital loads of the streams that the bays are now losing in depth and area.
>
> The water of Sacramento and San Joaquin rivers reaches first Suisun Bay, then San Pablo and San Francisco bays, and then escapes through the Golden Gate to the ocean. The forward movement is not continuous, but is reversed twice a day by the tides, with the result that many eddies are formed and the river water is gradually mingled with ocean water. The river water is also carried to all the remoter reaches of the bays. The sediment is widely spread within the bays, mingling with smaller quotas from minor streams. It is evident also that a part of it reaches the ocean, for in times of flood, while the rivers are turbid and opaque, the outgoing tide through the Golden Gate shows a tinge of yellow.
>
> Some information as to the extent and distribution of the recent deposits is afforded by the charts of the United States Coast and Geodetic Survey, which give soundings in all parts of the bays and at different dates. Complete surveys of Suisun Bay were made in 1867–68 and in 1887–88. A complete survey of San Pablo Bay was made in 1856, a small part was resurveyed in 1887, and the remainder was resurveyed in 1896. The northern part of San Francisco Bay was surveyed in 1855 and again in 1895–1901; its southern part in 1857–58 and in 1895–1899.
>
> The interval of 20 years between the two surveys of Suisun Bay included 16 years of the most active hydraulic mining, together with the 4 years immediately following, when the temporary deposits of debris in the mountains presumably yielded their maximum quantity of waste. The interval between surveys of San Pablo and San Francisco bays, averaging for all parts about 41 years, covered the same time as the Suisun Bay interval, with the addition of an earlier decade during which hydraulic mining was advancing toward its maximum and a later decade during which the flow of mining debris was slowly diminishing.
>
> Suisun Bay (See Plate 2-4) is relatively deep in the southern and middle parts, where it is traversed by a group of channels from the river mouths to Carquinez Strait. Among the channels are islands and a broad, irregular shoal, to part of which the name Middle Ground is given. At the north are two arms, broad and shallow, known as Grizzly Bay and Honker Bay. In the period of 20 years the shoals, having a total area of about 30 square miles, received an average deposit of 1.63 feet, the quantity of sediment being 50,000,000 cubic yards. The depth of fill was greatest in Honker Bay (2.17 feet) and least on the Middle Ground (1.25 feet). The channels are so irregular in form that it is not practicable to compute their changes with close approximation by means of the published soundings, but the general nature of their modifications is quite clear. Almost without exception they became narrower and deeper; almost without exception, also the quantity of material added at the sides was notably greater than the quantity scoured out between, so that a net fill resulted. A rough estimate places the net fill of channels at 13,000,000 cubic yards, and makes the total deposit in the bay 64,000,000 cubic yards.

In Carquinez Strait, which connects Suisun and San Pablo bays, the bottom is irregular. The depth changes so greatly within short distances that the magnitude of each recorded sounding may be assumed to depend in part on an accident of location, and computations of average depth are subject to considerable uncertainty. Moreover, the surveys on which the earliest and latest maps are based were made at uneven dates, so that the intervals between dates contrasted in different parts of the maps range from 20 to 41 years. A comparison was made by dividing the area into 14 parts and studying each part separately, and it was found that the depth had apparently increased in 3 divisions and diminished in 11. The average apparent loss of depth in the 11 divisions was much greater than the average gain in the other 3. From the data thus obtained it was estimated that the total amount of material deposited in the strait from the beginning of hydraulic mining to the year 1890, was 40,000,000 cubic yards.

San Pablo Bay (See Plate 2-3) is traversed, from Carquinez Strait to the constriction separating it from San Francisco Bay, by a broad channel of simple contour. North of this is a great shoal occupying more than half the total area, and south of it are minor shoals. In the 41 years between surveys the channel was much reduced in width and was also reduced in depth. The filling along the middle line was small compared to the marginal filling. The great northern shoal received a large deposit, and the eastern division of the southern shoal an important though small deposit, but the western division of the southern shoal suffered a loss. To give quantitative expression to some of these facts the computations were made by divisions, the channel being arbitrarily limited by the position of the 3-fathom contour in 1856, and the northern shoal being separated into two parts, distinguished by different dates of resurvey. The data are exhibited in Table 3. It is worthy of note also that the eastern part of the northern shoal received a much heavier deposit than the western part.

MR. GILBERT'S TABLE 3

Data on Sedimentary Deposits in San Pablo Bay Between the Survey of 185 and Later Surveys

Part of bay	*Period (years)*	*Area (square miles)*	*Depth of deposit (feet)*	*Volume of deposit (millio cubic yards)*
Channel	42	29.4	4.86	147.2
North part of north shoal	31	8.4	2.11	18.3
Main part of north shoal	41	60.9	2.97	186.3
Southeast shoal	42	7.3	2.84	21.4
Southwest shoal	42	7.2	—1.25	—9.3
Means and totals	41	113.2	*3.13	*366.0

* The mean depth and total volume of the deposits are adjusted to the me period of 41 years.

A summary of the above estimates as given by Mr. Gilbert, revised to indi percentages, follows:

Body of water	*Dates of surveys*	*Volume of deposits between dates of surveys*	*Volume of deposits 1849–1914*	*Per cent of total depo*
Suisun Bay	1867-1886	64,000,000	200,000,000	24.4
Carquinez Strait	1861-1890	40,000,000	50,000,000	6.1
San Pablo Bay	1857-1897	366,000,000	570,000,000	69.5

Total average annual deposit in bay system, 13,000,000 cubic yards.

During the progress of this investigation storage capacities we computed for Suisun Bay, Carquinez Strait and San Pablo Bay, fr the Coast and Geodetic charts, dates of 1918, 1923 and 1925 (See Pla 7-5 and 7-6). For comparison with Mr. Gilbert's estimate the co puted loss in storage as indicated by the charts, reduced to quan of silt, is as follows:

STORAGE IN ACRE-FEET

Body of water	*1918 chart*	*1923 chart*	*1925 chart*	*Storage Loss*	*Silt, cu. yds.*
Suisun Bay	--------	547,655	529,390	18,265	29,460,000
Carquinez Straits	--------	127,020	121,010	6 010	9,700,000
San Pablo Bay	1,252,275	--------	1,194,180	58,095	93,700,000

The estimate shown above was computed from all areas affected by high tide, not including marsh land. Mr. Gilbert does not give the boundary limits within which his study was made, but it is assumed that the two estimates so nearly cover the same area as to be closely comparable.

After computing the storages from the charts for the three years data were obtained from the Coast and Geodetic Survey office, showing the limits and dates of surveys from which each chart was made. By proportioning the dates and areas for each chart the average date of surveys included in each chart was determined as follows:

Section	*Date of chart*	*Average date of survey*	*Period covered by estimate*
Suisun Bay	1923	1895	
Suisun Bay	1925	1923	28 years
Carquinez Strait	1923	1877	
Carquinez Strait	1925	1922	45 years
San Pablo Bay	1918	1896	
San Pablo Bay	1925	1922	26 years

The survey of Suisun Bay for 1923 covered only 23,200 acres and the two charts differ in this area only, therefore the difference in storage of 18,265 acre-feet shown in a preceding table is relative to this area. It is probable that the sloughs leading into the bays have reached a stage of equilibrium but in any event silting in this part of the area is negligible.

It is probable that an assumption that silting is uniform over the entire area exclusive of sloughs with but a slight per cent of error would be safe. Correcting the estimate for Suisun Bay for the entire area exclusive of sloughs during the period of 28 years, the amount would be 41,727,000 cubic yards. In order to arrive at the amount of silting for each one of the sections for a period of 28 years it must be assumed that the annual rate of silting is uniform. Following is a corrected estimate for the entire area for a period of 28 years, 1895 to 1923:

Section	*Storage ac. ft. beginning period*	*Storage loss ac. ft.*	*Storage loss per cent*	*Silt cu. yds.*	*Per cent total silt*
Suisun Bay	547,650	25,870	4.7	41,727,000	28
Carquinez Strait	124,750	3,740	3.0	6 030,000	4
San Pablo Bay	1,256,700	62,560	5.0	101,000,000	68

The total amount of silt carried annually to the bays and strait, shown in the above table, amounts to 5,313,000 cubic yards, with an annual storage loss of 0.0017 per cent.

Since the period covered by Mr. Gilbert's report includes the period of maximum mining activities the reduction in annual silting from 13,000,000 to 5,313,000 cubic yards is very likely due to the ban placed upon hydraulic mining.

The accuracy of any estimate upon the quantity of silt deposited must depend entirely upon the accuracy of the methods employed in making the soundings and the conscientious employment of this method by those making the soundings. As all soundings to date have been made for the purpose of navigation, and are probably considered sufficiently accurate to the nearest foot or one-quarter fathom, it seems reasonable to assume that any results obtained as to the amount of silting may vary widely in per cent of accuracy, unless the appreciable errors in two or more surveys occur in the same direction. It is very likely that the soundings shown on the charts are somewhat greater than the actual depth, due to a slack line, or line deviating from the vertical. It appears then that the probable errors for separate surveys are in the same direction, and that the average difference in depths shown may be fairly accurate for large areas, if there is no personal equation involved. It is believed that a higher class of employees were used in making the earlier soundings but better methods are used in making soundings at the present time. There seems to be no way of reckoning with these two conditions except to consider that they may eliminate the personal equation.

By a comparison of the percentages shown in the two tables obtained by different methods and for different periods of time, it will be noted that the rate of silting in the various sections is slightly changed. Considering both estimates correct to a certain degree of accuracy, the indication is that Suisun Bay and Carquinez Strait have not yet reached a stage in silting where the currents have been stabilized or increased to such an extent as to carry a larger per cent of the total silt to Pinole Shoal in San Pablo Bay. Carquinez Strait was originally the control section west of Suisun Bay, but now the control section is at Pinole Shoal and the silting of Carquinez Strait is still in progress. (See Plates 3-15 to 3-19, inclusive.) This transposition of the control section may be due to natural silting at Pinole Shoal, decreased tidal volume in Suisun Bay, uplift and subsidence east of Hayward's fault, or to a combination of several or all of these causes.

The two estimates indicate that during the past 28 years the silt has not been moving any more rapidly toward San Pablo Bay than previously, and is not apt to encroach upon the water volume of San Francisco Bay to any great extent for some time to come. Since Mr. Gilbert has shown that between the years 1849 and 1914 there has been a filling of San Francisco Bay to the extent of 326,000,000 cubic yards it is assumed that this silting will continue, but as the volume of silt is a very small percentage of the water volume of the bay there is apparently little cause for alarm. The volume of the bay between mean lower low water and a plane approximately 6.7 feet above mean lower low water is about 1,225,000 acre feet. The plane 6.7 feet above mean lower low water, is the calculated average elevation of mean higher high water for San Francisco Bay.

Changes in the Golden Gate Bar.

When silting in San Francisco Bay increases, it does not necessarily mean that an increase in the amount of silt carried to the bar will occur at the same time. Increased silting in the bay may take place for some time before it reaches a point where its effect will be noticed at Golden Gate. As any decrease in the tidal prism tends to decrease the currents through the Golden Gate with an attendant decrease in the transporting power of the currents, it is not expected that silting on the bar will increase unless the tidal prism is reduced to such an extent that the flood waters in the rivers will have a noticeable effect upon the currents at the Golden Gate. Although it has been determined that the greater supply of material to the bar comes from along the coast, any decrease in velocity through the Golden Gate, resulting from a decreased tidal prism, should have its effect upon the deposition of the material on the bar. Mr. Gilbert, in making a study of the bar to determine the effect of a reduction in the tidal prism in the bays, found that between the years 1873 and 1900, the crest of the bar was lowered through most of its length, the average amount being 0.9 of a foot; the bar became notably narrower near its base; and its crest line moved between 400 and 500 feet toward shore. In taking up the study where Mr. Gilbert left it, the U. S. Army Engineers, 1st District San Francisco, California, determined the change in the bar between the survey of 1900 and the survey of 1921 by the Coast and Geodetic Survey and Army Engineers. (See Plate 8-1.) The change during this latter period conforms to the movement of the bar of the earlier period. A generalized cross-section of the bar in its middle division shows that from 1900 to 1921 the crest moved shoreward about 1500 feet and the height was lowered about 3 feet. As the survey of 1921 covered a portion of the middle section of the bar only it is not possible to give data on the change in length and only a part of the change in width can be noted. The area covered by the 1921 survey shows a decrease in width on the bottom which also conforms with the change of the earlier period.

Character of Silt.

The bottom of the bays is, almost everywhere, covered with soft blue mud described in Chapter III. On top it is jelly-like and is very slick. It has very little supporting power as indicated by the depth to which the drill column and drive pipe settled of their own weight in the drilling operations. A stick one inch square was pushed into the mud on the tidal flat off Bull's Head Point at low tide for a depth of 10 feet with one hand with very little effort. Had the stick been twice as long it is believed that it could have been sunk to its full length. As near as could be estimated it required as much effort to pull the stick up as to force it down. The mud is sticky and adheres to an object driven into it. On page 94 of his report, Mr. Gilbert, in speaking of dredging on Pinole Shoal says:

> I am informed by Capt. H. L. Demeritt, the engineer in immediate charge of the work, that all the dredged material would be classed by dredgers as blue mud—it is so coherent as to "stand up" on the dredge bucket like stiff mud or clay—but that a magnifying glass shows that it contains much fine gray sand.

The material deposited on the shoals has been carried to the bays by the rivers in suspension. Deposition has been in part due to the slackening of currents as the muddy water enters the bay and in part to flocculation as the silt laden river water met and mingled with the salty water in the bays. It is extremely fine, as shown in Exhibit 22, which is a report by the Bureau of Standards upon a mechanical analysis of sediment taken from Mare Island Strait in the operations of the U. S. Army Engineers. It will be noted that 97 per cent of the material would pass a No. 500 sieve if such a sieve could be made.

The following chemical analysis was made in the laboratory of the Mountain Copper Company of mud taken from the tidal flat just off Bull's Head Point in August, 1925. The data were obtained through the courtesy of Mr. T. B. Swift.

Weight of mud as it is found on the tidal flat, 81 pounds per cubic foot:

Silica	51.60 per cent
Iron	7.90 per cent
(Equivalent Ferric Oxide)	11.28 per cent
Aluminum oxide	19.71 per cent
Calcium oxide	1.16 per cent
Loss on ignition	13.30 per cent
Moisture	69.58 per cent

Silt Carried in Suspension.

Under normal conditions the water of the rivers is highly charged with silt during the flood season but carries a comparatively small amount during low stages of flow. As a matter of interest in the investigation of the Salt Water Barrier samples of bay water were analyzed to determine the amount of solid material carried in suspension. The first set of samples were taken on February 8, 1925, at the Army Point site to determine the relative amount of silt in suspension at various stages of the tide. On the day the samples were taken the predicted tidal range at the Presidio was 6 feet. The water was very turbid, almost the color of coffee to which cream had been added. The estimated combined discharge of the Sacramento and San Joaquin rivers into Suisun Bay was 153,000 second feet, the maximum for that year. The samples were taken just below the water surface at high and low tides with the following results:

Tide Feb. 8, 1925	*Time sample was taken*	*Chlorine, P.P.M.*		*Solids P.P.M.*	
Lower high	2.15 a.m.	262	Av. 201	125	Av. 118
Higher low	8.25 a.m.	140		111	
Higher high	1.55 p.m.	318	Av. 180	74	Av. 118
Lower low	7.25 p.m.	41		163	
Average		190		118	

The solids are reported in parts per million by weight. The residue was thoroughly dried but not ignited.

The average amount of solids carried in suspension in each cubic foot of water represented by the samples was 0.007375 pounds and the calculated net discharge of the rivers past Bull's Head Point (153,000 s. f.) would carry 1128 pounds of silt per second—equivalent to approximately 49,000 tons per 24 hours. If the material, after being deposited on the shoals, weighs 81 pounds per cubic foot, about 45,000 cubic yards of silt would be deposited west of the Army Point site per 24 hours.

On February 12–13, 1925, samples were taken to ascertain the relative amounts of silt carried in suspension at the Army Point and Point

San Pablo sites. The calculated combined discharge of the rivers into Suisun Bay was 132,200 s. f. on the 12th and 134,650 s. f. on the 13th. The color was about the same as on February 8. The predicted tidal range at Presidio for the two days was 4.1 and 3.7 feet respectively. The samples were taken at "slack" following the higher high and lower low tides for the reason that maximum salinity and minimum silt content were expected to occur at slack tide following higher high tide and minimum salinity and maximum silt content were looked for at slack tide following lower low tide. The results of the investigation, in which the salinity is reported as parts of chlorine per million and silt as parts of solids per million by dry weight (not ignited), are as follows.

ARMY POINT SITE—FEBRUARY 12, 1925

	Samples from tug at Hole 3550 (See Plate 3-3)			
	Higher high tide		*Lower low tide*	
	Samples 3.50 to 4.00 p.m.		*Samples 10.45 to 11.00 p.m.*	
Depth in feet	*Chlorine*	*Silt*	*Chlorine*	*Silt*
Surface				
10	65	166	35	146
20	62	163	33	144
30	63	163	36	157
40	63	161	33	163
50	63	167	30	239
Bottom				
55	--	---	26	765*
60	68	279	--	---
Average	64	183	32	---
Average exclusive of bottom	63	164	33	170

* Sample not representative. Sampler touched bottom and picked up some of the bottom material.

POINT SAN PABLO SITE—FEBRUARY 13, 1925

	Higher high tide		*Lower low tide*	
	NE. cor. Standard Oil Co. wharf		*From tug upstream from Hole 1000 (See Plate 3-10)*	
	Samples 3.50 to 4.00 p.m.		*Samples 10.45 to 11.00 a.m.*	
Depth in feet	*Chlorine*	*Silt*	*Chlorine*	*Silt*
Surface				
10	4060	56	2250	48
20	6280	33	2150	46
30	6150	58	3330	57
40	6160	*59	3280	61
50	----	---	2340	58
60	----	---	2380	62
70	----	---	2710	103
80	----	---	----	---
Bottom				
90	----	---	**5850	284
Average	5660	51	3036	90
Average above 40′ depth	----	---	2752	53
Average exclusive of bottom	----	---	2634	62

*Rock bottom—no scouring action.
**From a depression in the bottom.

By inspection of the data for each site it will be noted that with an estimated 133,000 s. f. discharge from the rivers into Suisun Bay the salinity at slack higher high tide is approximately double that at slack lower low tide, but that the silt in suspension at any depth is somewhere near the same. By comparing the two sites it is seen that the salinity is very much greater at the lower site and that the silt content is only about one-third as much. The conclusion reached is that the difference in silt content is a measure of the amount of silt that is deposited in Carquinez Strait and San Pablo Bay.

It will be observed that the silt content near the bottom is much greater than above. The exception is at Point San Pablo where, at the Standard Oil Company wharf, water runs on bare rock. Out in the channel, at this site, the silt content at the bottom was found to be 284 p. p. m., while above a depth of 60 feet it varies from 48 to 62 p. p. m. At the Army Point site the silt content at the bottom was practically the same (279 p. p. m.), although above a depth of 50 feet the content was from 161 to 167 p. p. m. At a distance of 5 feet above the bottom the silt content was 239 p. p. m. The significance of this observation appears to be that the tides scour the bottom in their movement up and down the bays. Whether this scouring action tends to maintain or destroy fixed channels remains for determination.

Pursuing the suggestion that the difference in the amount of silt carried in suspension represents the deposition of silt between Army Point and Point San Pablo the following computations are presented. Before any conclusions could be drawn a detailed study would be required involving a very large number of samples over a long period of time. In the calculations the bottom samples are disregarded.

Army Point Site		
Average silt content at high tide	164 p.p.m.	
Average silt content at low tide	170 p.p.m.	
Average silt content at Army Point Site		167 p.p.m.
Point San Pablo Site		
Average silt content at high tide	51 p.p.m.	
Average silt content at low tide	62 p.p.m.	
Average silt content at Point San Pablo Site		56 p.p.m.
Loss by deposition between the two sites		111 p.p.m.
Solids per cubic foot of water		0.00694 pound
Amount silt per second in 133,000 sec.-ft. of net river flow to ocean		923. pounds
Equivalent to about 40,000 tons per 24 hours.		

The computations indicate that silt was being deposited between Army Point and Point San Pablo, under conditions as of February 12–13, 1925, at the approximate rate of 36,600 c. y. per 24 hours if the silt is assumed to weigh 81 pounds per cubic foot. It is probable that a large part of this silt is deposited in the eastern end of San Pablo Bay where there is a sudden slackening of currents.

Unfortunately, the samples taken during the high water of February, 1925, did not include any from the eastern end of Suisun Bay. If these had been included it would have been possible to compare the probable deposition in Suisun and San Pablo bays of silt carried in suspension during the spring run-off. In the absence of these samples another attempt was made later to determine the comparison of the silt content at various points.

The greatest predicted tidal range for 1925 occurred on July 7. This tide was selected for studying hydraulics of the bays, salinity and silt. As a part of this study, measurements and samples were obtained at Collinsville, Suisun Point and Point San Pablo. The tidal graphs are shown on Plate 5-6.

Samples of water were taken at slack water following higher high tide and lower low tide at each of the three locations. They were taken at the surface, at each 10 feet of depth and at the bottom. Each sample was analyzed for chlorine but in this discussion the average throughout the entire depth only will be shown. The details are given in Chapter IX. In order to arrive at the average silt content at each location equal amounts of water from each sample were mixed together and this mixture was analyzed. Following is a summary of the results:

Averages expressed in parts per million

	Collinsville [1]		Army Point site [2]		Point San Pablo [3]	
Tide	*Chlorine*	*Silt*	*Chlorine*	*Silt*	*Chlorine*	*Silt*
Higher high	493	52	8548	75	15,860	26
Lower low	72	70	2460	64	11,270	84
Average	282	61	5504	69.5	13,565	55

[1] Samples from row boat 200 feet out from Collinsville Wharf.
High tide samples— 4.00 to 4.25 a.m.
Low tide samples—12.27 to 12.40 p.m.

[2] Samples from NE. corner Mountain Copper Co. wharf.
High tide samples— 2.50 to 3.10 a.m.
Low tide samples—10.30 to 10.40 a.m.

[3] Samples from tug approximately on line of profile drilling at Hole 1000.
High tide samples—12.30 to 12.50 a.m.
Low tide samples— 8.55 to 9.10 a.m.

The calculated combined discharge from the rivers into Suisun Bay had dropped to 10,470 s. f. on July 7 as indicated on Plate 9-8.

By comparing the results with those obtained on February 12–13, 1925, it will be noted that the average silt content at Point San Pablo was practically the same on the two dates. If the samples may be considered representative, it appears that with the rivers discharging from 10,000 to 130,000 s. f. the amount of silt carried past Point San Pablo toward the ocean is directly proportional to the net discharge of the rivers.

Comparing similar tides at Point San Pablo on February 13 and July 7, it will be observed that on the latter date the silt content is only 50 per cent of that on the former at slack high tide which follows the flood tide; and 35 per cent greater at slack low tide which follows the ebb tide. From this the conclusion that the more saline water of July 7 was transporting more silt toward the ocean on the ebb tide than on February 13, seems warranted. In other words, it appears that a portion of the silt deposited on the shoals of San Pablo Bay during the period of high water are scoured out and carried toward the ocean during the following summer months by the more saline and, consequently, heavier water.

The redistribution of silt deposited during the spring run-off as a probable result of scouring by the less turbid and more saline water is also indicated by the results of the July 7 work and this, perhaps, is the most interesting feature of the study. It will be noted that the average silt content of the water at the Army Point site is greater than at either Collinsville or Point San Pablo. Since the difference between Army Point and Point San Pablo is less than between Army

Point and Collinsville it follows that the net result is the transportation of silt from Suisun Bay to San Pablo Bay.

A study of the details of the table indicate that on July 7, material was being scoured from the bottom of San Pablo Bay and redeposited west of Point San Pablo and east of the Army Point site. Comparing the silt content at higher high tide, and keeping in mind that this follows the flood tide traveling up the bays, it will be noted that it increases from 26 p.p.m. at Point San Pablo to 75 p.p.m. at the Army Point site, which indicates that silt is picked up between the two points—how much, can not be said at this time. Following the same line of reasoning it appears that a portion of the silt brought to Suisun Bay from San Pablo Bay lodges there for the reason that the silt content at Army Point at higher high tide is greater than at Collinsville and is less at slack lower low tide following the ebb tide traveling down the bays.

Comparing the silt contents at lower low tide on July 7, it appears that the ebb tides are scouring the bottom of San Pablo Bay and carrying the silt thus picked up down the bay past Point San Pablo.

Rate of Settlement of Silt.

On July 20, 1925, the Mountain Copper Company investigated the rate of settlement in still water. The sample contained 0.1480 grams of solids per liter, equivalent to 0.00914 pounds per cubic foot of water. The results follow:

Period of settlement	*Total solids settled*	*Per cent settled*
At start	0	
4 hours	0.1230 grams	83
8 hours	0.1300 grams	88
12 hours	0.1400 grams	94
24 hours	0.1450 grams	98
48 hours	0.1460 grams	99

Colloidal Silt.

The word, "colloidal" is defined as resembling jelly or glue, uncrystalline, semi-solid, and capable of but slow diffusion; partly amorphus.

Colloidal silt is extremely fine and is in a state of semi-solution. It is usually a very finely divided clay which may be thought of as being partially dissolved. In the consideration of fineness μ (Mu) is taken at 1/1000 of a millimeter. Double Mu ($\mu\mu$) is then $1/1000 \times 1/1000$ mm. Particles greater than 100 $\mu\mu$ in diameter are said to behave in a mechanical manner, while those below 5 $\mu\mu$ in diameter behave in a chemical manner. Those between these limits behave in one way or the other. Each particle is supposed to carry a charge of electricity, generally assumed to be negative, but, in any case, all particles carry the same kind of charge which causes them to repel one another. Hence, the particles do not unite to form heavier particles which may deposit through the action of gravity. The particles will, however, in time settle in quiet water to form an impalpable, greasy-like deposit.

When salt is introduced into water carrying colloidal silt the electric charge carried by the particles is said to be neutralized after which it becomes possible for them to get together in large numbers, forming a particle having weight sufficient to cause it to sink. The neutralization is instantaneous and the time required for precipitation depends only upon the amount of disturbance in the water.

In depositing, a very smooth and compact surface, or skin, is formed which is not readily disturbed after remaining undisturbed for some time. This may account for the low value of Kutter's "n" which apparently must be assigned in hydraulic computations to account for the high discharge through the bays. Mr. Gilbert says on page 91 of his report that:

> It is conceivable that the floccules on reaching the bottom become units of the bed load and are rolled by the current, but it appears to me more probable that the same property of surface tension which determines flocculation serves also to weld the particles of the channel bed into a coherent mass which resists the scouring force of the current.

In its original form, clay contains ferric iron, giving it its yellow, or red color. After depositing and being cut off from an air supply the ferric iron changes to ferrous, which probably accounts for the dark color of the mud found everywhere on the bottom of the bays.

As far as known the amount of silt carried by the rivers in colloidal form has not been determined. Although the proportion may be small it may be an important consideration in the study of the silt problem for the reason that its deposition occurs largely where the fresh water meets the salt. During periods of high river discharge, when the silt content of the water is high, the meeting ground is in the eastern end of San Pablo Bay which may, in part, account for the difficulty in maintaining the channel across Pinole Shoal.

Probable Effect of Salt Water Barrier Upon Silting in the Bays.

It is generally believed that the channels of the bays are maintained by the passage to and fro of the river and tidal waters. It is evident that the currents have a scouring effect from the fact that the deepest channels occur at points of greater constriction as in the Golden Gate, in Carquinez Strait and between points projecting from opposite shores. Moreover, samples of water taken near the bottom show a great deal more silt than those above.

In discussing the changes in the channels in Suisun Bay during the silting process, Mr. Gilbert says:

> Almost without exception they become narrower and deeper.

In describing the channel through San Pablo Bay, he states that:

> In the 41 years between surveys the channel was much reduced in width and was also reduced in depth. The filling along the middle line was small compared to the marginal filling.

The question as to whether the bay channels would silt up if the tidal currents were eliminated seems open to argument. As will be seen by reference to the charts (Plates 2-3 and 2-4) the bottom of the bays, especially that of Suisun Bay, has the form of a submerged delta with irregular channels enclosing submerged islands as it were. Some argue, with considerable logic, that these channels would maintain themselves even better if the scouring were done by the discharge from the rivers only. The surging back and forth of the tide has possibly done more to shoal the channels than to deepen them. It is certain that the tidal currents do not prevent shoaling entirely, as evidenced by the dredging required in Mare Island Strait, across Pinole Shoal in San Pablo Bay and over the Middle Ground Shoal in Suisun Bay.

Under the action of the tidal currents the particles of silt scoured from the bottom are moved back and forth with a gradual net movement toward the ocean. The construction of the Salt Water Barrier would effect the bays above and below differently. Above the structure reversal of currents due to tidal movements would, of course, be eliminated. The movement of silt would then be influenced only by the discharge from the rivers and the movement would be in one direction only—toward the barrier. During the floods from the river the tendency would be to scour out the channels and carry the material thus eroded past the barrier. It is believed also that the bulk of the colloidal silt would lodge below the barrier since it would be there that it first met the salt water. Immediately below the barrier tidal currents would also be eliminated. At any other point below the barrier tidal currents would exist, but would have less velocity than at present as a result of the tidal prism above the structure having been cut off. It appears that the principal effect of the reduced tidal velocities below the barrier would be that smaller particles and less material would be carried back and forth with the tides.

The committee reporting upon the feasibility of a dam across the Charles River at Boston, which structure is similar to that proposed in this report, said:

> It is important to note that tidal scour is an advantage only when under exactly the right conditions. There are well known instances of harbors with little or no tide or river currents that have maintained their depths far better than other harbors with strong currents. Whatever is eroded from one place finds lodgment in another, and the place of settlement often turns out to be in some of the broader parts of the lower harbor, or at its mouth.
>
> An instance of this appears in the case of the Clyde at Glasgow. The old weir or half dam in the upper reaches was removed in 1879 for the express purpose of benefiting the harbor by increasing the scour. It worked so badly and caused so much damage and expense that the weir has been rebuilt solely for the purpose of preventing the damage that was being done to the harbor by the currents.
>
> The Thames Conservancy Board predicted * * * that the half dam then about to be built at Richmond, and which would cut off a large part of the tidal prisms, would result in serious shoaling below. That Board now states, "Its effect upon the regime of the river as a whole can not be said to be injurious."

Without hydraulic mining it is safe to say that deposition of silt in the bays would have been much less. With the barrier constructed there will be no more or less silt brought to the bays than without it. Hydraulic mining has, for the time being, been discontinued and if again permitted under federel or state control, some means will undoubtedly be taken to prevent the debris from entering the river channels. Maintenance of the flood control projects, and of the proposed deep waterways to Stockton and Sacramento will require dredging of material from the lower rivers which would otherwise reach the bays. In this connection, Messrs. C. E. Grunsky and Leonard Cox in their report of February 28, 1925, on the Economic Aspects of a Sacramento Deep Water Ship Canal, state on page 98:

The only purpose of this discussion is to show that in the long run the silt problem as a menace to navigation is not to be feared. Nevertheless the fact must be recognized that in a year of extreme flood conditions—such high stages for example as prevailed in the season 1861–1862—there will be large quantities of sand and gravel swept into these channels that will for a time make difficult the maintenance of the full depth demanded by the navigator. Such years are, however, of rare occurrence, and ill effects resulting from the occasional flood stage can be forestalled in the lower rivers, at least by continuous dredging operations to provide the space in the channel bed for the sand which would otherwise encroach on the navigation section of the river. The figures above cited would seem to indicate that the dredging required to keep the lower Sacramento River at the desired navigable depth, with possible interference therewith only as a result of the great floods of rare occurrence even under the influence of hydraulic mining, would have been only two to three million cubic yards per annum. Now that hydraulic mining has ceased it would seem safe to assume that not more than the smaller of these amounts or 2,000,000 cubic yards of material per annum would require removal by dredging to make certain of the maintenance of the desired depths in navigable waters of both the lower river and the bays.

With the development of irrigation and flood control in the Great Central Valley, the amount of silt carried to the bays will become less for the reason that a large portion of the floods, which under present conditions carry large quantities of silt to the bays, will be stored in mountain reservoirs to be released during the summer months as clear water.

If a barrier is constructed at any one of the sites investigated for the purpose of this report, there surely will be a change in currents with a resultant effect upon the deposition of silt. The extent of this effect is more or less problematical and any conclusions must therefore take somewhat the form of conjecture. A few deductions will be noted for the purpose of determining what may be anticipated with the barrier constructed at any one of the sites.

Considering a barrier constructed to hold the water level on the upstream side no higher than elevation + 2.9 U. S. G. S. Datum, the initial silting that occurs in the Sacramento and San Joaquin rivers will be unchanged for the reason that during flood stage the control section at Chipps Island holds the water level above this section much higher than below. At low river stage there will no longer be a flow to and fro across the tidal flats as the water surface above the barrier will be nearly stabilized, and the current will be in the same direction at all times. This will tend to reduce the transportation, along the stream beds, of the silt initially deposited because of the reduced currents toward the bays and the loss of the stirring effect of the reversal of currents. It therefore seems probable that there will be a greater accumulation of silt in the rivers and may even become of such proportions as to necessitate the heightening of levees or in increased dredging activity—probably the latter. This condition holds for a barrier at any one of the locations, but may be offset by the development of new reservoirs in the upper reaches of the Sacramento River and its tributaries, which would materially diminish the supply of silt near its source. No serious trouble is contemplated with silt from the San Joaquin. Mr. Gilbert estimated that only about one-seventh of the silt reaching Suisun Bay during the period of 1849–1909 came from the San Joaquin River. This proportion may be slightly changed under present conditions as the period 1849–1909 covers the years of greatest mining activities, but on account of the comparative velocities of the two streams, this proportion can not greatly be changed.

The method of operating the gates would undoubtedly have some effect upon silting. Assuming that the gates are opened only long enough to take care of the flood flow in the river, the deposition of colloidal silt will be somewhat changed, depending upon the location of the barrier since this deposition occurs principally at the junction of the fresh and saline waters.

The area in the bays which at present most seriously hinders navigation is the Pinole Shoal because this area is the natural dumping ground for silt reaching San Pablo Bay from Napa River as well as from the streams draining the Great Central Valley. It is also the junction of fresh and salt waters where colloidal silt is deposited through flocculation during the flood season. Therefore, the effect upon this area with a barrier at any one of the three sites should be given primary consideration in regard to silting.

If the barrier is constructed at the Army Point site, it is probable that the effect upon colloidal silting will be slight as this site is near the upper limit of the junction of saline and fresh water when silt is prevalent, except at the beginning of a flood. The tendency, however, would be to increase the silting from this source in Carquinez Strait. The currents through Carquinez Straits would be affected most at low stage of the river as the current at present is controlled principally by the tidal volume in Suisun Bay. With this volume cut off it is anticipated that the outward current will be much less and for the same reason the reverse current would be materially decreased. This would retard the movement of silt toward San Pablo Bay. In Chapter V it is shown that with a discharge from the Sacramento and San Joaquin of 500,000 s.f. or more, there will be a continuous outward flow through the flood gates, but this flow would be absorbed at flood tide a short distance below the barrier. The general tendency at flood stage would then be a reduction of currents in the straits for the same reason as at low stage, resulting also in a slower movement of silt toward San Pablo Bay. This would tend to slightly reduce the accumulation of silt at Pinole Shoal which is supplied from the rivers and upper bays.

With a barrier at Dillon Point, colloidal silting will be confined to a much smaller area, bringing this centralized area to, or near, the present area of greatest deposition in the vicinity of Pinole Shoal. The currents through Suisun Bay and Carquinez Strait will be materially decreased in velocity, and the stirring effect of reverse currents will be eliminated. The beneficial effects of the reduction of average outward velocity due to an average tide and average flood in the rivers probably will be negligible for the reason that the present average velocity of less than 3 f.p.s. has little transporting power. Under conditions of extreme high tide and extreme flood in the rivers, however, the outward velocity probably has its effect upon movement of silt toward San Pablo Bay. This condition will be eliminated. With due consideration given to the above line of reasoning it appears to be impossible to come to any conclusion as to whether the effect of a barrier at Dillon Point will be beneficial or detrimental to Pinole Shoal.

Apparently the greatest beneficial effect upon the Pinole Shoal would be derived from the construction of a barrier at Point San Pablo. Instead of a large fluctuation of depth on Pinole Shoal as at present there would be a more uniform depth near that attained at high tide except in years of deficient run-off. The deposition of colloidal silt would be removed from Pinole Shoal to an area directly below the barrier and might, in time, reach such proportion as to require dredging there.

Since, at times of flood stage in the rivers, muddy water is easily discernible in San Francisco Bay, it may be assumed that there is at present some silting in San Francisco Bay from this source. Currents, carrying this silt, in general traverse the east side of the bay and reach south San Francisco Bay one hour before and at low water slack tide at the Gate. (Refer to pages 91-92, Exhibit 15.) It is therefore believed that an increase in the silt deposit along the east shore may be expected as flocculation of colloidal silt will not occur until it has reached the upper end of San Francisco Bay and a large percentage of this will not settle immediately, but will be transported by the current for some distance before it reaches its final resting place. This increase may or may not be offset by the decreased transporting power of the current above the barrier.

There is one point connected with silting which heretofore has not been mentioned in this report and which may have an important bearing on the subject. As the salt disappears from above the barrier an aquatic plant growth may result. Such a growth would cause more rapid silting along the shores and in back water channels and small bays. This, however, may not affect the velocities in the central channels to the extent of increasing the amount of silt transported beyond the barrier, and certainly will only hasten the ultimate condition that is at present being approached at Pinole Shoal.

Probable Effect of Barrier Upon Golden Gate Bar.

It appears from the foregoing that neither the reduction of the tidal prism brought about by silting of the bays and reclamation of delta and marshes around the bays, nor the silt being carried through the Golden Gate, are having a detrimental effect on the bar and that there is reason to believe that the construction of the Salt Water Barrier might not be detrimental in its effect upon the bar, especially if built at one of the upper sites investigated.

Mr. Gilbert's investigations tend to show that, theoretically, with a decreasing tidal prism there should be an increase in the size of the bar and he has not advanced a reason for an actual decrease. Since surveys at different periods show conclusively that the bar is moving shoreward and at the same time is decreasing both in height and width there must be a steady increasing or decreasing in currents at present undefined which have their effect upon the deposition of the bar material.

It has occurred to those employed on the present investigation that the fact that the currents through the Golden Gate are decreasing, on account of a decreasing tidal prism, might be the solution of the decreased bar volume, and a discussion of what might be expected will be given here for what it is worth. In this connection reference should be made to Plate 3-1.

Since it has been accepted as very probable that the bar has been made up largely of material transported by the northward ocean currents along the coast, it is assumed that the original location of the bar was at a point where the strongest current of previous time through the Golden Gate caused an eddy in the northward current of the ocean. As the current through the Golden Gate has steadily decreased in strength it is natural to assume that the location of the bar would gradually move toward shore, and probably assume the same proportions or increase in volume. The reason, however, that the bar has decreased rather than continued stable, or increased in dimensions, may be due to the shape of the coast line adjacent to Golden Gate and to the fact that the strongest current, which has a greater silt transporting capacity than any current nearer shore, probably extends in almost a straight line between Pescadero Point and Point Reyes. As the eddy line moves nearer shore, the currents, having less silt in suspension, naturally deposit less, and the stronger current on the outside of the bar is moving the silt from this side of the bar farther along the coast. Thus the bar is gradually diminishing in size.

If the above theory is correct, any decrease in the tidal prisms of the bays should have a beneficial rather than a detrimental effect upon the Golden Gate bar which is contrary to general opinion. In the final studies careful consideration should be given to this phase of the problem.

CHAPTER IX

SALINITY

If it were not for the discharge of the Sacramento and San Joaquin rivers, salt water, practically equal in salinity to that of the ocean water, would occupy all of the bays, delta channels and river channels to points well above the cities of Sacramento and Stockton since all are arms of the Pacific lying below sea level. This condition is prevented, however, by the discharge of fresh water from the two great rivers which serves to push back the ocean water.

If the river discharge were uniform throughout the year, and if there were no tidal currents, the salinity at any point in the bay system would be practically constant. Under conditions of tidal fluctuations, however, the line of demarcation between fresh and salt water moves up and down stream twice each day even though the river discharge remains uniform. The changes of tides are both daily and seasonal so that the movements of water up and down the bay vary between wide limits. Spring tides, being higher than the ordinary tides, carry the ocean water farther into the bays and from the bays farther up the river and delta channels. The advance of salt water is therefore most rapid during the season of low river discharge and high tides occurring in the middle of the summer.

As has been brought out, the discharge of the rivers has a wide range, varying, roughly, from three times normal in wet years to one-third normal in a dry year such as 1924 was. The rivers are usually high in the early spring and serve to flush out the brackish water from the delta channels and Suisun Bay resulting from encroachments of salt water during the previous summer and fall when the river discharge had dropped to the extent that it was not sufficient to act as a natural barrier against the encroachment. In years of large run-off fresh water extends through Carquinez Strait and into San Pablo Bay, but as the river discharge decreases with the advancing season the brackish waters from San Pablo Bay find their way through the strait and into Suisun Bay. The time of the first appearance of brackish water at the upper end of Carquinez Strait, as well as at other upstream points, depends principally upon the discharge from the rivers. The distance upstream the brackish water extends depends upon the river discharge and upon the time element. With a given river discharge, less than sufficient to act as a natural barrier against salt water, the salinity at upstream points increases as time goes on as will be shown in the following paragraphs.

Advance of Salt Water Up the Bays.

It is a well known fact that when salt water is brought in contact with fresh water the former, on account of its greater specific gravity, will displace the latter. In his report upon the Charles River Dam at Boston Mr. John R. Freeman found that:

If a layer of turbid fresh water be run carefully upon the surface of turbid salt water in such a manner that the two waters mix but slightly, a peculiar phenomenon is noticed; that is, the finely divided matter in suspension in the salt water begins to precipitate, and shortly a layer of clear salt water appears below the fresh water, which still retains its turbidity. In case the fresh water in this experimental work contains any heavy particles these break through the line of demarcation between the fresh and salt water after a short time, and soon cause a mixing of the two waters, with a consequent precipitation of all the turbidity. Changes in the surrounding temperature, or a difference in the temperature of the two waters, will hasten their intermingling and complete sedimentation. If the waters are of practically equal temperature, and are allowed to remain quiet at a constant temperature, the layer of turbid fresh water may remain on the surface of the salt water for some hours, the turbidity of the salt water in the meantime being entirely precipitated.

The phenomenon described is the key to the entire salinity problem of the delta. It explains the relatively great salinity of water found in deep channels; the increase in salinity as depth is attained; the progress of salt water upstream through the bays and the climbing of salt water to higher elevations through ship locks where these separate bodies of fresh and salt water. The relative rates of precipitation in fresh and salt water are of particular interest in connection with silting of the bays discussed in Chapter VIII.

Mr. Freeman states further that:

The effect of the influx of a volume of salt water under a body of fresh water is much the same as above, the salt water floating the turbid fresh water without mixing with it to any great extent, if its influx is slow.

It will be recalled that in a quotation in Chapter V, relative to the 1861–1862 flood, it was reported that for two or three months the surface portion of the entire waters of the bay consisted of fresh water to a depth of from 18 to 24 inches and that at Golden Gate, for nearly a fortnight, the stream on the surface was continuously flowing toward the Pacific, composed entirely of fresh water, the tide not affecting the surface flow.

The reason for the flood tide coming in first on the bottom and for the strength of the early ebb tide near the surface is found in the marked excess of the specific gravity of the relatively salty, cool, incoming water from the ocean, as compared with the ebb water which has been warmed by the sun over the shallow portions of the bays and further lightened by the admixture of river water.

It has been determined that salt water will travel long distances under fresh water occupying deep channels in which there is no flushing current from a river or other source. The deeper pockets stop the upstream progress of the salt water only for the time required to displace the fresh water in them. Since resistance to flow is extremely small with very slow velocities, it requires only a small difference in the specific gravity of the fresh and brackish water to cause the advance of the latter if sufficient time is allowed.

The Army Engineers developed some interesting data in their study of the practicability of a salt water guard lock in the Sabine–Neches Waterway, Texas. The reports are contained in House Document No. 234, 68th Congress, 1st session.

Sabine Lake, a comparatively shallow tidal basin approximately 17 miles long and averaging about $6\frac{1}{2}$ miles in width, is joined with the Gulf of Mexico at one end through Sabine Pass much as Suisun Bay is connected with San Pablo Bay by Carquinez Strait. At the other end it receives the discharge from Neches and Sabine rivers so that the conditions are very similar to those being considered in this report. The United States has improved the system of waterways at Sabine Lake by providing a channel with a project depth of 30 feet at mean low tide through Sabine Pass thence via a canal around the northerly side of Sabine Lake and up the two rivers. Movements of salt water up the Neches River are quite common at low river stages as in the case of the Sacramento and San Joaquin rivers.

In speaking of the canal around the lake the Chief of Engineers says:

> The presence of the Port Arthur and Sabine–Neches canals with guard lock open modifies in several ways the natural diffusion of salt water in the lake, but with one exception these modifications are negligible. The exception concerns the action of so-called salinity currents, which are currents set up due to the difference in specific gravity of salt and fresh water, and the consequent tendency, when the two come together in a channel, is for the salt water to move upstream along the bottom forcing the fresh water downstream along the top. This action is much more pronounced with deep channels than with shallow. It follows that when salt water makes its appearance in Sabine Pass, and when the discharges of the Sabine and Neches rivers are sufficiently low to permit it to enter, it will, through the action of salinity currents, move more rapidly up the canal than up the much more shallow lake. Therefore, given the conditions that Sabine Lake is comparatively fresh and that the river discharges are low, the existence of the open canal will result in the appearance of salt at the mouth of the Neches (river) at an earlier date than would occur were the canal absent or closed by a guard lock.

It is reported that, other things being equal, salt water will advance up the canal about four times as fast as up the lake when both are filled with comparatively fresh water and the river discharges are low.

> A portion of the discharge of the Neches River finds its way to Sabine Pass via the canal. Observation shows that when the Neches is discharging 15,000 cubic feet per second or above, the current down the canal overcomes the advance of any salinity currents while if the discharge falls below 8000 cubic feet per second that of the canal falls below 3000 cubic feet per second and under unfavorable tide conditions there may be an advance of salt water up the canal toward the guard lock; when the Neches falls below 4000 cubic feet per second the canal discharge becomes less than 2000 cubic feet per second and the salt water will soon make an appearance at the site of the guard lock. During this period there will be a similar advance of salt up the nearby lake, but at only about one-fourth the rate up the canal. With conditions reversed, we find, as might be expected, that the canal is quickly cleared of salt whereas the lake may remain polluted for many months. If, as in 1917 and 1918, the Sabine and Neches rivers show low discharges through the winter and spring, Sabine Lake may remain continuously salty from one season to the next and exceed the canal in salinity.

Some property owners on the lower Sacramento and San Joaquin rivers fear that channel enlargement which is now under way and the proposed deep water ways to Sacramento and Stockton will induce a greater tendency for salt water to find its way into the river and delta channels. During the trial of the Antioch case it is said that much evidence was presented to show that the deepening and widening of the channel of the Sacramento River was largely to blame for the increase in salinity in lower rivers. On page 20 of the 1921 Report on the San Francisco Bay Marine Piling Survey, it is stated:

> The situation relating to the upriver penetration of the (brackish) bay water is aggravated, too, by the fact that the work of channel enlargement in progress since 1913 and being done by the U. S. Government, in cooperation with the State of California, on the Sacramento River below Rio Vista has been a material factor in facilitating tidal flow in the lower reaches of that river and in augmenting the circulation of water around Sherman Island, thereby expediting the upriver advance of the bay water.

It has been demonstrated on San Francisco Bay, on the Lake Washington Ship Canal at Seattle, and more particularly on the Sabine-Neches Waterway in Texas, that salt water, on account of its greater density, seeks the deeper channels and holes. Deep channels permit the heavier salt water to flow upstream along the bottom, underneath the fresh water which it tends to displace. It follows that any dredging done to deepen the channels through the bays and up the rivers would result in increased salinity in the delta region. Generally speaking, any increase in the carrying capacity of the lower rivers through deepening, widening, or straightening of the channel, will, in the writer's opinion, permit of easier access of salt water into the delta. It is believed that insofar as salinity is concerned the deepening of channels is the more important consideration, which suggests the possibility of increased salinity resulting through the construction of the proposed 26-foot ship channel through Suisun Bay and San Joaquin River to Stockton. As described in Chapter VI the present authorized navigation project through Suisun Bay provides for an 18-foot depth across Point Edith and Middle Ground shoals at mean lower low water which, it will be seen from inspection of Plates 5-20 and 5-21, is less than the present depths in the lower Sacramento River channel. The shoals in Suisun Bay under present conditions therefore tend to retard the upstream advance of salt water. With a 26-foot channel excavated through the shoals the advance of salt water probably will be more rapid than under present conditions. Assuming, however, that improvement of the lower Sacramento River is necessary for protection against floods, and that in the natural development of the Great Central Valley deep waterways will be of economic importance, it is evident that some artificial means must be adopted to prevent the easier access of salt water through the deepened channels. It is believed that those responsible for the investigation of the proposed Salt Water Barrier had in mind the increasing danger from salinity under conditions of future development at the time funds for the investigation were requested.

Mixing of Fresh and Salt Water in the Bays.

It has been shown that where there is a slow influx of salt water under a body of fresh water they will not mix materially so long as there is no disturbance. In his study of salinity in the Lake Washington Ship Canal, Mr. W. M. Meacham concluded that the chemical diffusion of salt water upward through a body of fresh water is so slow as to be negligible. Mechanical diffusion, or mixing, and mixing deto difference in the temperature of the salt and fresh water, are material factors.

Mechanical mixing is due to a number of causes among which are the tidal currents, currents produced by the discharge of the rivers into the bays, winds which create considerable disturbances over the shallow waters of the bays, and the propellers of numerous vessels plying the bays. It is probable that the tidal currents are largely responsible for the thorough mixing which takes place in the bays, for by reference to Table 7-1 it will be noted that the amount of water above the Army Point site is over 700.000 acre-feet at low tide and about 1,200,000 at high tide while corresponding figures for the Point San Pablo site are about 1,500,000 and 2,500,000 acre-feet. These volumes of water are pushed back and forth by the tides, becoming more salty during the protracted annual low water stage of the rivers and freshening again as the rivers rise to their winter and spring high stages.

It is reported that in August, 1920, tests were made by placing floats in the rivers at their mouths to determine the movement of water upstream during the period from low tide to high tide. The floats were so designed that their motion would not be affected by wind and would correspond closely with the upstream flow of the water. Tests were made on three days in the Sacramento and on three different days in the San Joaquin. The floats moved upstream 10.3, 10.05 and 10.25 miles up the channel of the Sacramento and 10.6, 10.35 and 10.46 miles up the San Joaquin. As tides are effective to points well above Sacramento and Stockton it is apparent that any salt water which might creep up along the bottom of the deeper channels would become thoroughly mixed with the fresh water in the river channels even though it escaped thorough mixing in the bays.

Due to the mixing of the salt water entering the bays through the Golden Gate with the fresh water from the rivers during low stages of flow only a portion of the salt water arriving with the previous flood tide leaves the bays at ebb tide, carrying with it a portion of the fresh water which was originally in the bays. The result is that after one tidal cycle the bays are saltier than they were before and that the salt has been diffused to a considerable distance from the Golden Gate. Likewise, some of the brackish bay water which in dry years enters the river and delta channels during the late summer and fall months with each flood tide is retained in the river channels causing the water in these channels to become saltier with each flood tide until the river discharge increases to the point where it is sufficient to push the brackish water back toward the bays.

Periods of Low River Discharge.

In considering salinity in the delta region it is interesting to look into the past to determine the seriousness of the situation for, in years of normal river discharge, there is no salinity problem in the delta. It is said that in 1921–22, when the run-off was something less than normal, salinity was not noticed at points above Sherman Island. Reliable measurements of stream flow are not available for years prior to 1905 but the run-off from the Great Central Valley is closely related to the seasonal rainfall and rainfall records are available as far back as 1850.

On page 117 of the 1923 Proceedings of the Sacramento River Problems Conference, Mr. C. E. Grunsky, Jr., says:

> The rainfall records of the U. S. Weather Bureau indicate that the season 1919–20, which was one of less than half normal, was preceded by two seasons, 1916–17 and 1917–18, which were 70 per cent and 55 per cent of the normal, respectively, and by a third season, 1918–19, which was barely normal. These figures show a four-year period, 1916–1920, during which the annual rainfall would average about 68 per cent of the normal annual. Looking backward to find a period that even approximated this shortage, the most protracted period of shortage prior to 1916–1920 is found to be the three-year period, 1868–1871, during which the annual rainfall averaged 72 per cent of the normal annual. Shorter periods where two years of subnormal rainfall occur are found between 1850 and 1920, but the two periods of most protracted shortage are 1868–1871 and 1916–1920.
>
> In this connection a former resident of Twitchell Island testified in the Antioch case that he resided at Kentucky Landing from 1870 to 1875 and that on one or two occasions during that period the water in the San Joaquin River in front of his residence became so salty or brackish that it could not be used for household purposes, and he was forced to sail upstream sometimes as far as the mouth of Mokelumne River so as to get water fresh enough to drink. The witness could not remember the exact year, but judging from the rainfall records, the conclusion may be reached that such a condition would have occurred in the fall of 1871.

It will be recalled that Commander Ringgold found brackish water near the mouth of the Sacramento and San Joaquin rivers in August, 1841, as mentioned in Chapter I.

Monthly Distribution of River Discharge.

Since all of the flow of the San Joaquin River is diverted for irrigation purposes early in the season, dependence must be placed on the Sacramento to supply the needs of the delta irrigators and to act as a natural barrier against invasions of salt water. The characteristics of the Sacramento are therefore of particular interest in this study.

From long-time records of measurements made by the U. S. Geological Survey, in cooperation with the State of California it has been determined that the average annual run-off from the Sacramento and principal tributaries is 21,400,000 acre-feet. It has been estimated by the State Department of Public Works that the mean annual run-off from the entire drainage basin for a 50-year period is 25,200,000 acre-feet as stated in Chapter II. The difference of 3,800,000 acre-feet (15 per cent) represents minor drainages not measured by the Geological Survey and includes diversions that are made above the gaging stations.

From the data appearing in a paper by H. D. McGlashan, District Engineer, U. S. Geological Survey, contained in the 1923 Proceedings of the Sacramento River Problems Conference, the measured run-off in typical years is about as follows:

Year	Run-off from Sacramento and principal tributaries — Total	Mean
Average year	21,400,000 acre-feet	29,500 second-feet
High water 1906-07	35,900,000 acre-feet	49,600 second-feet
Low water 1919-20	8,540,000 acre-feet	11,800 second-feet
* Lowest of record 1923-24	5,200,000 acre-feet	7,174 second-feet

* From data furnished by Mr. McGlashan during the investigation.

Under present conditions of non-regulated flow, the monthly distribution of the discharge from the Sacramento and tributaries is estimated by Mr. McGlashan to be as follows:

Monthly distribution in per cent of total for the year

Year	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sep.*
Average	2	4	6	15	16	16	15	13	8	3	2	2
1906-07	1	2	6	7	17	25	16	10	8	4	2	2
1919-20	5	4	7	6	6	14	22	17	8	4	4	3
*1923-24	8.3	7.5	8.0	9.2	19.6	9.2	11.1	8.0	4.9	4.7	4.7	4.8

* From data furnished by Mr. McGlashan during the investigation.

The table shows that only 15 to 20 per cent of the annual discharge, regardless of the type of year, runs off during the low water period, June to September, which is the period of steadily decreasing discharge with practically no chance of replenishment from precipitation. It is also the period of heavy demand for irrigation and for water to act as a barrier against salinity in the delta.

Return Flow.

As previously stated, all of the natural flow of the Sacramento and San Joaquin rivers is required during the irrigation season in years of low run-off to supply the requirements of the upper valleys and for this reason the delta users would be dependent upon return flow to supply their needs unless restrictions were placed upon upstream diversions. Return flow is already an important factor in relieving the salinity situation in the delta region, particularly in the late summer months, and the situation would be less serious if the volume of the return water increases with the continued development of irrigation in the two valleys through the use of water which of necessity will have to be provided through construction of storage reservoirs on the upper reaches of the rivers and their tributaries. The increased return flow will tend to sustain the river flow throughout the low water period but it is doubtful that its volume will be sufficient to act as a barrier against salinity even though the water could be spared for that purpose. Not all of the return flow would be available for this purpose as some of it, under ordinary circumstances, would be rediverted before it reached the delta. The measurement of return flow had been sadly neglected until 1924 and as a result there are little data available relative to its quantity or quality.

In his report for 1924 the State Water Supervisor says:

> The conditions surrounding return water to the Sacramento River differ considerably from those on the San Joaquin. Here a large portion of the return flow follows the troughs in the basins on either side of the river, and is discharged to the river in definite channels at points fairly well downstream.

It was found that in 1924 the total return from Red Bluff to Sacramento, for the four months, June to September, amounted to 33 per cent of the diversions in that period on the same stretch of the river. The water supervisor's report for 1925 shows 40 per cent return on the same portion of the river from July 1 to October 31 and it is stated that the only return water considered was that which entered through definite return channels. It does not include seepage or return water which could not be directly measured.

There is apprehension upon the part of irrigators relative to the fitness of the return water for use in irrigation, especially in case of the return from the rice fields located in more or less alkali areas. In order to determine the difference in salts and alkali contained in river water and return water the State Water Supervisor caused tests to be made of samples of both. On July 30, 1924, a sample was taken of the Colusa Trough water at the Maxwell Road and at the same time one was taken from the adjacent Maxwell Irrigation District canal carrying water diverted from the Sacramento River at the pumping plant about seven miles distant. The results of the tests are shown in the following table taken from the Water Supervisor's report:

	Parts per million	
Test	*Return water in Colusa Trough*	*Canal water from Sacramento River*
Alkalinity bicarbonates	207.00	121.00
Alkalinity carbonates	0.00	0.00
Total hardness	164.00	156.00
Sulphates as SO_4	0.50	1.50
Chlorides as Cl	65.00	65.00
Alkali as Na	49.00	19.00
Alkali coefficient*	24.00	107.00
Alkali rating	Good	Good

* Alkali coefficient is the depth in inches of water which on evaporation would yield sufficient alkali to render a four-foot depth of soil injurious to the most sensitive crops.

The water supervisor states that early in the fall the rice fields are drained of all the water which has been ponded during the summer, and at this time, therefore, there is considerable increase in the return to the Sacramento River of such water. A sample of water taken from the back-borrow-pit of District 787, just above its junction with the river at Knights Landing on September 12, 1924, at the peak of the fall drainage, expressed in parts per million, analyzed as follows:

Total solids	582	Permanent hardness	[illegible]
Suspended solids	73	Chlorine as Cl	82
Dissolved solids	509	Sulphates as SO_4	93
Bicarbonates	260	Alkali coefficient	24
Total hardness	213	Alkali rating	Good
Temporary hardness	85		

No comprehensive conclusions can be drawn from the few tests that have been made but the indications are that there is no immediate cause for alarm insofar as the salinity of the return water is concerned. The salinity of the river water is given in U. S. Geological Water Supply Paper 274, pages 93 and 107.

Salinity of Sea Water.

The salinity of sea water is not uniform over the world. It may be said that sea water contains from 19,000 to 20,000 parts of chlorine per million parts of water. U. S. Geological Survey Paper 479 gives 19,350 parts per million, as normal. This represents the average of 77 analyses by W. Dittman, of sea water collected by the Challenger expedition, "Challenge Report, Physics and Chemistry," Volume I, 1884, page 203.

Mr. C. E. Grunsky, Jr., discusses the salinity of sea water briefly on page 115 of the 1923 Proceedings of the Sacramento River Problems Conference. Quoting Mr. Grunsky:

> The quantity of mixed salts which occur in sea water is about in the proportion of 3500 parts of salt to 100,000 parts of water by weight. About 90 per cent of the salts that occur in sea water are chlorides. If, for convenience, the chlorides in a mixture of sea water and river water are calculated as sodium chloride or common salt, 3000 to 3100 parts of chlorides in 100,000 parts of water will indicate almost pure ocean water. A sample of ocean water taken near the Cliff House, San Francisco, on October 15, 1920, contained 3065 parts of chlorides (calculated as sodium chloride) in 100,000 parts of water.

It is found that in the bay region salinity is expressed in various ways, the most common being as common salt (NaCl), and as chlorine (Cl). To reduce chlorine content to salt content multiply the former by 1.65.

On February 17, 1925, at the time the approximate combined discharge of the Sacramento and San Joaquin rivers into Suisun Bay was 131,440 second-feet, a sample of ocean water was taken at the entrance to the Golden Gate near the Cliff House. Analysis of the sample showed it to contain 16,120 parts of chlorine per million. The relatively low salinity is, no doubt, the result of the high river discharge. The sample was taken from the surface and therefore represented the fresher water floating on top of the more salty ocean water.

In comparison with the above, the salinity in Puget Sound near Seattle, Washington, is of interest. Analyses of samples taken in 1925 about 200 yards north of Alki Point, at the surface and at depths of 10, 20 and 30 feet show the following average salinity expressed in parts chlorine per million:

November 1	17,285	November 29	16,600
November 9	17,240	December 7	16,880
November 16	16,710	December 31	16,540
November 22	17,035	January 15	16,680

Limits of Salinity of Water for Irrigation and Industrial Uses.

There is a difference of opinion as to the limit of concentration of salt in irrigation water but it is generally believed that for average conditions in the delta region 100 parts of chlorine (Cl) (165 parts of salt, NaCl) per 100,000 is the limit which can be used with safety. This concentration is said to have been reached on August 1, 1924, at the middle of Ryer Island, Grand Island, Andrus Island and Bouldin Island. If the salinity of ocean water may be taken at 19,350 parts chlorine per million, it follows that a mixture of 1 part of ocean water and 18.35 parts of fresh water would have a salinity of 100 parts of chlorine per 100,000. Since the river water is not absolutely fresh, but contains some chlorine, the amount of ocean water required to produce a mixture with the river water containing 100 parts of chlorine per 100,000 would be somewhat less than indicated above.

It is the belief of some people that salinity in the delta region has been exaggerated but there is no question that it constitutes a serious menace. It is true that under present conditions the salinity in the delta, in normal years, is menacing for a few days in the fall only, but considering the marshes surrounding the upper bays and the towns and industries located along their shores the encroachment of salt water presents a serious problem almost every season.

Mr. J. A. Wilcox, Manager of the Benicia Water Company, estimates that water containing 50 parts of salt (30 parts chlorine) per 100,000 will do for domestic use and 35 parts (21 Cl) for boiler water. He states that not in excess of 20 parts of salt (12 Cl) are desirable and this is the aim of the Benicia Water Company. He estimates that over a long period there is an average of about 4½ months per year that water carrying less than 50 parts of salt per 100,000, could be pumped from the bay at Benicia.

Benicia is an example of towns located on the bay which would benefit as a result of the construction of the Salt Water Barrier, providing it were built at some location to the west. It has a population of about 3500. The town receives its water supply from two reservoirs located in the nearby hills, augmented by pumping from Carquinez Strait when fresh water is available there. All of the water is chlorinated. During years of low water supply it has been necessary to haul water from upstream points to the town by barge. The water company is said to have barged water as early as 1908. According to Mr. Wilcox, water was barged in 1913; from November 30, 1918, to February 15, 1919; and from April 26, 1920, to December 1, 1920. From December 1, 1920, to June, 1921, water was pumped from submerged barges tied up at the city wharf. The barges were filled at low tide when the water was comparatively fresh and emptied by pumping from them during the period of high tide. The cost of securing fresh water at Benicia in 1920 is reported at from $100,000 to $120,000.

Salinity as it Affects Industries.

The entire shore line of the bay system offers potential industrial sites. At present the principal industries requiring fresh water in their processes are located along about 30 miles of the south side of Carquinez Strait and of Suisun Bay from San Pablo Bay to the town of Antioch. This stretch of water front is ideally situated for the reason that it is served by two transcontinental railroads, ocean going vessels and two power lines. Living conditions are ideal. At the time the plants were located it was believed that fresh water would be available in unlimited quantities. Companies locating farthest upstream expected to have fresh water available at all times while those locating on Carquinez Strait expected to be able to pump fresh water for their use at least during periods of low tide.

Mr. C. W. Schedler, General Manager of the Great Western Electro-Chemical Company, whose plant has been located at Pittsburg since 1916, has stated that no difficulties on account of salinity of the bay water were encountered at their plant until 1920. During the summer of that year the salt content of the bay water was such as to interfere with their process. The years 1921, 1922 and 1923 were fairly satisfactory but again in 1924 conditions became acute, causing damage in the stoppage of their processes and resulting in deterioration of their equipment, estimated at not less than $35,000. Other industries have been affected in a similar manner. They use steam boilers, air compressors, vacuum pumps, locomotives, cranes, condensers, coolers, pumps, presses, washers, rolls, dry kilns, elaborate pipe systems, etc. All are subject to rapid deterioration when saline water is used in them. The Columbia Steel Company at Pittsburg uses large quantities of water in cooling some of their finished products such as steel wire, plate, rods, etc., and the presence of salt in the water rusts the product and reduces their sale value when in competition with the output of other plants.

All of the industrial plants have their own fire fighting systems. Salt water, if it gets into the system, soon eats into the pipes and while the pipe may not be perforated, it may be so weakened that it would fail just as the time dependence was being placed in it in an emergency. The most careful inspection might not reveal the weakness.

It has been estimated that the investment in industrial plants from Crockett to Antioch is in excess of \$60,000,000. If it is assumed that 5 per cent of this amount is invested in equipment subject to corrosion from salt water, \$3,000,000 would represent the investment in this class of equipment. Mr. Schedler, on page 88 of the 1924 Proceedings of the Second Sacramento–San Joaquin River Problems Conference, says that the increased depreciation on this equipment brought about by the salinity conditions experienced in 1924 amounted to over \$150,000.

Not only is there a large expense due to maintenance of plant, but the process is sometimes affected, resulting in losses. Mr. Schedler states that in 1924 the salinity at their Pittsburg plant, for the period July, August and September, was approximately half that of the ocean water. In July of that year it was necessary to shut down their hydrochloric acid plant on account of stoppage in the pipe system. Upon dismantling it was found that the entire pipe system was plugged with salt. The system was cleaned out and the plant put in operation but the next morning the plant was down again from the same cause. From that time on, well water was purchased from the city of Pittsburg for about two months until a well could be sunk on their own property. The water from the new well was found to be of poor quality but usable.

It is reported that the California–Hawaiian Sugar Corporation, whose plant is located on Carquinez Strait at Crockett, spends over \$100,000 in obtaining fresh water in years of low run-off. This plant, alone, uses approximately 2,000,000 gallons of fresh water per day. It is also reported that during the World War the manufacture of T.N.T. by the Giant and Hercules powder companies was limited by the available supply of fresh water.

The principal requirement for a factory location is an abundance of good fresh water which can be obtained at a cost no greater than that of pumping through a low head. It has been demonstrated that the waters of the rivers, Suisun Bay and Carquinez Strait are suitable if incursions of salt water can be prevented, and this explains the interest which industrial companies have in the construction of the Salt Water Barrier.

Teredo.

The unusual facilities offered on the shores of San Pablo Bay, Carquinez Strait, Suisun Bay and the lower river channels have attracted many large industries. The water front structures erected by these industries were all built with untreated piling because of the absence of marine activity and the belief that the fresh water discharged by the Sacramento and San Joaquin rivers would be sufficient to prevent the invasion of the various forms of marine borers which inhabit salt water.

San Francisco Bay proper is said to have been subject to marine borer activity since records have been kept although, according to tradition, the ship worm was not known in Spanish days and did not become a menace until the period following the gold rush in 1849. Prior to 1914 the only ship worm observed by biologists was the Xylotrya. This borer, together with the Limnoria, were the ones which had caused the principal damage in San Francisco Bay prior to that date.

Early in 1914, following two years of low run-off, the activity of marine borers was noticed in the dykes of the Mare Island Navy Yard, at a dock between Crockett and Vallejo Junction, and at a dock located at Oleum. This attack appeared to be sporadic like the earlier ones, but in 1917 attacks by the same shipworm, identified as a teredo, which has caused so much destruction in European waters for centuries past, again appeared in the vicinity of Mare Island and during the following years spread very rapidly and increased in severity. In the latter part of 1919 the attacks had progressed to such an extent that parts of waterfront structures and, in some cases, whole docks began to fail. In 1920 these failures assumed such proportions and became so frequent as to present a critical situation. As a result the San Francisco Bay Marine Piling Committee was appointed and a survey of the whole problem was definitely begun in September, 1920. The committee made three reports, one dated August, 1921, one dated January 15, 1922, and the last on February 20, 1923. These reports contain the most authentic information on the subject and they will be quoted freely in this report.

In the upper bay system, including Carquinez Strait and the immediately adjacent waters of San Pablo Bay, many pile structures, although built of untreated timbers, had stood from 30 to 40 years. Untreated piles at Port Costa, driven prior to 1870, remained untouched by teredo although several periods of low rainfall had intervened which might have permitted invasions of salt water into the upper bays and delta region. The destruction since 1917 has been swift. Every water front structure as far upstream as Antioch has been attacked by teredo. It was estimated by the committee that during the two years preceding their first report the damage done by the marine borers in the area described amounted to more than $15,000,000 in terms of replacements and repair.

The survey brought out the fact that in 1920 certain forms of marine life had gone up the Sacramento River as far as Walnut Grove and that these same forms were luxuriantly thriving in piling attacked in Carquinez Strait as salt water had invaded that territory. It was concluded that barnacles and hydroids precede teredo and that the occurrence of young mussels on marine piling is a danger sign to look out for teredo.

Teredo navalis, barnacles and mussels made their appearance in the wharf of the Mountain Copper Company off Bull's Head Point in the winter of 1920, but they were exterminated by the flood waters of April and May, 1920. In their 1921 report the committee stated that it was highly probable that the bay system was then thoroughly seeded with teredo and that even in normal years there is a possibility of its invading the territory above Carquinez Strait with sufficient effect to cause some damage.

New, untreated piles driven in April, 1921, in 36 feet of water at Crockett, were attacked so heavily, especially at the mud line, as to be broken off in December of that year. Another pile driven in the latter part of January, 1920, and pulled $3\frac{1}{2}$ months later in May, showed a penetration by teredo of two inches. In a redwood salt water tank on the ninth floor of the California–Hawaiian Sugar factory at Crockett, teredo penetrated the lumber two inches in eight weeks in July–September, 1920.

After the teredo attack of 1920 the Southern Pacific Company is reported to have spent about \$2,000,000 at Benicia and Port Costa in replacing untreated piles which had been in place 40 years.

In August, 1924, it was estimated that the Associated Oil Company would have to spend from \$150,000 to \$200,000 before Christmas to repair damage done to their Avon wharf by teredo. On the night of October 29th of that year the wharf collapsed at a time when a large oil tanker was discharging its cargo. The wharf caught fire and before the tanker could get away the fire spread to it. The result was the loss of seven lives, the loss of the tanker and its cargo and the destruction of the wharf, all directly attributed to encroachments of salt water into Suisun Bay bringing with it the teredo.

At the Booth Cannery, at Pittsburg, a 16-inch pile which had been driven at the end of the company wharf in March, 1924, was pushed over in October of the same year by the superintendent of the plant kicking it with his foot. The entire pile had been honeycombed at the mud line.

The principal piling timber in the San Francisco Bay system is Douglas fir brought down from Oregon and Washington. Redwood and blue gum Eucalyptus, although frequently asserted to be immune to borer attack, appears but little, if any, better than other common species.

Teredo enter the wood as minute larvae and leave only a pinhole to mark the entrance. There is nothing to indicate to the casual observer either their presence or the degree of destruction which they have accomplished. A close inspection with a lens is generally necessary to reveal the minute openings in the wood.

The marine borers at work in San Francisco Bay are said to belong to two groups of animals, to the Mollusca and to the Crustacia. The boring mollusks all belong to one family, the Teredinidae. Most of the borers working on the timber structures drill slender tubes into the wood by means of their shells and have a pair of plumose or paddle-shaped pallets near their siphons which serve as plugs to close the outer end of the burrows against intruders. These borers line their burrows with a film of pearly nacre and drill tubes of different lengths up to and even exceeding four feet into submerged or floating wood. They seem to have the boring instinct well developed and continue drilling throughout most of their lives. This family of borers is represented in San Francisco Bay by at least three different species. These are the Xylotrya setacea tryon, the large borer of the Pacific coast; the Teredo diegensis Bartsch, a small species of the California Coast; and the notorious Teredo navalis Linnaeus.

When full grown in the waters of San Francisco Bay, the Xylotrya setacea ordinarily measures as much as two feet in length and has a diameter at the head or shell-bearing end of three-fourths inch. Tubes over three feet in length and seven-eighths inch in diameter have been found in old piling on the San Francisco waterfront. The most upstream location reported by the committee in 1921 was at Crockett, on Carquinez Strait, where a few large individuals were found in piling of the California–Hawaiian Sugar Refining Corporation which was heavily infected by teredo. It does not appear to adapt itself readily to the brackish water as does teredo navalis.

Teredo diegensis is the smallest molluscan borer found in the bays and is most restricted in distribution. It is of little interest in this investigation for the reason that it does not appear to have taken part in the destruction of piling in the upper bay in recent years. It usually has a length of from one to four inches. The largest tube found by the committee was about six inches long and five-sixteenths inch in diameter.

Teredo navalis is known as the "Pile-worm of brackish waters," and is the same as found in the dikes of Holland. It is the medium-sized species of the three molluscan borers occurring in the San Francisco Bay system. When full grown it is generally from six to eight inches long, and has a diameter at the head end of from one-quarter to three-eighths inch. The whitish, worm-like body lies in the burrow which enters the pile horizontally and generally turns downward and expands within one or two inches to a nearly uniform diameter throughout the rest of its course. The head, or shell bearing end, is at the bottom of the burrow. The posterior end of the body is at the mouth of the burrow where the mollusk protrudes its two siphons through the minute pore. Water for respiration and carrying food enters one of the siphons while chips from the drilling and the excreta pass out through the other. These siphons are drawn in and the mouth of the hole closed by two pallets at the least disturbance. It is probable that teredo navalis reaches sexual maturity in the first year of its growth. It is believed to be short lived, only a few surviving the winter. A heavy death rate has been found in the autumn associated with decreasing salinity.

Teredo navalis spreads very rapidly. It has been estimated that the number of ova produced in the larger females approximates 2,000,-000. During its larval life the young teredo may be carried by tidal currents for long distances, hence the ease with which it invades new territories. The length of larval life is sufficient to permit even a transoceanic transfer in the tank of a steamer. They are supposed to be capable of swimming about for at least a month during which time they develop a foot and a set of bivalve shells. They are then ready to settle down on the wood, and transform into the boring adult type.

The point of most severe attack on a pile is at the mud line, although teredo will work at any point below mean tide line.

The factor of salinity is one of fundamental importance in the distribution of teredo navalis. It is clearly a species surviving a wide range of varying salinities and is thus capable of appropriating promptly tidal areas which the ocean is tending to invade. The lethal action upon teredo of brackish or fresh water is a function of two variables, the salinity (or lack of it) and the length of time between recurring periods of higher salinities which permit resumption of more normal functioning. A teredo might be able to survive completely in repeated exposure to fresh water, provided ocean water of sufficient salt content was available between times, which explains their survival through the winter months of high river discharge at points above Carquinez Strait. The effect of low salinity on teredo navalis is summarized on page 367 of the Third Annual Progress Report of the San Francisco Bay Marine Piling Committee as follows:

> Experimental observations on the activity of teredo navalis in various salinities, as manifested by the extension of the siphons, indicate that the organism is normally active in salinities as low as 9 parts per 1000, and below this point the activity decreases with decrease in salinity. Below a salinity of 7 parts per 1000, the proportion of active individuals decreases very rapidly until at 3 parts per 1000 no teredos are extending their siphons.
>
> The average lethal salinity for teredo navalis has been determined experimentally as 5 parts per 1000.
>
> Teredos obtain some protection from water of a salinity below the lethal (5 parts per 1000) by stopping the mouth of the burrow with the pallets and thus preventing the entrance of water from the outside. At the same time, a supply of salt water is held within the burrow. It is probable that the salinity of this retained water is gradually diluted by diffusion through the wood and that the organisms are finally killed in this way. If, however, the salinity rises above 5 parts per 1000 before the salinity of the retained water becomes diluted enough to kill the organism, it will be able to obtain a fresh supply of water and survive for a longer period.
>
> A period of 33 days below 4 parts per 1000 salinity has destroyed 90 per cent of the teredos in piles at Crockett. Immediately prior to the above period an interval of 20 days below 5 parts per 1000 salinity occurred, but the record shows frequent peaks of 4 parts per 1000 salinity or more during this interval. It is probable that the salinity actually rose to 5 parts per 1000 at some time during the days on which these peaks occurred, since the water samples were not always taken at the major tide. Thus it seems reasonable to measure the period of survival as the period below 4 parts per 1000 salinity, i. e., 33 days. The period necessary to destroy the surviving 10 per cent of the organisms is impossible to determine definitely at present.
>
> Teredos show remarkable recovery from sudden changes of salinity in aquaria. They have also survived great changes in the salinity of the bay water during the past season. (1921–1922.)

The salinity referred to in the above quotation is based upon the formula $S = 1.8050\ Cl + 0.030$. It gives approximately the proportion of ocean water in Carquinez Strait water used in the experiments, but includes also the saline content of the stream and seepage water.

Among the conclusions reached by the committee are the following:

> Marine borers are very active in San Francisco Bay and connected waters, and in places where their attack is severe will destroy untreated piling in as

short a time as six to eight months. In other places the untreated piling may last from two to four years.

The data in hand indicates that it is fair to expect creosoted Douglas fir piling in San Francisco Bay to give a life of 15 to 20 years under present conditions and practice. Certain piles are of authentic record from the Oakland Long Wharf which were sound when removed after a service of 29 years. Poor treatment, or damage to creosoted piling by careless handling, rafting, storage or construction, will materially reduce the life which might otherwise be rendered by such piling.

Records of Salinity.

In general the salinity of the bay waters increases with depth; decreases with distance from the Golden Gate; and decreases as the discharge from Sacramento and San Joaquin rivers increases. The salinity at any point in the bay system varies from year to year, being relatively low in a year of large run-off from the Great Central Valley and relatively high in a year of small run-off.

The invasion of salt water into the delta region is serious only in years of deficient run-off but the salt menace has been growing worse during the past few years. In 1916 the State Water Commission took up the study of salinity of the rivers and delta channels but the work was interrupted during the World War and was not again taken up until the dry season of 1918–19 brought the subject forcibly to the attention of the public. In 1920 a combination of an unusually dry year and large diversions for the irrigation of crops in the valleys brought about a deeper invasion of salt water into the delta region than ever before known. Nineteen hundred and twenty-four was the most severe year of record. The discharge of the Sacramento at Red Bluff was the lowest of any year of the past 30. At Sacramento the discharge was less in 1920, but in 1924 the peak of flow was reached earlier in the season. Salt water appeared in the delta early in June, 1924. On June 1 of that year the concentration at Collinsville was as heavy as on July 22, 1920. In 1924 the maximum concentration of salt in the delta was greater and occurred earlier in the season.

In the past, as at present, salt water invaded the lower river and delta channels in years of low rainfall and run-off. As noted in Chapter I, the water at the mouth of the rivers was brackish in 1841. It is said that trouble from salinity was experienced in 1850–51, 1870–71 and in 1912–13.

Many data are available relative to the salinity of the upper bay waters since salinity became a menace to industries and agricultural interests. One of the most interesting records is that kept by the California and Hawaiian Sugar Refining Corporation in connection with their refinery at Crockett. It shows the extent of the invasion of Suisun Bay and the rivers by salt water for each year since 1908.

Fresh water for use in their refining process is obtained by water barges which are towed upstream until water of the desired quality is reached. The record kept includes the distance above Crockett which it was necessary to go on each trip to obtain the water and the salinity of the water obtained. The barge is filled when the samples taken show a salinity of not more than 7 or 8 parts of sodium chloride (salt) per 100,000 so that the data furnish an excellent record of the distance brackish water of that concentration invaded the upper bay and river channels. When the water in Carquinez Strait is fresh enough it is pumped direct to the plant from the refinery dock. On Plate 9-1 is shown the average distance above Crockett traveled each month, since 1908, by the barges to obtain suitable water. The record does not show the distance upstream that it would have been necessary to go in all years, for in recent years, when the distance is too great, water is obtained from a storage reservoir in Marin County, west of Crockett. It will be noted that it was necessary to go above the mouth of the rivers every year from which it may be concluded that the whole of Suisun Bay becomes brackish during the fall months of each year.

The most complete record of salinity in the delta region is that kept by the State Department of Public Works, Division of Water Rights. This record, for 1919 to 1924, inclusive, is shown in graphical form on Plate 9-2 while that for 1925 is shown on Plate 9-3. The location of the stations at which observations were made is indicated on Plate 9-4. It will be noted on Plates 9-2 and 9-3 that the approximate discharge of the Sacramento River at Sacramento and of the San Joaquin River at Lathrop, or Vernalis, is shown.

As indicated on Plate 9-5, taken from the State Water Supervisor's report for 1924, maximum and minimum salinity at Antioch, on the San Joaquin River, and at Rio Vista on the Sacramento, occurs at about the time of slack tide following high and low tides. The salinities shown on Plate 9-2 represent the maximum as the samples were, in general, taken about two hours after high tide.

In his 1924 report the State Water Supervisor says:

> Freeport and Lincoln Highway bridges were the farthest upstream stations maintained in 1924 on the Sacramento and San Joaquin rivers, respectively. Tests at Freeport showed a maximum of 15 parts of chlorine per 100,000 on August 16 and the maximum at Lincoln Highway bridge was 14 parts on September 6.

The upper limits in the delta region reached in 1924 by salt water in proportions generally believed to be dangerous for irrigation use (100 parts of chlorine per 100,000) are shown on Plate 2-5. The upper limit on the Sacramento River which, it is estimated, would have been reached had conservation measures not been adopted is also shown. It will be noted that it lies just below the town of Freeport.

In a letter from Mr. Geo. A. Atherton, General Manager, California Delta Farms, Inc., dated November 22, 1924, he says:

> In 1924 the area (in the delta) that was affected extended very much farther east (than in 1920) and the salt situation was very serious and included all of the lands west of Old River (See Plate 2-5) north of the territory about Byron and, on the east side of Old River, included Victoria, Woodward, Bacon, Mandeville and Medford islands, the upper and lower Jones Tract and McDonald Tract, and, on the north side of the San Joaquin River, included Bouldin Island, Venice Island, Empire Tract, King Island, Reclamation District No. 548 and the lower portions of Staten Island and, to a lesser degree, adjoining lands farther east, but on these tracts the saline content was 100 parts chlorine or more to 100,000 parts of water and gradually increased in content, of course, farther down the river.
>
> Most of the domestic water supply in this territory is obtained from the river. In 1920 there was no time when the river water was not generally

used for domestic purposes. During this year, 1924, the situation was so bad that in some instances the stock would not drink the water and all of the tenancies brought their household drinking water from Stockton by boats.

On August 12, 1924, the maximum salinity at Rio Vista was 608 parts chlorine per 100,000. The salinity considered dangerous for irrigation, 100 parts of chlorine per 100,000, was found at Howard Ferry on Steamboat Slough, above Rio Vista, on August 5, 1924.

According to the records of the Great Western Electro-Chemical Company the maximum salinity reached since their plant was established at Pittsburg in 1916, occured in August, 1924. The high points in other years were reached in the month of September, 3480 parts chlorine per million in 1921, and 2425 parts per million in 1922, which represents the highest days of the entire year. The average salinity of the water at Pittsburg during the low water period expressed in parts chlorine per million, is as follows:

Year	*June*	*July*	*August*	*September*	*October*
1921	62	262	1,395	2,140	824
1922	33	97	1,177	1,740	464
1923	55	256	752	----	---
1924	5,900	8,120	11,450	8,410	4,250

The figures are as they appear in a paper presented at the 1924 Sacramento-San Joaquin River Problems Conference, page 89 of the Proceedings. The samples were of the "bleed" type, taken over 24 hours each day. It will be noted that the average salinity for three months in 1924 was approximately half that of ocean water.

Some very interesting data are shown on Plates 9-6 and 9-7. Plate 9-6 consists of a group of graphs showing:

(a) The salinity of bay water at the Southern Pacific ferry slips at Benicia and Vallejo Junction at high and low tide, and at the surface and bottom, in 1920.

(b) The relative salinity of water in 1920 at six stations, Martinez to Walnut Grove, samples of which were taken at the surface at high tide.

Plate 9-7 shows the relative salinity of bay water in 1921 at eight stations along the water front from Pittsburg to Tiburon. The depth, and stage of tide at which the samples were taken, were not ascertained but, in any event, the curves show the relative salinities at the various stations.

The salinity, as shown on Plates 9-6 and 9-7, is not expressed in terms of chlorine but in terms of "salinity" used in the San Francisco Bay Marine Piling Survey from which the graphs are reproduced. This "salinity" represents the oceanic portion of bay waters only, and neglects the stream and seepage, or land water, contributions, since marine borers, the subject of the report, are only adapted to the normal saline complex of sea water. The "salinity" in parts per 1000 is derived from the formula $S = 1.8050 \, Cl + 0.030$. See page 99 of the committee report dated August, 1921.

In his study of the salinity situation as it affected the water supply for the town of Benicia, Mr. J. A. Wilcox found that a close relation exists between the salinity of the bay water at Benicia and the height of the Sacramento River at Sacramento. It was determined that when the river at that point is above the 11-foot gage height fresh water can be obtained from the bay at the Benicia city dock for at least an hour or two each day, or for sufficient time to load the water barge tied up there. At this minimum gage height at Sacramento Mr. Wilcox, in his report of February, 1921, says that there will be a few days each month during unfavorable tide conditions (small run-out) when no fresh water is available at Benicia. As the river rises at Sacramento above the 11-foot gage the length of time of fresh water at Benicia is said to increase and is less affected by tide conditions.

Following this line of thought, a study was made as a part of the investigation of the Salt Water Barrier to develop the relation between the combined discharge of the Sacramento and San Joaquin rivers and the salinity of bay water at various points. Samples of bay water were taken each month beginning at the time the rivers were high in February, 1925, and ending the following February. The stations selected were the Mountain Copper Company wharf off Bull's Head Point, at the lower end of Suisun Bay and the Standard Oil Company wharf at Point San Pablo, located at the lower end of San Pablo Bay. The object was to secure a record covering one full year which might be considered normal, or at least typical. It was believed that a fairly good idea of the advance and retreat of salt water up and down the bays could be obtained by plotting the monthly data on the curve of continuous record kept by the Great Western Electro–Chemical Company at Pittsburg and the weekly record kept by the Mountain Copper Company at Bull's Head Point, which latter two, for all practical purposes, determine the general shape of the curves at the sites being considered for the Salt Water Barrier.

In general, the samples were taken at the time of slack water following higher high and lower low tides. In July, September, November and December, 1925, and in January and February, 1926, the tides sampled were those having the maximum range for the month. Samples were taken at the surface and at each 10 feet in depth to the bottom in order to determine the increase in salinity with depth and to arrive at the average salinity in a vertical section. At slack water following higher high tide the salinity should be at its maximum while the minimum should occur at slack water following lower low tide. The average of the two should be the approximate average for the day on which the samples were taken. In addition, gage readings were recorded at short intervals between the time of high or low tide, and the time the samples were taken. The samples were analyzed for chlorine in the laboratory at the University of California, College of Agriculture, Division of Plant Nutrition, under the direction of Mr. P. L. Hibbard. The results are shown on Plates 9-8 and 9-9. The salinity at Collinsville on July 7, 1925, is also shown on Plate 9-9.

At Pittsburg the water samples are taken at the pump house of the Great Western Electro-Chemical Company. The pump intake is located approximately 75 feet from shore and 5 feet below the elevation of mean low tide in the same position that it has occupied for several years. Mr. Schedler advises that the samples are a bleed on the pump line so arranged that the water drips into a barrel 24 hours each day for all water pumped into their tank. Their method, however, is to pump as much water as possible at low tide, although at times it is impossible to obtain all water required at the low stage. Mr. Schedler states in a letter of June 25, 1925:

> I believe that our sample represents very closely the average of the water in front of our plant during the 24 hours of the day.

The drip sample is analyzed once each week and is reported in parts chlorine per million. (Determined as chlorides.)

The Mountain Copper Company samples at Bull's Head Point are taken at weekly intervals at high and low tides, one being obtained at the surface and one from the bottom where the depth below mean tide level is about 27 feet. The salinity was reported in terms of "salinity" as used in the San Francisco Bay Marine Piling Survey but on Plate 9-8 the figures have been reduced to parts chlorine per million in order that all of the graphs be on the same basis for comparison.

By reference to the graphs, Plate 9-8, it will be noted that the salinity in 1924, as shown by the Mountain Copper Company records, was much more severe than in 1925. This is further borne out in the State Water Supervisor's Report for 1925 from which the following data were extracted:

COMPARISON OF MAXIMUM SALINITY, 1924 and 1925, IN PARTS CHLORINE PER 100,000

Station	1924 Amount	1924 Date		1925 Amount	1925 Date	
O. & A. Ferry	1345	August	28	762	September	26
Collinsville	1150	August	16	448	September	6
Emmaton	802	August	6	136	September	4
Three-Mile Ferry	692	August	30	81	September	6
Rio Vista	608	August	12	21	September	2
Isleton	310	August	14	12	September	16
Antioch	1080	August	20	356	September	4
Jersey	708	August	30	81	September	6
Webb Pump	414	September	6	24	September	4
Central Landing	288	September	24	10	September	2
Medford Pump	236	September	26	19	September	19
Ridge Pump	126	September	16	35	September	2
Middle River	186	September	30	13	September	10
Holland Pump	308	October	4	18	September	22
Mansion House	148	October	12	11	September	16

In order to secure more complete information as to the relation between the inflow from the rivers and the salinity of the bays, the State Water Supervisor established early in February, 1926, four new salinity stations on Suisun and San Pablo bays which will be maintained throughout the year. The stations are located at Bay Point, Bull's Head Point, Oleum and Point Orient. The data to be obtained should be of great value in future studies of the proposed Salt Water Barrier.

Control of Salinity.

It has been demonstrated that Suisun Bay and Carquinez Strait can be kept clear of salt water if fresh water is available in large quantity as for example, during periods when the Sacramento and San Joaquin are in flood. Also it has been found that a combined river discharge of about 3500 second-feet as measured at Sacramento and Vernalis sufficient to prevent encroachments of salt water into the delta region if this amount of water is allowed to flow into Suisun Bay which, of course, suggests the storage of flood waters in mountain reservoirs to be released during the low water period in amount sufficient to keep the flow into Suisun Bay at or about 3500 second-feet. This phase of the problem was discussed briefly in Chapter II and will not be elaborated upon here as it is outside the scope of this report.

A great deal has been accomplished through cooperation of water users in the Great Central Valley and it is certain that continued and increased cooperation will be necessary unless storage reservoirs, or the Salt Water Barrier, are constructed. The success of cooperation was effectually demonstrated in 1920. When it was foreseen that there was to be a severe water shortage, and that crops would be lost unless the most economic use of the available water was practiced, an Emergency Water Conference was held at which the appointment of a Water Master was decided upon. The respective rights to divert water from the rivers having never been determined, it was mutually agreed to place the division of the water in the hands of the Water Master. On page 164 of the 1923 Proceedings of the Sacramento River Problems Conference, Mr. Paul Bailey states:

> The plan followed was to effect reductions in the use of water as exigencies required, on the part of those who could best spare it. By keeping close contact with field conditions, and through the excellent cooperation of the project managers, a maximum of about 24 per cent reduction in the use of water, compared to that at the same time in 1919, was effected during the most critical 10 days of the season and this without damage to crops.

In 1924 conditions were even more severe than in 1920 and the policy of strict economy in the use of water was again adopted. By the middle of July, 1924, the discharge of the Sacramento had fallen off to 700 second-feet at Sacramento and at the same time the San Joaquin had dropped at 400 second-feet. Salt water had invaded the delta channels in quantities to make irrigation dangerous below Isleton and Howard Ferry on the Sacramento and the Webb tract in the San Joaquin area. (See Plate 2-5.) Beginning about July 25th, cuts were made in diversions of upriver irrigators and other economies were put into effect. The results accomplished are summed up in the Water Supervisor's Report for 1924 as follows:

> These measures were reflected very soon in an increased flow past Sacramento to the delta. From the lowest discharge of 700 cubic feet per second the flow increased nearly 50 per cent to an average of 1020 during the first week of August, and to 1500 cubic feet per second by the time the rice water drainage commenced in the latter part of August. During this time the inflow at Red Bluff remained practically constant. At Howard Ferry, on Steamboat Slough, from a chlorine content of 100 parts per 100,000 on August 5th, there was a drop of 42 parts on August 20th and to 10 parts by September 1st. From a situation where the salinity was menacing irrigation as high up as Walnut Grove, Sutter Island and Upper Ryer Island, such relief was obtained that by the latter part of August, irrigation could be safely carried on above a line through the southern end of Staten, Tyler, Andrus, Grand, Ryer and Prospect islands.

The water supervisor estimated that had no conservation measures been adopted salt water would inevitably have reached proportions in the Sacramento portion of the delta dangerous to irrigation practically to Clarksburg and the northern boundaries of Reclamation District No. 999. (See Plate 2-5.)

Some are of the opinion that it will not be necessary to allow the estimated 3500 second-feet of water to flow into Suisun Bay to act as a natural barrier against invasions of salt water and argue that if the water required for irrigation purposes in the delta is permitted to flow to the delta there would be no salinity problem there. The fallacy of this argument should be evident from the discussion of the upstream progression of salt water contained in the first part of this Chapter. Even were it true that the problem in the delta could be solved in this manner the industries located along the shores of the upper bays would receive no relief whatever through the adoption of the plan.

In considering the control of salinity in the reservoir to be created through construction of the Salt Water Barrier we are confronted with the problem of controlling the entrance into the reservoir of salt water through the ship locks and as leakage around the flood gates. Leakage past the floodgates can be prevented by maintaining the water surface above the barrier at a higher elevation than below but in any event the entrance of salt water by this route would be comparatively small. The question then is: Can salt water work its way through the ship locks in sufficient quantity to vitiate the purpose of the Salt Water Barrier, or diminish its effectiveness? The amount of water required in the operation of the barrier and the probable amount of salt water which will find its way into the fresh water reservoir above it are dealt with in Chapter X but it remains to find ways of controlling the interchange of fresh and salt water in order to avoid unnecessary contamination of the fresh water lake. The means of controlling the entrance of salt water will have been recognized in the designs and discussion contained in Chapter IV.

It has been proven, notably on the Panama Canal and at Lake Washington Ship Canal, Seattle, that where ship locks separate bodies of fresh and salt water the salt water tends to climb through the locks even though the water surface on the fresh water side is maintained at a considerably higher elevation than on the salt water side. Ship locks therefore cause salt water to invade areas that never before were salt unless provisions are made to control it. At Miraflores Locks on the Panama Canal, salt water climbed to Miraflores Lake, some 50 feet above sea level. At the Lake Washington Ship Canal locks the surface of the fresh water lake is maintained about 25 feet above extreme low tide and 7 feet above extreme high tide.

Mr. W. M. Meacham of Seattle, who has made a study of methods for keeping salt water out of lock controlled waterways, concludes that:

> A low lift lock will pass a greater amount of salt water at a lockage than a high lift lock of the same size, the reason being that there is less fresh water taken in and, therefore, less dilution. A lock will also pass more salt water when the tide is high than when low. On account of the salt water from a low lift lock having a higher specific gravity than that from a high lift lock, it travels along waterways faster.
>
> During long, low-water seasons, or periods when there is little or no water furnished from the watershed above, a lock is most effective in causing large areas of salt infected water

A sufficient volume of water, either stored or continuously supplied from the watershed above, is necessary for keeping salt water out of lock controlled waterways.

The flow of salt water through the ship locks, and the resulting contamination of the fresh water lake above at the Lake Washington ship canal, furnishes an excellent example of what may be expected at the Salt Lake Barrier since conditions are much the same. Exhibit 23, which will be found in the envelope at back of Volume II of this report, is a published article on "The Control of Sea Water Flowing into the Lake Washington Ship Canal," by E. Victor Smith and Thomas G. Thompson. It is particularly interesting because it contains a summary of the results of eight years of experience in the operation of the ship locks and of investigations of their effect upon the salinity of the lake above. As described in the pamphlet, there are two ship locks in operation. Authorities at the locks advise that in 1923 the larger one was filled and emptied 8044 times and the smaller one 19,334 times (See Table 6-34). The article (Exhibit 23) shows how completely salt water replaces the fresh water in the locking operation when the lower gates are opened to Puget Sound and how the salt water escapes into the fresh water lake when the upper gates are opened. It brings out how the fresh water lake will be contaminated if proper control is not provided; describes the method adopted at the Lake Washington locks for controlling salinity, and shows how readily the lake is cleared of salt water when fresh water is available for that purpose. The authors' conclusions 2 and 3 are of particular interest as they indicate that salt water finding its way into the fresh water lake through the ship locks can be removed quite efficiently through the use of a large, deep salt water sump above the locks and by drawing off the salt water from the bottom of this sump. The plan resorted to at the Lake Washington locks is shown on page 6 of the pamphlet. The plan adopted for the Salt Water Barrier is shown on the preliminary designs and is discussed in Chapters IV and X of this report.

The amount of river water required to keep the reservoir back of the Salt Water Barrier fresh is of vital importance. The amount can not be predicted accurately at this time for the reason that data sufficient for this purpose are not available. It is possible, however, that conclusions based on an extensive study of the San Francisco Bay System would be no more reliable than those drawn from the experience gained in the operation of the Lake Washington ship canal locks. With this possibility in mind an inquiry was addressed to the Army Engineer's office at Seattle, relative to the amount of fresh water required to keep the lake above those locks fresh. The letter referred to and Colonel W. J. Barden's reply, dated July 20, 1925, will be found as Exhibit 24. The exhibit supplies some very valuable data. Not only are the conclusions stated pertinent to the proposed Salt Water Barrier but a great deal can be learned about salinity above the locks, and its control, by a close study of the accompanying map and tables. While the conditions are not identical at the two places they are analogous, considering the Salt Water Barrier built at the Army Point site. The area of Suisun Bay is approximately 32,000 acres in comparison with 25,000 acres as given for Salmon Bay, Lake Union and Lake Washington. By inspection of the profile of the Lake Washington ship canal on page 5 of Exhibit 23, it will be noted that there is a "hump" in the bottom between the locks and Lake Union similar to Middle Ground shoal in Suisun Bay. On page 3 of the same exhibit it is stated that the depth across this "hump" is 31 feet. If the proposed San Joaquin River and Stockton channel is constructed a channel depth of 26 feet at mean lower low water will, no doubt, be provided through Suisun Bay, and if the water surface of the fresh water lake above the barrier is maintained 2.5 feet above mean sea level the resulting depth across Middle Ground shoal will be about 32 feet, or 29.5 feet if the water surface is permitted to drop in the late fall to mean sea level.

The deep channels of the lower Sacramento and San Joaquin rivers will act as a secondary salt water sump or trap, much as Lake Union does, in case some salt water does get past Middle Ground shoal. (See statement near top of page 6, Exhibit 23.)

An examination of the salinity tables which form a part of Exhibit 24 will show that the concentration decreases with distance from the ship locks and in this connection the advantage would lie with the Salt Water Barrier for Suisun Bay is about twice as long as the Lake Washington ship canal. Also, it will be seen that salinity increases with depth; that it is greater in the fall than in the spring; and that in 1924–25 it gradually increased at practically all of the stations until November and then decreased very noticeably in December, and until February, when it again started to increase. The sudden drop from November to December was undoubtedly due to the discharge through the lock culverts from November 10th to 25th after a long period of no discharge of lake water with the exception of that passing through the salt water conduit.

An outstanding feature of the salinity table, Exhibit 24, is that the salt water remaining above the ship locks in the spring, after the flushing accomplished as a result of the winter rains, is confined principally in Lake Union at a depth greater than 30 feet which is about the controlling depth between the locks and Lake Union. Attention is also called to the salinity of the water at the outlet of the salt water discharge pipe before and after a lockage, and to extreme variance in the salinity at top and bottom within the ship lock. The very high salinity of 10,809 at depth of 55 feet is probably the result of salt water being trapped in the lock behind the upstream lock gate sill. This sill is at elevation —12, 37 feet below the water surface in the fresh water lake, in comparison with the 55-foot depth at which the sample was taken.

Features of the Salt Water Barrier Proposed for the Control of Salinity.

The object is to remove any salt water getting past the barrier as quickly and quietly as possible. The general type of barrier proposed, although radically different from those considered in earlier discussions, was designed with the belief that it will more nearly accomplish the desired result than any other type. Another type might have less first cost but unless certain principles are adhered to the purpose of the barrier will be partially defeated.

A large gate area is required to pass the floods from the Great Central Valley. In designs previously proposed for the Salt Water Barrier wide shallow gates were suggested and, in fact, the argument has been advanced that a wide site for the barrier must be selected in order that length sufficient to mount these shallow gates on the crest of the barrier would be available. In the design proposed herein deep gates have been adopted with their sills either 50 or 70 feet below mean sea level in all cases. The type of gate proposed is one opening upward from the bottom sill rather than one which is lowered to pass the flood.

It has been shown that the heavier salt water seeks the deeper channels and that, to prevent mixing of the salt and fresh water, disturbances must be avoided.

This suggests the necessity for a broad, deep sump located in a position to trap all salt water that finds its way into the fresh water lake with provision made for drawing off the salt water settling to the bottom of this sump. In all of the preliminary designs, where a deep sump does not exist naturally it will be noted that the sump, with bottom gently rising away from the barrier, has been provided adjacent to the principal source of salt water invasion (the ship locks) in fulfillment of the first requirement and Stoney gates have been provided to satisfy the latter. As the deepest part of the sump, with the exception noted later, is next to the Stoney gates the most concentrated salt water will collect there. During periods when the water surface above the barrier is maintained at, or above, high tide level the salt water can be drawn off by raising the Stoney gates slightly. When the water surface above the barrier for any reason falls below the elevation of high tide the Stoney gates must be closed as otherwise salt water from below the barrier will pass into the fresh water lake through the gates. Under these conditions salt water collected in the sump should be gotten rid of by raising the Stoney gates slightly at low tide when the head will be sufficient to "squeeze out" the salt water unless the water in the fresh water lake is lowered considerably below mean sea level, but this is not contemplated.

The exception mentioned above occurs in the designs in which 50-foot by 60-foot flood gates are shown. In this case the bottom of the salt water sump at the upstream end of the ship locks is at elevation −55, more as an extra precaution than a necessity. It is probable that the salt water from the locks will be deflected into the larger sump above the flood gates but that settling into the smaller and deeper sump would be pumped back to the salt water side through the conduit provided for that purpose.

In operating the Stoney gates to rid the sump of salt water it will be best, but perhaps not ordinarily necessary, to open all of them very slightly rather than only a few of them a larger amount, for a large volume of water should not be drawn from the sump at any one place or from a small area. In this connection it has been found that the salinity of the water at the outlet of the salt water siphon at the Lake Washington ship canal locks is less than the mean salinity of the water at its intake. Tests showed that the siphon was drawing in some of the fresher water from above the inlet. Velocities in the sump must be kept low for, otherwise, the currents set up would produce an undesirable mixing effect.

It is believed that from this discussion it will be evident that shallow gates mounted on top of a barrier structure would be of little value as a means of ridding the lake above of salt water during the low water period. Other openings at the bottom of the lake, or pumping, would be necessary unless the special type of ship lock, described in Exhibit 25, was adopted. If low openings were provided they should be made large since the inefficiency of small openings has been demonstrated. If the salt control openings were made large their cost would tend to offset any saving which might result through the use of shallow floodgates.

It is believed that the Stoney gates will be very effective in flushing salt water out from above the barrier when there is fresh water available for the purpose, since all of the water will be drawn out from the bottom of the lake where the salt water tends to collect. As designed, the control works at the Salt Water Barrier should be much more efficient than those in the Lake Washington ship canal. There the flood waters are discharged over the top of an ogee dam so that there is a tendency for the fresh water to float on top of the salt water and escape over the top of the dam with resulting inefficient flushing. The lock culverts in those locks are used as much as possible to avoid passing flushing water over the ogee spillway but the culverts are not at the bottom of the sump where they should be to draw off the water of highest salinity. The salt water siphon was installed as an afterthought and, although it serves its purpose well, it is rather small and draws its water all from one spot in the sump. Also, the sump is too small. The conclusions stated in Colonel Barden's letter, Exhibit 24 relative to improvements which are suggested to secure higher efficiency of the control works at the Lake Washington ship canal locks are pertinent.

By reference to the designs of the Salt Water Barrier it will be noted that in all cases the bottom of the salt water sump and the Stoney gate sills are below the sill of the upper lock gates and in this respect the design with the larger Stoney gates is to be preferred for the deeper the sump, the better. It will also be noticed that the lines of excavation are laid out with easy curves and the bottom should slope gently toward the sump above the Stoney gates.

In order to reduce the entrance of salt water, provision has been made for sealing all floodgates with water stops. The lock filling conduits have been placed with their inlets as low as possible so the salty water, insofar as practicable, will be used in filling the lock. As a precaution against failure of the Stoney gates to relieve the salinity above the barrier in the event the water surface there should be allowed to fall below mean sea level, a salt water relief conduit six feet in diameter with inlet about 10 feet below the upper lock gate sill, is provided in one of the lock walls. As described in Chapter IV this conduit is connected with pumps capable of drawing off large quantities of water.

Since the volume of salt water entering the fresh water lake at each lockage is dependent upon the size of the ship lock, locks of various sizes have been provided. The smaller vessels should, of course, use the small lock. Intermediate gates have been added in the larger locks in order that use of the full length of the lock may be avoided if not required to accommodate the length of a vessel. Although not indicated on the drawings, it is proposed that lock gate leaves split horizontally at elevation —15 shall be installed in the larger locks to avoid discharging of a full lock of salt water into the fresh water lake unless necessary to open the whole lock gate to accommodate vessels having a draft in excess of that provided by the half gates. It will also be noted that the fish ladder has been designed to prevent the passage of salt water through it to the fresh water side of the barrier.

The layouts shown on Plates 4-18 and 4-20 may have some advantages over the others but considerable study would be required before it could be concluded that the advantage of having the ship locks separated from the floodgates would offset the advantage of having the large sump next to the locks where the salt water could settle more quietly to the bottom. It would, of course, be safer for vessels in time of extreme flood from the rivers to have the ship locks away from the high velocities through the flood channel and it is possible that the salinity could be controlled even more efficiently. In the design shown on Plate 4-20, there are only two Stoney gates provided adjacent to the ship locks upon the assumption that they would be sufficient to draw off the salt water from above the locks. If they were not adequate the salt water would proceed up the ship channel through Suisun Bay unless it should be deflected to find its way down the sloping bottom of the flood channel to the flood gates where it could be drawn off. In this respect the design shown on Plate 4-18 is preferable to that shown on Plate 4-20 as will be evident from an examination of both.

In a case like that shown on Plate 4-33 it is probable that a part of the salt water passed through the ship locks will find its way into the deep hole above the barrier although an effort is made to direct its flow into the sump above the Stoney gates but it is probable that, eventually, the deep hole referred to will be silted up. In any event the salt water there can do not harm, for it would be trapped there much as salt water flowing up the Lake Washington ship canal is trapped in Lake Union. In the designs shown on Plates 4-37 and 4-47, the salt water entering through the ship locks is purposely deflected into the deep hole above the barrier.

Effect of Elimination of Salt Water Upon Sewage.

This is a subject outside the scope of this report but is one relative to which some express concern, as evidenced by the following quotation from a letter received during the field investigation:

> The creation, however, of a fresh water lake with a slight current, or with very little, will have a direct effect upon the question of sewage discharge and sewage flow in the river itself. If the sewage flow be retarded, then we will have either a backing up or a raising of the proportion of sewage in the stream to a questionable level. There must, in addition, be con-

> sidered the question of extensive sewage deposits in a body of fresh water of limited area as opposed to that deposit in the same area of water which is salt or semi-salt and subject to tidal flow.

No investigation was made of the effect upon sewage of building a Salt Water Barrier in the San Francisco Bay system but the conclusions reached by the committee charged with the investigation of the feasibility of constructing the Charles River Dam at Boston are interesting since one of the important considerations was that of the effect of the dam upon sewage pollution. The fresh water basin created by the dam is reported to have an area of only 800 acres. Before construction of the dam the estuary was filled with tidal water from Boston harbor. Among their conclusions are the following:

> Fresh water, gallon for gallon, disposes in a normal manner of more sewage than salt water; the tendency of salt water is rapidly to precipitate sewage in sludge at the bottom.
>
> For the proper disposition of sewage in water, it is essential that the water be well supplied with oxygen. This is accomplished by the contact of its surface with the air, and this surface water is carried down by the action of the waves and currents, and especially by the vertical movement caused by changes of temperature. Bodies of fresh, nearly still water, are well oxygenated to a depth of 25 feet or more in ordinary summer weather, and to much greater depths with the autumn cold. No considerable part of the basin, with a permanent level at grade 8 or 9, would be over 25 feet in depth.
>
> Letting in salt water under the fresh interferes with the vertical circulation necessary for oxygenation and the salt water under the fresh soon loses its oxygen if any waste material is admitted to it.
>
> Changing a fresh water basin into a salt from time to time interferes with bacterial, animal and vegetable growths, which effectively aid in taking care of and digesting sewage.
>
> A comparatively still body of fresh water with animal and plant growths will dispose of a considerable amount of sewage admitted from time to time, and will tend to purify itself, even if no more fresh water is added.
>
> Such a body of fresh water will dispose of more sewage if comparatively still than if in motion.
>
> Although the amount of fresh water coming over and through the Watertown dam is found by careful measurement to seldom average less than 70 cubic feet per second for the 24 hours in dry seasons, there is good reason to believe this is sometimes reduced to 30 cubic feet a second, for a month at a time, by storage in mill ponds while turbines are shut down.
>
> Notwithstanding the amount of sewage that enters the basin at present (1903), which our Chief Engineer estimates as equivalent to the constant discharge by a population of from 5000 to 8000 people, including that which comes from the Fens and from the Beacon Street houses, it is the unanimous opinion of the engineers and experts of the committee that a fresh-water basin, owing to its supply of oxygen and large area, would not affect injuriously the health of the inhabitants of the neighborhood.

On page 43 of the report it is stated that:

> The results (of the investigation) are very instructive, and show a decided superiority in fresh water, and a decidedly greater tendency to precipitate a sludge and give off offensive odors in salt water.

And on page 49:

> Fresh water * * * will be better adapted for receiving sewage without causing offensive deposits or offensive odors than either salt or brackish water.

In letter of February 5, 1925, Mr. John R. Rablin, chief engineer, Metropolitan District Commission of the Commonwealth of Massachusetts, states:

> The report of John R. Freeman, chief engineer, which you say you have on file, describes the expected effect of the change from tidal water to fresh water. Judging by general conditions and the use of the basin for bathing and recreation purposes, the condition conforms generally to that predicted by Mr. Freeman in his report.

CHAPTER X

WATER REQUIREMENTS FOR OPERATION OF BARRIER

Outline.

There are seven main sources of loss of fresh water that will accompany the operation of a Salt Water Barrier. Evaporation during the summer months will be one of the largest sources of loss, but a variable amount depending upon the area of water surface above the barrier as determined by the location of the structure, and upon the character of the season. A second loss will be occasioned through the operation of the locks. This loss also will be a variable amount, but not between such wide limits as evaporation. A third loss will occur through leakage around the gates. This factor will be independent of the location of the barrier, depending only upon the periphery of the floodgates and the difference in elevation of water surface on the two sides of the barrier. In addition, fresh water will be required in the operation of the fish ladder, and to supply the needs of industries, municipalities and irrigation. The use of water for irrigation will not be discussed in this report, as it is a subject which properly belongs in the investigation of the water resources of California now being conducted by the State Division of Engineering. However, it is believed that water to supply the needs of irrigation in the delta and on the marshes about the bays, will ordinarily be drawn from natural flow or storage reservoirs constructed in the drainage basins of the Sacramento and San Joaquin rivers, as, otherwise, the water level behind the barrier in a year of low run-off, would be reduced to the extent of interference with navigation and to the point where the control of salinity upstream from the barrier would be difficult, if not impracticable. An exception might be made in a year of severe water shortage when draft from the fresh water lake would be permitted to irrigate crops during the latter part of the season, which, otherwise, would be without water.

The seven sources of loss will be continuous. In addition, it will be found necessary to flush out the whole reservoir at intervals of a year or more, but now impossible to determine exactly. This requirement will be due to the gradual diffusion of encroaching sea water, the accumulation of salts through the ground water return of irrigation water, and contamination due to growth of aquatic plants and the general accumulation of other contaminating agents.

This study is based upon conditions that would exist during seasons of very low run-off like 1919–20 and 1923–24, with storage in the mountains well developed. During such seasons, the run-off from the smaller, uncontrolled streams is lower in proportion than the general average of the seasonal run-off, and it may be expected that practically all the run-off of the main streams will be retained in the reservoirs.

This portion of the report is closely interwoven with the investigations of the Water Resources of California now in progress by the

State Department of Public Works, Division of Engineering and Irrigation, and until that work is farther advanced, it is impractical to draw final conclusions with respect to the water supply for the barrier. For lack of complete data upon which to base the study, it is necessary to make certain assumptions which may require modification as a result of more complete information becoming available. In general, however, modification of the assumptions should not greatly modify the findings of this chapter.

Evaporation.

True evaporation from the surface of a large body of water is difficult to determine. On pages 61–63, Bulletin 9 of the California State Department of Engineering, 1920, "Water Resources of Kern River," the results of observations for Buena Vista and Tulare lakes are given; and on page 79 of the report on the San Jacinto River Hydrographic Investigations, 1922, by the California State Division of Water Rights, are given the results of measurements at Lake Elsinore. These results represent all known available data for Tulare Lake; a six-year average at Lake Elsinore; the year 1920 at Buena Vista Lake; and a 13-year average at East Park Reservoir. Table 10-1 shows the results referred to above, together with U. S. Weather Bureau records of evaporation from pans at Berkeley and San Francisco; pan records for the year 1925 at Alvarado near the south end of San Francisco Bay; and a 19-year record at Lake Chabot by the Spring Valley Water Company. The above represent the true evaporation, rainfall being treated as so much water added to the pan, or lake surface, and not affecting the figures for evaporation. There is also shown the record kept by the Leslie Salt Refining Company at their plant near San Mateo. The last named record represents net loss, that is, rainfall is deducted from the true evaporation to arrive at the actual loss of water.

Evaporation will not be the same for all portions of the reservoir back of the barrier, for, owing to the higher temperatures, the loss from the rivers and delta channels will be greater than from the lower portions of the reservoir. It is believed that the adopted value of 3.50 feet per year represents as closely as can be estimated from present data the losses from this source. This, however, may be too low a value, especially during dry years, considering that the temperature of the water over the shallow flooded portions of the bays will be relatively high.

Gate Leakage.

For estimating purposes it is assumed that leaks will occur through an opening of about one-sixteenth inch or say 0.005 foot, around the full periphery of the gate below water surface. Leakage will not always occur from the fresh water side. There will, at times, be a leakage from the salt water side. At other times fresh water will leak out near the surface, and salt water will leak in near to the bottom.

At the maximum concentration of chlorine, sea water weighs 64.28 pounds per cubic foot and as fresh water weighs 62.4 pounds there is a difference of 1.88 pounds per cubic foot. Assuming the chlorine content of sea water as 19,000 parts per million, the increment in weight is about 0.1 pound per 1000 parts of chlorine per million. If the salinity below the constructed barrier is assumed as 16,000 parts per million, the weight would be about 64 pounds per cubic foot, and as the water above the barrier will not be strictly fresh, the weight may be assumed as 62.5 pounds, resulting in a difference in weight per cubic foot of 1.5 pounds. With the salt water surface at elevation 0 (50 feet above the gate sill), the head necessary to balance on the fresh water side would be 51.25 feet. Under this condition, there would be no leakage at the bottom, but the leakage from the fresh water side would gradually increase toward the surface. With the water surface on each side at the same elevation, salt water would leak in throughout the full depth. For conditions between, there would be leakage in both directions. With water surface at elevation 2.5 on the fresh water side; a mean of elevation 0 on the downstream side; and a mean tidal range of 4.7 feet; the mean maximum differential head on the sill would be 4.85 feet and the mean minimum would be 0.15 feet. Since the balancing head is 1.25 feet, the effective maximum head producing outflow at the sill of the 50-foot by 60-foot gates would be 3.60 feet and at high tide the head producing flow of salt water would be 1.10 feet. The mean velocity between two different heads h_1 and h_2 is

$$\frac{5.35\left(h_2^{3/2} - h_1^{3/2}\right)}{h_2 - h_1}$$

When h is 0, mean V reduces to $5.35\sqrt{h}$. For the leakage from the fresh water side at the sill $V = 5.35\sqrt{3.6} = 10.2$ f.p.s. for 75 per cent of the time. The head along the guides varies from 3.60 feet to 4.85 feet for a depth of 47.65 feet and from 4.85 feet to 0 for a depth of 4.85 feet. The mean V for 47.65 feet $= 16.5$ f.p.s. The mean V for 4.85 feet $= 11.8$ f.p.s. These last two velocities are at mean low tide. As the tide rises this condition of flow from the salt water side will start, but there will always be a flow of fresh water at the top.

The mean velocity along the gate sill, with inflow of salt water, is 5.6 f.p.s. for 25 per cent of the time. Along the guides, the inflow of salt water will be from 0 for a depth of 0 feet to 5.6 feet for a depth of 46 feet, extending over 25 per cent of the time. The minimum outflow of fresh water past the guides will be 2.1 f.p.s. through a depth of 6.4 feet.

The outflow of fresh water along the sill will be, for 24 hours, 75 per cent of $10.2 \times .005 \times 50 = 1.91$ c.f.s. The outflow past the guides will be $2(16.5 \times 47.65 + 4.85 \times 11.8 + 2.1 \times 6.40) \times .005 \div 2 = 4.28$ c.f.s. for 24 hours. The total outflow of fresh water will be 6.19 c.f.s. per gate. The inflow of salt water along the sill will be 25 per cent of $5.6 \times .005 \times 50 = 0.35$ c.f.s., and along the guides it will be 25 per cent of $2(0 + 5.6 \times 46) \times .005 \div 2 = 0.32$ c.f.s. The resulting total inflow of salt water $= 0.67$ c.f.s. per gate.

Assuming that the salt water will remain at the bottom, near the gates, and will flow out at the next low tide, thus cutting down the actual loss of fresh water, the net loss will be $6.19 - 0.67 = 5.52$ c.f.s.

per gate or, for 30–50-foot by 60-foot gates an average net loss of 166 c.f.s., equivalent to 329 acre-feet per day.

If the water surface above the barrier were held at elevation 0, the inflow of salt water would be greater than the outflow of fresh water during the 24 hours. At high tide, the velocity at the gate sill would be equal to that due to a head of 3.65 feet = 15.3 f.p.s.; past the guides the mean velocity would be 13.9 f.p.s. for 50 feet and 8.2 f.p.s. for 2.35 feet = 14.3 f.p.s. for 50 feet. At half tide, V at the sill = 8.79 f.p.s. corresponding to a head of 1.2 feet. The mean velocity at the sill during the period high tide to half tide would be 12.4 f.p.s. At half tide, the mean velocity past the guide would be 5.86 f.p.s. The mean velocity during this period for a depth of gate of 50 feet = 10.7 f.p.s.

At low tide, the velocity of fresh water at the sill = 8.79 f.p.s., equivalent to a head of 1.2 feet. Past the guides, mean V = 10.62 f.p.s. for 47.65 feet and 8.2 f.p.s. for 2.35 feet, equivalent to a V for 50 feet of 10.5 f.p.s. The discharge Q, of salt water at high tide = 10.75 c.f.s.; Q at half tide = 5.13 c.f.s. At low tide, the flow of fresh water = 7.45 c.f.s. Plotting the curve of discharge against head, downstream flow being plotted as a minus quantity, it is found that at half low tide the flow downstream = the flow of salt water. The mean discharge of salt water, flowing 75 per cent of the time, is found to be 7.0 c.f.s., equivalent to 5.25 c.f.s. for 24 hours. The mean discharge of downstream flow for 25 per cent of the time is 3.5 c.f.s., equivalent to 0.88 c.f.s. for 24 hours. Assuming that the downstream flow consists of salt water that has passed upstream, the net inflow of salt water is 4.37 c.f.s. per gate or 131 c.f.s., equivalent to 260 acre-feet per day for 30–50-foot by 60-foot gates. The loss of fresh water, due to sluicing out the salt water is 102 c.f.s., as explained later.

Loss from Operation of Locks.

Whenever the lower gates of a lock, located between bodies of fresh and salt water are opened, the more dense salt water rushes in at the bottom and crowds the fresh water out, forcing it to flow downstream on top of the salt water until finally diffused. Likewise, when the lower gates are closed and the upper ones opened, the salt water passes upstream out of the lock and is replaced by fresh water. This is very clearly demonstrated in the discussion of Salinity Variation in the Locks on pages 7 and 8 of Exhibit 23.

The number, size and volume of the locks at the various sites investigated for the Salt Water Barrier are shown in Table 10-2.

The large lock at Lake Washington, where the tests of salinity were made, is the same size as the 80-foot lock proposed in this report. The salinity of the water below the proposed barrier probably will not differ widely from that shown under Series 1, in Table 1 of Exhibit 23, and for convenience it has been assumed to be 16,000 parts of chlorine per million, which is the degree of salinity assumed for the water leaking upstream around the gates.

Using the values given in Series 2, 3 and 4, in Table 1 of Exhibit 23—and the lock capacities shown in Table 10-2—Table 10-3 has been prepared to show the number of acre-feet of fresh water that are displaced by salt water with each opening of the lock gates to the salt water, and the number of acre-feet of salt water that enter the fresh water lake with each opening of the lock gates to the fresh water, if the water surface above the barrier is maintained at elevation + 2.5 and if full depth lock gates are used.

In Table 10-3 the quantity of salt water is based on a concentration of 19,000 parts of chlorine per million, the approximate mean saline strength of sea water. In other words, the number of acre-feet of salt water that are given represent the number of acre-feet of sea water that would enter or leave the locks if all the salt content of the water that passes in and out were concentrated into a portion of the water which would have a chlorine strength of 19,000 parts. This appears to be the most convenient base to which to reduce the saline content in terms of quantity of salt water, although the use of any other base would yield the same results in the determination of the loss of fresh water.

Table 6-33 shows the total number of lockages per 24 hours for each site, while Table 6-34 shows the estimated number of annual lockages. The figures given summarize the lockages in both directions, consequently the average number of lockages in each direction will be half of those indicated. Table 10-4 shows the total loss of fresh water and inflow of salt water for each side per 24 hours, based upon traffic as it occurred on July 6–7, 1925, and assuming that full depth lock gates are used.

The salinity of the water above the Lake Washington locks under various conditions is shown in Table 3, on page 9 of Exhibit 23. The concentration in the salt water sump just above the locks is of particular interest. In figure 2, on page 5 of the same exhibit, Station 3 is shown to be located in the dredged sump. See page 3 of the exhibit also.

By reference to Table 3 in Exhibit 23, it will be noted that at Station 3, at a depth of 45 feet, the concentration following a very dry summer is 9075 parts of chlorine per million. In the computation of gate leakage, the concentration of the inflowing salt water is assumed to be 16,000 parts per million. If it is assumed that all this salt water is sluiced out, and that behind the barrier it is diluted to 9000 parts of chlorine, for each acre-foot of salt water that enters there will be required to effect the stated dilution seven-ninths acre-feet of fresh water, which, of course, would be lost in the sluicing. The total loss would be 102 cubic feet per second.

In Tables 10-3 and 10-4, the concentration of the salt water that enters is assumed to be 19,000 parts of chlorine per million. If this is diluted to 9000 parts of chlorine, there will be required for each acre-foot of salt water that enters, ten-ninths acre-feet of fresh water, which will be lost in sluicing out the salt water. This loss of fresh water, together with that which is lost directly as given in Table 10-4, is summarized in Table 10-5. The quantities shown are based on traffic conditions as observed on July 6–7, 1925. While lockages on those two days may be assumed to represent the number required to handle the maximum daily traffic at the present time, they probably are low considering the future, because of natural increase in traffic to keep up with the growing communities and because of the increment to be brought about through the increase in industry above the barrier following its construction.

The use of water shown in Table 10-5 is based on the assumption that each lock gate leaf is made in one section. If these are built in two sections, with the elevation of the dividing line at elevation —15, so that light draft vessels could be passed by operating only the upper part of the gate, much of the interchange of fresh and salt water during a lockage could be prevented. Table 10-6 shows the loss of fresh water and the inflow of salt water through one operation of the locks with the upper part only of the gate opened.

In the data on vessel traffic during the July 6 and 7, 1925, observations have been separated into two classes—those vessels that could be locked through by using the upper section of the gates, and those that would require the operation of both sections. In Table 10-7, prepared from these data and data in Tables 10-3 and 10-6, the total amount of fresh water required to operate the locks is shown.

Comparing the use of water as shown in Tables 10-5 and 10-7, there is found to be a large saving in water through the use of lock gates built in two sections. This saving as of July 6–7, 1925, is summarized below.

SAVING OF FRESH WATER PER 24 HOURS BY THE USE OF LOCK GATES BUILT IN TWO SECTIONS

Quantities are in acre-feet

Type of gate	*Army Point site*	*Dillon Point site*	*Point San Pablo site*
Each leaf in one section	963	1291	2207
Each leaf in two sections	489	892	1398
Saving of water	474	399	809

At the three sites, this would amount to annual savings of 173,000, 146,000 and 295,000 acre-feet, respectively, if the average daily traffic is assumed to be as it was on July 6–7, 1925.

Industrial and Municipal Use.

The following letter shows the present use of fresh water by industries in and around Pittsburg:

C. A. HOOPER & CO.

Lumber Merchants.

Balfour Bldg.

San Francisco, Cal., Oct. 30, 1924.

Mr. W. R. Young, C. E.,
U. S. Reclamation Service,
Campus, University of California,
Berkeley, California.

My Dear Mr. Young:

In conformity with our conversation on our recent trip, I beg to give you herewith a resume of the water used by the main industries in Pittsburg at the present date:

Columbia Steel Co., under the signature of Mr. N. A. Becker, Gen. Supt., that their daily consumption is	4,600,000 Gals.
Great Western Electro Chemical Co., under the signature of Mr. C. W. Schedler, Gen Manager, is	3,000,000 Gals.
Redwood Manufacturers Co., under the signature of Mr. W. M. Casey, Gen. Manager, is	2,200,000 Gals.
Pioneer Rubber Co., under the signature of Mr. W. G. Lamond, Gen. Manager, is	1,000,000 Gals.
F. E. Booth Co. given me verbally by Mr. F. E. Mullins, Gen. Manager, is	800,000 Gals.
The National Metals Co. of California	20,000 Gals.
Total	11,620,000 Gals.

Other smaller industries have not reported.

A. J. JONGENEIL,
General Manager.

With a present daily use of 11,620,000 gallons in the comparatively small area of Pittsburg, it seems reasonable to assume that for the whole region above Army Point, with the growth that would come with the construction of a barrier, this use would ultimately amount to 100,000,000 gallons per day equal to 155 c.f.s., or 307 acre-feet per day. With a barrier at Dillon Point, this use might amount to 120,000,000 gallons per day equal to 186 c.f.s., or 368 acre-feet, and at Point San Pablo a use of 200,000,000 gallons equal to 310 c.f.s., or 614 acre-feet per day might be expected.

Summary of Water Required for Operation of the Barrier.

Table 10-8 summarizes, by months, the requirements in acre-feet and second-feet, upon the assumption that the gate leaves at the ship locks will be built in two sections, divided horizontally at elevation —15, and that the water surface above the barrier will be maintained at elevation + 2.5. It should be noted that the indicated requirements to meet losses used in the tables of barrier operation, do not include any allowances for irrigation use in any year. The effect of irrigation draft which may be permitted in years of extreme deficient run-off has not been computed.

In addition to the quantities shown in Table 10-8, there are the requirements for flushing out the bays, previously mentioned. Below elevation + 2.5, the volumes in the bays above the three dam sites, according to Table 7-1, are: Army Point, 1,116,000 acre-feet; Dillon Point, 1,235,000 acre-feet; Point San Pablo, 2,400,000 acre-feet. The necessary frequency of flushing, and the amount of water that must be wasted to restore the waters in the bay to the required degree of purity, cannot be foretold without additional data. Complete information as to the work that has already been done at Lake Washington, supplemented by other data that can be gathered at that point, will help materially in answering the problem of the encroachment of sea water. The problem of the collection of salts through the return ground waters can be studied locally. Some data have already been collected, and additional data must be gathered. The question of contamination from industrial waste, sewage and other agents must also be studied. When these problems are more thoroughly understood, the question of flushing can be answered with a greater degree of certainty.

Water Available for Operation of the Barrier.

In Table 10-9, is given the rainfall for stations around the bays by months, both for the period of record and for the year 1924. The rainfall represents a source of accretion to the water supply for the barrier which will not appear in any records of run-off of streams, and a large part of this rainfall is not now available for use, as it passes on out to the sea. In addition to the rain on the open water surface, there are in the neighborhood of 500,000 acres of land in the delta islands and in marshes contiguous to the bays from which rainfall reaches the river by seepage, as there are no defined water channels.

Assuming that 40 per cent of the rainfall on the 500,000 acres of land enters the channels and bays, the equivalent area of open water surface would be 200,000 acres. The total equivalent open water surface for the catchment of rain above the respective barrier sites at elevation + 2.5 would be: Army Point, 267,000 acres; Dillon Point, 271,000 acres; Point San Pablo, 352,000 acres. Using the totals given in the last two columns of Table 10-9, the accretions to the water supply from local rainfall would be as shown in Table 10-10.

In addition to the rainfall shown in Table 10-10, there ultimately would be, *in normal years*, a discharge from the Sacramento and San Joaquin rivers of from 10,000,000 to 15,000,000 acre-feet in excess of municipal and irrigation requirements. In this study it is assumed that none of the water from the Kings River, nor from streams south of the Kings, reaches the bay. Likewise the proposed irrigation draft from those streams has been omitted from the quantities assumed as irrigation draft in Table 10-11. This table covers the period beginning with the season of 1919–20, and embraces the dryest years of record. The quantities are approximate because the study of irrigation requirements and storage development for the two valleys has not been completed.

The amount of return flow from irrigation, and the proportion that would be rediverted for irrigation under the condition of complete agricultural development of the two valleys, cannot be foretold at this time, but the residue available for the operation of the barrier probably will be small.

Owing to the increasing difficulty of maintaining the reservoir upstream from the barrier free from salt water as the water surface is permitted to fall, and also because of navigation requirements, it probably will not be advisable to allow the surface of this reservoir to fall below mean sea level (elevation 0). Likewise, because of the nature of the levees and the cost of drainage in the delta region, the ultimate maximum allowable water surface, for periods of several months' duration, may, for the purpose of the study, be fixed at 4.0 feet above sea level, although later developments may show that this maximum storage height may even be increased to 5.0 feet. Table 7-2 gives the total storage capacity for the reservoir above each of the three sites as follows:

SUMMARY OF TABLE 7-2

STORAGE CAPACITY IN ACRE-FEET ABOVE THE THREE BARRIER SITES

Quantities are in acre-feet

Range of water surface	*Army Point*	*Dillon Point*	*Point San Pablo*
0 to +2.5	161,000	169,000	344,000
0 to +4.0	260,000	273,000	565,000
0 to +5.0	335,000	352,000	714,000

During normal years, there would be practically no water available for the operation of the barrier from natural stream flow between July 1st and October 1st. During 1920, the period would have been from June 1st and October 1st, and in 1924 this period would have been from May 1st to October 1st.

Table 10-12 gives the requirements in acre-feet by months, and accumulated, for water in the operation of the barrier at each of the three sites during the above named periods. (See Table 10-8 also.)

From data contained in Tables 7-2, 10-8, 10-10, 10-11 and 10-12, Table 10-13 has been prepared, covering the average season, the season of 1919–20 and that of 1923–24. It shows the total seasonal water supply available and the seasonal requirements for each of the three sites; also the shortages during the respective seasons and the water available for flushing out the reservoir above the barrier for each site investigated. In some cases the shortage is due to lack of reservoir capacity and in others to lack of seasonal water supply.

The quantity 12,000,000±, in the column headed "Water Supply," is the figure assumed as the probable discharge from the Sacramento and San Joaquin rivers, in a normal year, in excess of municipal and irrigation requirements. Other figures in this column are derived from stream flow (Table 10-11) and rainfall (Table 10-10). As the rainfall data for 1919–20 at the stations used in the study were rather incomplete, the totals for that season were assumed slightly in excess of those for 1923-24 shown in Table 10-10. The rainfall assumed for 1919–20 is as follows:

Location of Barrier	*Accretions to water supply from rainfall*
Army Point	300,000 acre-feet
Dillon Point	305,000 acre-feet
Point San Pablo	400,000 acre-feet

A considerable error in the assumed rainfall would have but a small effect upon the final results of the study.

The quantities appearing in the column "Water Required" are taken from Table 10-8 in which, it should be noted, evaporation from the exposed water surface is considered.

Quantities under "Water Shortage" are derived from Tables 7-2 and 10-12. The shortage is the difference between the requirements during the irrigation season and the quantity in storage in the reservoir above elevation 0. The reservoir is assumed to be full at the beginning of the periods covered in Table 10-12.

In the column, "Available for Flushing" (Table 10-13) 12,000,000 ± acre-feet are shown for the average year with the barrier located at the Army Point and Dillon Point sites, while 11,000,000 ± are shown for the Point San Pablo site. At best, the 12,000,000 ± acre-feet is a rough approximation of the average seasonal water supply; and as the addition of rainfall and the deduction for water required in operating the barrier at either of the two upper sites would result in changing the figure by less than 500,000 acre-feet, it was assumed that the amount of water available for flushing at the two upper sites, in an average year, would be 12,000,000 ± acre-feet. With the barrier located at the Point San Pablo site, however, the decrease in water available for flushing, due to operation of the barrier, modified by accretions from rainfall, amounts to nearly 1,000,000 acre-feet, and the water available for flushing at that site in an average year was, accordingly, reduced to 11,000,000 acre-feet, although this refinement may not be justified in view of the other rough assumption made. The quantities available for flushing in the seasons 1919–20 and 1923–24 are equal to the supply minus the water required for operation decreased by the shortage.

From Table 10-13, it is evident that if the maximum height of water surface above the barrier is restricted to elevation + 2.5, the water stored in the reservoir thus formed will not be sufficient to operate the barrier at any of the three sites during the irrigation season, even in years of heavy run-off from the Great Central Valley, and, therefore, it will be desirable to seek the highest practicable elevation at which to maintain the storage level. As previously stated, the elevation at which the water surface may be held will depend upon the ability of the delta levees to resist the pressure, and this can only be determined by experience.

It should be noted that the shortages due to lack of reservoir capacity increase as the barrier is moved downstream, although the capacity of the reservoir is greater. This is principally due to the greater evaporation, and to the larger requirements of navigation, industries and municipalities, as indicated in Table 10-8.

The sequence of supply and demand can not be known accurately; therefore the shortages given in the table are minimums since the figures are based upon the assumption that, in years of low run-off, all available water can be conserved up to the capacity of the reservoir above the barrier. It is possible, however, that the small surplus in years of deficient water supply will reach the reservoir within a very short period so that the storage capacity will be taxed beyond its limit, with the result that some of the run-off must be wasted.

It will be noted by examination of Table 10-13 that as the storage elevation behind the barrier is raised, the amount of water available for flushing out the reservoir in years of low run-off is decreased. According to the table no water would be available in the season 1923–24 to flush out the reservoir created through construction of a barrier at the Point San Pablo site whether water were impounded to elevation + 2.5, + 4.0 or + 5.0. It appears that, in any case, there would be no flushing water available in 1923–24 if water were stored to elevation + 5.0, although in a normal year there would be a large amount of water available for flushing, regardless of where the barrier is constructed or of the elevation at which the water surface above the barrier is maintained.

If the above analysis is correct, it may be concluded that since one of the principal objects of the Salt Water Barrier is to conserve fresh water, it will be desirable to maintain the largest practicable storage capacity above the structure. Likewise, it is evident that the farther downstream the location for the barrier is chosen, the greater will be the quantity of water required for operation, and the greater will be the shortages during seasons of low run-off. Since the shortage must be supplied from mountain storage in order to maintain sufficient depth for navigation, and to hold the water level at an elevation where the reservoir will not be deluged with salt water whenever the ship-locks are opened, it is apparent that consideration of the necessity for conservation of water would require the selection of one of the upstream sites—Army Point, Dillon Point, or Benicia, if the latter, upon investigation is found to be suitable structurally.

PART TWO

EXHIBITS, TABLES AND ESTIMATES ACCOMPANYING REPORT ON SALT WATER BARRIER

Exhibit 1

REQUEST FOR SURVEY

SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION.
700 Second Street,
Sacramento, California.

January 4, 1923.

Hon. A. P. Davis, Director,
U. S. Reclamation Service,
Washington, D. C.

Dear Sir:

The undersigned, representing the Sacramento Valley Development Association and land interests of the Sacramento region, desire to bring to your attention a proposed project for solution of the salt water problem of the Sacramento River delta and request the cooperation of the U. S. Reclamation Service in an effort to determine the feasibility, probable effectiveness and the approximate cost of the proposed works.

The project referred to is known as "the salt water dam project." Briefly, it contemplates the construction of a dam across San Francisco Bay, approximately from Point Richmond to Tiburon, or other point as may be determined, the purpose being to confine the salt water below and create a fresh water lake above the proposed structure.

As you no doubt are aware, a serious problem has been created in the delta region by encroachment of salt water due to extensive diversions in the upper and central valley. The solution of this problem by construction of a dam as indicated has been proposed by Capt. C. S. Jarvis, Board of Engineers, U. S. A. For further information we inclose herewith a copy of a paper prepared by Capt. Jarvis in which he discusses the proposed project.

The benefits which it is expected may be derived by the construction of a dam as proposed includes elimination of the salt water problem and the creation of a vast fresh water lake which will provide a water supply for the rapidly growing communities and industrial plants bordering the bay of San Francisco and will afford a source of irrigation supply which can be distributed over extensive areas with a moderate pumping lift. It would seem that the construction and operation of such a dam may have the effect of practically eliminating waste of Sacramento River water during the summer season.

Present knowledge of this project based upon the Jarvis report is not sufficient to warrant definite conclusions as to feasibility, approximate cost and benefits to be derived. It is desired that a survey be had which will warrant such conclusions.

We very much desire such an engineering study and investigation by the U. S. Reclamation Service and hereby make application for a survey. We believe the Service is the proper body to make this study because of its vast experience in dealing with irrigation projects. This is an irrigation project. The fact that it is designed to form a barrier against salt water in no way detracts from its standing as an irrigation enterprise which primarily it is.

We believe a survey of this project by the U. S. Reclamation Service would be a logical step in the development of plans for large scale irrigation in the Sacramento Valley begun nearly twenty years ago and continued from time to time. We believe this is one of the most important of the various units which in time must comprise a completed Sacramento Valley project, and we very respectfully ask that when funds are available a sufficient amount be set aside to enable the Service in cooperation with the State of California or other interests here to make a thorough survey upon which definite conclusions may be based.

Captain Jarvis in reply to our inquiry has estimated the cost of the further surveys needed at $25,000. We will undertake to secure from local sources one-half of this sum or of such other sum as may be deemed necessary for a cooperative survey.

We very respectfully ask that the Reclamation Service, when funds are available, undertake such survey in cooperation with the proper state authorities and services, and that one-half of the cost of such survey be met from the Reclamation Service funds.

We trust this may have your favorable consideration.

Yours very truly,

SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION,
By W. A. BEARD, President.

DELTA LAND SYNDICATE,
By D. HADSELL, Chairman.

Exhibit 2

CONTRACT OF JANUARY 26, 1924

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

Contract between the United States; the Department of Public Works, Division of Engineering and Irrigation, of the state of California, and the Sacramento Valley Development Association, providing for continuation of cooperative investigation of the proposed Iron Canyon Project and cooperative investigation of proposed control works on the Lower Sacramento River, California.

THIS AGREEMENT, Made this 26th day of January, 1924, between the UNITED STATES OF AMERICA, by HUBERT WORK, Secretary of the Interior, pursuant to the act of February 21, 1923 (42 Stat., 1281), and the act of March 4, 1923 (42 Stat., 1540), party of the first part; the DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION, OF THE STATE OF CALIFORNIA, pursuant to Chapter 286, Session Laws of California, 1923, and Chapter 121, Session Laws of California, 1923, party of the second part, and the SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION, a corporation duly organized and existing under the laws of the State of California, party of the third part: Witnesseth:

2. WHEREAS, The Secretary of the Interior has allotted from the appropriation made for miscellaneous investigations of reclamation projects, available until December 31, 1924, the sum of Twenty Thousand Dollars ($20,000.00) to be expended in the continuation of investigations of the proposed Iron Canyon Project and in the investigation of proposed control works on the Lower Sacramento River in California, and

3. WHEREAS, The Department of Public Works, Division of Engineering and Irrigation, of the State of California, has available the sum of Ten Thousand Dollars ($10,000.00) to be expended in said investigations, and

4. WHEREAS, The Sacramento Valley Development Association has available the sum of Ten Thousand Dollars ($10,000.00) to be expended in said investigations, and

5. WHEREAS, The Commissioner of the Bureau of Reclamation has, under the authority of the Secretary of the Interior, approved for investigation and is willing to undertake and make the examinations, surveys and estimates necessary to determine the feasibility of alternate plans now suggested in connection with the proposed Iron Canyon Project in California and also investigation of a proposed system of control works on the Lower Sacramento River in the State of California.

6. NOW, THEREFORE, In consideration of the premises and the mutual covenants and agreements herein contained, it is stipulated and agreed between the parties hereto as follows:

7. The Secretary of the Interior, upon the execution of this contract, will make available for the work proposed herein, the sum of Twenty Thousand Dollars ($20,000.00); the Department of Public Works, Division of Engineering and Irrigation, of the State of California, upon the execution of this contract, will make

available as hereinafter provided, for the work proposed herein, the sum of Ten Thousand Dollars ($10,000.00) and the Sacramento Valley Development Association, upon the execution of this contract, will deposit with the Special Fiscal Agent of the Bureau of Reclamation at Denver, Colorado, for the work proposed herein, the sum of Ten Thousand Dollars ($10,000.00).

8. As to the said sum of Ten Thousand Dollars ($10,000.00) to be made available by the Department of Public Works, Division of Engineering and Irrigation, of the State of California, the Engineer in charge of the work, pursuant to paragraph 13 hereof, shall determine in his discretion the items of expenditure which shall be chargeable against said sum, and shall voucher the said items directly to the state officer designated by the Department of Public Works, Division of Engineering and Irrigation of the State of California.

9. Each item of the work need not be paid in the proportion of the funds provided by this agreement, but the aggregate cost of the work shall be paid in said proportion, to wit: One-half (½) by the United States, one-fourth (¼) by the Sacramento Valley Development Association and one-fourth (¼) by the Department of Public Works, Division of Engineering and Irrigation, of the State of California; provided, that any payments in excess of said proportions made by either party out of the funds available during the progress of the work shall be adjusted when the report contemplated by paragraph 15 hereof is made; provided further, that should the entire amount herein provided be not expended there shall be returned to each party any excess of the money made available by it over its proportion of the expenditure.

10. When the sums of money as specified in paragraphs 7 and 8 have been made available as therein provided, the Bureau of Reclamation of the Department of the Interior and the State Department of Public Works acting in cooperation, will, so far as the expenditure of the sum of Forty Thousand Dollars ($40,000.00) will permit; (a) Make such additional examinations, investigations and studies as may be determined advisable in connection with the water supply, flood control and power development at the proposed dam and reservoir site heretofore investigated at Iron Canyon, including the necessary changes in plans and estimates to provide reliable information thereon under such new conditions as may now be proposed. (b) Make examination and survey of a proposed canal (known as the Low Line Canal) diverting from the Sacramento River at or near the mouth of Red Bank Creek for the irrigation of lands on the west side of the river in the proposed Iron Canyon Project. Said investigations will include, (1) classification of materials, the preparation of designs and estimates of cost of construction and the examination of irrigable lands for the purpose of determining the estimated per acre cost and the feasibility of the reclamation thereof, and (2) examination of feasibility of irrigation of lands in Tehama County, California, lying above said Low Line Canal, by pumping from said canal or otherwise. Said investigation and report are also to bring up to date the study of the water supply data for said proposed Iron Canyon Project and the possibilities for irrigation and power development therefrom. (c) Make examination and investigation of the cost and feasibility of constructing control works on the Sacramento River so as to prevent the salt water from San Francisco Bay rendering the fresh water in the river unfit for irrigation and domestic use during periods of low river flow. Said examination and report will include investigation of surface and subsurface conditions in connection with the development of plans and estimates of cost of the proposed regulation.

Provided that, of the total sum of $40,000 to be made available for this work the sum of $10,000 or as much thereof as may be needed shall be expended upon the surveys and investigations relating to the Iron Canyon Project which are set forth in paragraphs (a) and (b) of this section, and the sum of $30,000, together with any surplus remaining from that portion of the fund herein specified to be used upon the Iron Canyon Project surveys, shall be expended in examinations and investigations relating to the cost and feasibility of constructing control works on the Lower Sacramento River, as provided in paragraph (c) of this section.

11. The Bureau of Reclamation of the Department of the Interior, the Department of Public Works, Division of Engineering and Irrigation, of the State of California, and the Sacramento Valley Development Association, agree to furnish for this investigation as they may be called for, all records and reports and engineering data concerning the work to be performed under this contract, that they now have or that they can feasibly obtain; receipts shall be given for data furnished and said data will be returned to said parties at the close of these investigations.

12. All surveys and investigations contemplated hereunder shall follow a general plan of operation to be agreed upon by the Chief Engineer of the Bureau of Reclamation, the State Engineer of California, and the Sacramento Valley Development Association, through its president and general manager. Said plan may be amended from time to time as the work progresses.

13. The work shall be performed by the Bureau of Reclamation of the Department of the Interior under the supervision of an engineer designated by the Chief Engineer of the said Bureau. An assistant engineer shall be designated by the State Department of Public Works, Division of Engineering and Irrigation, to work under the direction of the said supervising engineer.

14. On completion of the surveys and investigations herein provided for, all field notes, original plans, calculations, reports and other data acquired or prepared during the investigations and surveys shall be filed with the Bureau of Reclamation of the Department of the Interior, and complete copies thereof shall be furnished the State Department of Public Works. The said original records shall be accessible at all times to the State Engineer of California, or his duly authorized representative, and to the duly authorized representative of the Sacramento Valley Development Association, upon application.

15. A report of the results of said surveys and investigations shall be promptly made by the Engineer of the Bureau of Reclamation in charge, outlining the scope of the investigations, and giving a complete record thereof with detailed estimates as contemplated by paragraph 10 hereof, with suitable explanatory maps. Plans and other documents as exhibits, together with the names of the parties hereto and all cooperating officers and a summary of expenditures incurred in the investigations, which expenditures shall include the usual overhead and general charges of the Bureau of Reclamation. The report and recommendations shall be subject to the joint approval of the Chief Engineer of the Bureau of Reclamation and the State Engineer of California. In case of their failure to agree, the Chief Engineer of the Bureau of Reclamation and the State Engineer of California shall submit separate conclusions and recommendations, both of which shall be embodied with the report.

16. This contract provides only for preliminary surveys and investigations insofar as the funds to be made available, as provided in paragraphs 7 and 8 hereof, will permit, and in no way obligates the United States, the Department of Public Works, Division of Engineering and Irrigation, of the State of California, or the Sacramento Valley Development Association, as to any future action regarding the proposed projects. All work and expenditure under this contract shall cease whenever the funds to be so made available, as provided in paragraphs 7 and 8 hereof, shall become exhausted whether said work shall have been completed or not.

17. No member of or delegate to congress, or resident commissioner, after his election or appointment or either before or after he has qualified and during his continuance in office, and no officer, agent, or employee of the government, shall be admitted to any share or part of this contract or agreement, or to any benefit to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company, where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the Act of Congress approved March 4, 1909 (35 Stat., 1109).

IN WITNESS WHEREOF, This contract has been executed by the parties hereto the day and year first above written.

THE UNITED STATES OF AMERICA.
By HUBERT WORK, Secretary of the Interior.

[SEAL]

May 7, 1924.

DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION, OF THE STATE OF CALIFORNIA.

By W. F. McCLURE, Director of Public Works and State Engineer.

Attest: MYRTLE V. MURRAY, Secretary.

SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION.

By W. A. BEARD, President and General Manager.

Attest: M. A. SEXTON, Secretary.

Exhibit 3

CONTRACT OF JUNE 26, 1924

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

Contract between the United States; the Department of Public Works, Division of Engineering and Irrigation, of the State of California; and the Sacramento Valley Development Association, amending and supplementing contract dated January 26, 1924, between the same parties, providing, in part, for cooperative investigation of proposed control works on the Lower Sacramento River, California.

THIS AGREEMENT, Made this 26th day of June, 1924, between the UNITED STATES OF AMERICA, by Elwood Mead, Commissioner of the Bureau of Reclamation, under the provisions of the Act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof or supplementary thereto, party of the first part; the DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION, OF THE STATE OF CALIFORNIA, pursuant to Chapter 286, Session Laws of California, 1923, and Chapter 121, Session Laws of California, 1923, party of the second part; and the SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION, party of the third part; WITNESSETH:

2. WHEREAS, By contract dated January 26, 1924, between the United States of America; the Department of Public Works, Division of Engineering and Irrigation, of the State of California; and the Sacramento Valley Development Association, certain cooperative investigations in the Sacramento Valley in California were provided for, including an investigation of proposed control works on the Lower Sacramento River at a total expense of Forty Thousand Dollars ($40,000.00), and

3. WHEREAS, There is available from the appropriation made by congress for secondary investigations during the fiscal year 1924 the sum of Five Thousand Dollars ($5,000.00) which may be expended in the continuation of the investigation of proposed control works on the Lower Sacramento River in California, and

4. WHEREAS, The Department of Public Works, Division of Engineering and Irrigation, of the State of California, has available the sum of Five Thousand Dollars ($5,000.00) which may be expended in the continuation of said investigation.

5. NOW, THEREFORE, In consideration of the premises and the mutual covenants and agreements herein contained it is stipulated and agreed between the parties hereto as follows:

6. Effective upon the date of this contract the Commissioner of the Bureau of Reclamation, under the authority of the Secretary of the Interior, will make available for the continuation of the investigation of proposed control works on the Lower Sacramento River in California, the sum of Five Thounsand Dollars ($5,000.00), and the Department of Public Works, Division of Engineering and Irrigation, of the State of California, will on the same date, make available a like sum for the said work.

7. As to the said sum of Five Thousand Dollars ($5,000.00) to be made available by the Department of Public Works, Division of Engineering and Irrigation, of the State of California, the engineer in charge of the work, pursuant to paragraph 13 of the said contract dated January 26, 1924, shall determine, in his discretion, the items of expenditure which shall be charged against said sum and shall voucher the said items directly to the state officer designated by the Department of Public Works, Division of Engineering and Irrigation, of the State of California.

8. Each item of the work need not be paid in the proportion of the funds provided by this agreement, but the aggregate cost of the continuation of the said investigations, as herein provided for, shall be paid in said proportion, to wit: One-half by the United States and one-half by the Department of Public Works, Division of Engineering and Irrigation, of the State of California; provided, that any payments in excess of said proportions made by either party out of the funds available during the progress of the work shall be adjusted when the report contemplated by paragraph 15 of said contract dated January 26, 1924, is made; provided, further, that should the entire amount herein provided be not expended, there shall be returned to each party any excess of the money made available by it over its proportion of the expenditure.

9. The provisions of Articles 11, 12, 13, 14, 15 and 16 of said contract dated January 26, 1924, shall govern the work of the said investigation, as herein provided for, and shall be considered a part of this contract the same as if the said Articles were set out in detail herein.

10. No member of or delegate to congress, or resident commissioner, after his election or appointment or either before or after he has qualified and during his continuance in office, and no officer, agent, or employee of the Government, shall be admitted to any share or part of this contract or agreement, or to any benefit to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company, where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the Act of Congress, approved March 4, 1909 (35 Stat., 1109).

IN WITNESS WHEREOF, This contract has been executed in triplicate by the parties hereto the day and year first above written.

THE UNITED STATES OF AMERICA.

[SEAL] By ELWOOD MEAD, Commissioner, Bureau of Reclamation, Department of the Interior.

DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION, OF THE STATE OF CALIFORNIA.

By W. F. MCCLURE, Director of Public Works and State Engineer.

Attest: MYRTLE V. MURRAY, Secretary.

[SEAL] SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION.

By W. A. BEARD, President and General Manager.

Attest: M. A. SEXTON, Secretary.

Exhibit 4

CONTRACT OF MARCH 3, 1925

Contract between the United States of America and the Department of Public Works, Division of Engineering and Irrigation, of the State of California, providing for the completion of the investigation of proposed control works on the Lower Sacramento River, California.

THIS AGREEMENT, Made this 3d day of March, 1925, between the United States of America, by Hubert Work, Secretary of Interior, under the provisions of the Act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof or supplementary thereto, party of the first part, and the Department of Public Works, Division of Engineering and Irrigation, of the State of California, pursuant to Chapter 386, Session Laws of California, 1923, and Chapter 121, Session Laws of California, 1923, party of the second part; WITNESSETH:

2. WHEREAS, By contracts dated January 26, 1924, and June 26, 1924, between the United States of America; the Department of Public Works, Division of Engineering and Irrigation, of the State of California; and the Sacramento Valley Development Association, certain cooperative investigations in the Sacramento Valley in California were provided for, including an investigation of proposed control works on the Lower Sacramento River at a total expense of Fifty Thousand Dollars ($50,000.00).

3. WHEREAS, There is available from the appropriation made by Congress for secondary investigations, the sum of Fifteen Thousand Dollars ($15,000.00) which may be expended for the completion of the investigation of the proposed control works on the Lower Sacramento River in California, and

4. WHEREAS, The Department of Public Works, Division of Engineering and Irrigation, of the State of California has available the sum of Fifteen Thousand Dollars ($15,000.00), which may be expended for completion of the investigation of the proposed control works on the Lower Sacramento River in California, and

5. WHEREAS, The Commissioner of the Bureau of Reclamation has, under the authority of the Secretary of the Interior, approved for investigation and is willing to undertake the completion of the investigation of the proposed control

works on the Lower Sacramento River in the State of California, provided for by the contracts dated January 26, 1924, and June 26, 1924, between the United States of America; the Department of Public Works, Division of Engineering and Irrigation, of the State of California; the Sacramento Valley Development Association; and the agreement covering plan of procedure dated June 9, 1924, made in compliance with the terms of said contracts.

6. NOW, THEREFORE, In consideration of the premises and the mutual covenants and agreements herein contained it is stipulated and agreed between the parties hereto as follows:

7. The Secretary of the Interior, upon the execution of this contract, will make available for the completion of the investigation of the proposed control works on the Lower Sacramento River in California, the sum of Fifteen Thousand Dollars ($15,000.00) and the Department of Public Works, Division of Engineering and Irrigation, of the State of California, upon the execution of this contract, will make available the sum of Fifteen Thousand Dollars ($15,000.00) for the completion of the investigation of the proposed control works on the Lower Sacramento River in California.

8. As to the said sum of Fifteen Thousand Dollars ($15,000.00) to be made available by the Department of Public Works, Division of Engineering and Irrigation, of the State of California, the engineer in charge of the work, pursuant to paragraph 12 hereof, shall determine in his discretion the items of expenditure which shall be chargeable against said sum, and shall voucher the said items directly to the state officer designated by the Department of Public Works, Division of Engineering and Irrigation, of the State of California.

9. Each item of the work need not be paid in the proportion of the funds provided by this agreement, but the aggregate cost of the work shall be paid in said proportion, to wit: One-half (½) by the United States of America, and one-half (½) by the Department of Public Works, Division of Engineering and Irrigation, of the State of California; provided that any payments in excess of said proportions made by either party out of the funds available during the progress of the work shall be adjusted when the report contemplated by paragraph 14 hereof is made: provided further, that should the entire amount herein provided be not expended as herein provided there shall be returned to each party any excess of the money made available by it over its proportion of the expenditure.

10. When the sums of money as specified in paragraphs 7 and 8 have been made available as therein provided, the Bureau of Reclamation of the Department of the Interior and the State Department of Public Works acting in cooperation, will undertake the completion of the investigation of the proposed control works on the Lower Sacramento River in the State of California, provided for by the contracts dated January 26, 1924, and June 26, 1924, between the United States of America; the Department of Public Works, Division of Engineering and Irrigation, of the State of California; the Sacramento Valley Development Association; and the agreement covering plan of procedure dated June 9, 1924, made in compliance with the terms of said contracts.

11. The Bureau of Reclamation of the Department of the Interior and the Department of Public Works, Division of Engineering and Irrigation, of the State of California, agree to furnish for this investigation as they may be called for, all records and reports and engineering data concerning the work to be performed under this contract that they now have or that they can feasibly obtain; receipts shall be given for data furnished and said data will be returned to said parties at the close of these investigations.

12. The work shall be performed by the Bureau of Reclamation of the Department of the Interior under the supervision of an engineer designated by the Chief Engineer of said Bureau. An assistant engineer shall be designated by the State Department of Public Works, Division of Engineering and Irrigation, to work under the direction of the said supervising engineer.

13. On completion of the investigation herein provided for, all field notes, original plans, calculations, reports and other data acquired or prepared during the investigation shall be filed with the Bureau of Reclamation of the Department of the Interior, and complete copies thereof shall be furnished the State Department of Public Works, Division of Engineering and Irrigation, as the work progresses. The said original records shall be accessible at all times to the State Engineer of California or his duly authorized representative.

14. A report of the results of said investigation shall be promptly made by the engineer of the Bureau of Reclamation in charge, outlining the scope of the

investigation, and giving a complete record thereof with detailed estimates and with suitable explanatory maps, plans and other documents as exhibits, together with the names of the parties hereto and all cooperating officers and a summary of expenditures incurred in the investigation, which expenditures shall include the usual overhead and general charges of the Bureau of Reclamation. The report and recommendations shall be subject to the joint approval of the Chief Engineer of the Bureau of Reclamation and the State Engineer of California. In case of their failure to agree, the Chief Engineer of the Bureau of Reclamation and the State Engineer of California shall submit separate conclusions and recommendations, both of which shall be embodied with the report.

15. This contract provides for the completion of the investigation of the proposed control works on the Lower Sacramento River in the State of California insofar as the funds provided for in paragraphs 7 and 8 hereof will permit, and in no way obligates the United States of America, or the Department of Public Works, Division of Engineering and Irrigation, of the State of California, as to any future action regarding the proposed project. All work and expenditures under this contract shall cease when the funds to be so made available as provided in paragraphs 7 and 8 hereto shall become exhausted whether said work shall have been completed or not, or when said work shall have been completed.

16. No member of or delegate to congress, or resident commissioner, after his election or appointment or either before or after he has qualified and during his continuance in office, and no officer, agent, or employee of the government, shall be admitted to any share or part of this contract or agreement, or to any benefits to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company, where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the Act of Congress approved March 4, 1909 (35 Stat., 1109).

IN WITNESS WHEREOF, This contract has been executed by the parties hereto the day and year first above written.

THE UNITED STATES OF AMERICA.
By HUBERT WORK, Secretary of the Interior.

DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION, OF THE STATE OF CALIFORNIA.

(SEAL)

By W. F. McCLURE, Director of Public Works and State Engineer.

Attest: MYRTLE V. MURRAY, Secretary.

Exhibit 5

CONTRACT OF MARCH 16, 1926

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

Contract between the United States and the California Development Association providing, in part, for continuation of cooperative investigation of proposed control works on the Lower Sacramento River, California.

THIS AGREEMENT, Made this 16th day of March, 1926, between THE UNITED STATES OF AMERICA, by Elwood Mead, Commissioner of the Bureau of Reclamation, under the provisions of the Act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof or supplementary thereto, party of the first part, hereinafter referred to as the United States, and the CALIFORNIA DEVELOPMENT ASSOCIATION, a corporation duly organized and existing under the laws of the State of California, party of the second part, hereinafter referred to as the Association; WITNESSETH:

2. WHEREAS, By contracts dated January 26, 1924, June 26, 1924, and March 3, 1925, between the United States, the Department of Public Works, Division of Engineering and Irrigation, of the State of California, and the Sacramento Valley Development Association, certain cooperative investigations in the

Sacramento Valley in California were provided for, including an investigation of proposed control works on the Lower Sacramento River, at a total cost of Eighty Thousand Dollars ($80,000.00); and,

3. WHEREAS, The California Development Association has available the sum of Four Thousand, Four Hundred and Fifty-seven Dollars and Fifty Cents ($4,457.50) which may be expended for continuation of the investigation of the proposed control works on the Lower Sacramento River in California; and,

4. WHEREAS, The Commissioner of the Bureau of Reclamation has, under authority of the Secretary of the Interior, available for allotment from the appropriation for cooperative and general investigations, secondary projects, as contained in the Act of March 3, 1925 (43 Stat., 1141, 1171), such a sum of money as, when added to the sum of money available by the Association, will not exceed the aggregate sum of Six Thousand Dollars ($6,000.00).

5. NOW, THEREFORE, In consideration of the premises and the mutual covenants and agreements herein contained, it is stipulated and agreed between the parties hereto as follows:

6. The Association has deposited with the Special Fiscal Agent of the Bureau of Reclamation at Denver, Colorado, the sum of Four Thousand, Four Hundred and Fifty-seven Dollars and Fifty Cents ($4,457.50), the receipt whereof is hereby acknowledged, for continuation of the investigation of the proposed control works on the Lower Sacramento River in California. Should it be necessary, in the progress of the work of said investigation, to expend funds in addition to those made available by the Association, the United States will expend from the appropriation for cooperative and general investigations, secondary projects, as contained in the Act of March 3, 1925 (43 Stat., 1141, 1171), such sum or sums as, when added to the funds made available by the Association, shall not exceed the aggregate sum of Six Thousand Dollars ($6,000.00).

7. The work shall be performed by the Bureau of Reclamation of the Department of the Interior under the supervision of the Chief Engineer of said Bureau.

8. So far as applicable, and where not inconsistent with the provisions hereof, the provisions of the said contracts dated January 26, 1924, June 26, 1924, and March 3, 1925, between the United States, the Department of Public Works, Division of Engineering and Irrigation, of the State of California, and the Sacramento Valley Development Association, shall be applicable.

9. No member of or delegate to congress or resident commissioner, shall be admitted to any share or part of this contract or to any benefits to arise therefrom. Nothing, however, herein contained shall be construed to extend to any incorporated company if the contract be for the general benefit of such corporation or company.

IN WITNESS WHEREOF, This contract has been executed by the parties hereto the day and year first above written.

THE UNITED STATES OF AMERICA.
By Elwood Mead, Commissioner of the Bureau of Reclamation.

(March 30, 1926.)

CALIFORNIA DEVELOPMENT ASSOCIATION.
(SEAL) By N. H. Sloane, Secretary and General Manager.

Exhibit 6

CONTRACT OF SEPTEMBER 19, 1924

Department of the Interior

Bureau of Reclamation

THIS AGREEMENT, Made September 19, 1924, in pursuance of the Act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof or supplementary thereto, between THE UNITED STATES OF AMERICA, hereinafter styled the United States, by Walker R. Young, Engineer, Bureau of Reclamation, thereunto duly authorized, and subject to the approval of the proper supervisory officer of the Bureau of Reclamation, and the East Bay Municipal Utility District, a corporation organized under the laws of the State of California, hereinafter styled Contractor, its successors and assigns; WITNESSETH:

2. WHEREAS, The United States is now engaged in making certain investigations in connection with proposed salt water control works on the Lower Sacramento River, and among other things is engaged in making certain borings to a shallow depth in Carquinez Strait; and,

3. WHEREAS, The United States has assembled and is utilizing certain equipment and organization which can be used to advantage in performing certain work desired by the contractor.

4. NOW, THEREFORE, In consideration of the premises the United States will carry to a depth which may be agreed upon by the parties hereto, for the benefit of the contractor, one of the holes now being drilled by the United States.

5. Where the operations of this contract extend beyond the current fiscal year it is understood that the contract is made contingent upon congress making the necessary appropriation for expenditures thereunder after such current year has expired. In case such appropriation as may be necessary to carry out this contract is not made, the contractor hereby releases the United States from all liability due to the failure of congress to make such appropriation.

6. For and in consideration of the faithful performance of this contract, the Contractor shall pay to the United States the actual expense incurred by the United States in performing the work required by the contractor, plus the sum of $300. This payment shall be made promptly upon receipt by the contractor of itemized statement showing expenditures incurred by the United States.

7. No interest in this agreement shall be transferred by the Contractor to any other party, and any such transfer shall cause annulment of the contract so far as the United States is concerned; all rights of action, however, for breach of this contract are reserved to the United States, as provided by section 3737, Revised Statutes of the United States.

8. It is further stipulated and agreed that in the performance of this contract no persons shall be employed who are undergoing sentences of imprisonment at hard labor which have been imposed by courts of the several states or territories or municipalities having criminal jurisdiction.

9. No member of or delegate to congress or resident commissioner shall be admitted to any share or part of this contract or to any benefit to arise therefrom. Nothing, however, herein contained shall be construed to extend to any incorporated company if the contract be for the general benefit of such corporation or company.

IN WITNESS WHEREOF, The parties have hereto signed their names the day and year first above written.

THE UNITED STATES OF AMERICA.
By WALKER R. YOUNG, Engineer, Bureau of Reclamation.

EAST BAY MUNICIPAL UTILITY DISTRICT,
By A. P. DAVIS, Chief Engineer and General Manager.
P. O. Address, 505 17th St., Oakland, California.

Exhibit 7

PLAN OF PROCEDURE

Berkeley, California, June 9, 1924.

Agreement covering general plan of procedure for surveys and investigations of a proposed system of control works on the Lower Sacramento River and certain alternative plans for the proposed Iron Canyon Project, all in the Sacramento Valley, State of California.

The undersigned at a meeting held in the office of the Bureau of Reclamation at Berkeley, California, on the day and date above written, with W. L. Huber, G. A. Elliott, A. J. Cleary and B. A. Etcheverry, members present of an advisory committee appointed by the California State Department of Public Works, agreed upon the following as an outline of a tentative program to be followed in the above named investigations:

Lower Sacramento River Control Works

1. It is recognized that the primary purpose of this investigation is to determine the feasibility and probable cost of a system of control works as proposed

and to this end the funds now available are to be devoted chiefly to investigation of prospective dam sites, designs and estimates of cost.

2. *Sites to be considered:* Field work to be confined to Army Point, Dillon Point and San Pablo Point sites.

3. *Field Examinations:* One outfit operating two shifts to be placed on diamond drilling. Work to begin at Army Point site. Number of holes to be adjusted to costs as work progresses. At least two or three holes to be drilled in the sections of deepest water at the Dillon Point and San Pablo Point sites. Holes to be located primarily for estimating quantities of earth and rock fill and possible location of lock structures. No land holes to be drilled, surface indications being deemed sufficient for estimating purposes. It is expected that $15,000 to $20,000 will be expended in exploration work.

Based upon estimates prepared by Mr. Young and informal bids received from the International Diamond Drill Contracting Co. of San Francisco, it is believed that it will be more economical to do the drilling by force account. Moreover, force account work is considered advisable in this instance since it allows for a more flexible program.

4. *Office Studies:*

(a) Effect of barrier on flood plane elevations, silting of Suisun and San Pablo bays, tidal prism of San Francisco Bay, and navigation.

(b) Design of barrier. Principal consideration to be given to plan of constructing locks and gates to one side and making an earth and rock fill across the natural channel. Trial designs of other types of structure to be made in sketch form only.

(c) Design of required locks and gates for navigation and passage of flood water. Desirable design condition for passing floods is that an area of waterway be provided in structure equal to that of the present natural channel. Flood plane should be run through Suisun Bay joining on the Debris Commission elevations at Collinsville. Flood quantities of the Debris Commission to be used and marsh land in Suisun Bay outside of that necessary for a channel to be assumed as reclaimed.

5. *Preparation of Report.*

Iron Canyon Project

1. *Field Work:* Survey of low line canal taking out of river in the vicinity of Red Bank Creek. Survey to be adequate for making estimate of costs and areas of land above and below canal line. To be run south as far as funds will permit.

Survey of siphon across Sacramento River if funds are sufficient.

2. *Office Studies:*

(a) Determine from maps, the areas that can be served by gravity and the pumping lifts to other areas.

(b) Cost estimate of canal and structures.

(c) Revise estimates of power that can be developed at Iron Canyon Dam.

(d) Consider use of gates in spillway for increasing storage behind dam.

(e) Revise cost estimates of dam.

3. *Preparation of Report:*

DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION.

By WALKER R. YOUNG, Engineer.

DEPARTMENT OF PUBLIC WORKS, DIVISION OF ENGINEERING AND IRRIGATION.

By PAUL BAILEY, Deputy Chief of Division.

SACRAMENTO VALLEY DEVELOPMENT ASSOCIATION.

By W. A. BEARD, President.

NOTE:—This plan of procedure was amended to include a brief geological examination of the barrier sites by Mr. Kirk Bryan. See Mr. Bailey's letter of August 13, 1924.

Exhibit 8

SACRAMENTO VALLEY INVESTIGATIONS

STATEMENT OF FUNDS CONTRACTED

Item	United States	State of California	Local interests	Total
Contract dated January 26, 1924	$15,000 00	$7,500 00	$7,500 00	$30,000
Contract dated June 26, 1924	5,000 00	5,000 00	----------	10,000
Contract dated March 3, 1925	15,000 00	15,000 00	----------	30,000
Contract dated March 16, 1926	1,542 50	----------	4,457 50	6,000
Contract dated September 19, 1924:				
*East Bay Municipal Utility District	----------	----------	603 30	603
Totals	$36,542 50	$27,500 00	$12,560 80	$76,603

DISTRIBUTION OF COST INCURRED BY CONTRACTORS AS OF FEBRUARY 29, 1928

Item	United States	State of California	Local interests	Total
Distribution of costs	$37,736 92	$27,110 10	$12,560 80	$77,407

* Cost of extending two holes drilled at the Army Point site to obtain data for the East Bay Municipal Util District, not required in connection with the investigation of the salt water barrier.

[1] This report, to February 29, 1928, is not final as further costs will be incurred by the United States in complet the final report of the project.

Exhibit 9

DETAILED STATEMENT OF COST OF INVESTIGATIONS

Prin. Feat. No. 1
Phys. Feat. No. 30-51a

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SACRAMENTO VALLEY PROJECT
SALT WATER BARRIER
Examinations and Surveys
California-Cooperative

February, 1928
Consolidated Report

Class number	Class of work	Quantity			Cost		Unit cost
		Unit	This month	To date	This month	To date	To date
351	Estimates					$28,716 75	
358	Experimental investigations					21 30	
669	Reconnaissance					13 73	
672	Topography					1,152 53	
673	Trial lines					43 05	
668	Location surveys					73 67	
684	Wash borings	l. f.		23,842		30,131 33	1.265
685	Core drilling (diamond)	l. f.		799		7,130 10	8.924
209A	Consulting boards					624 94	
209B	Geological examinations					244 93	
202	Camp maintenance					1,390 91	
209	Engineering and inspection					709 33	
	Subtotal					$70,252 57	
224	Superintendence and accounts					3,200 43	[1]7.4%
212	General expense					3,954 82	[1]9.2%
	Grand total actual cost all parties					$77,407 82	
50	Less expenditures by state of California					27,110 10	
	Actual cost, U. S. and local interests					$50,297 72	
	Estimated cost, all parties [2]					$76,603 30	

[1] Percentages of overhead cost apply only on direct cost of the United States, excluding the expenditures by California.
[2] This report is not final cost of investigations, as further expense will be incurred in assembling report of project.

Description of work:
For cooperative investigations of the Salt Water Barrier, Sacramento Valley, California, under contracts with the State of California and local interests

Approved: L. R. Smith,
Chief Clerk

Correct: L. J. Moran,
Costkeeper

Exhibit 10

ECONOMIC ASPECTS

LAW OFFICES OF
HADSELL, SWEET & INGALLS
433 California Street,
San Francisco.

July 2, 1926.

Dr. Elwood Mead,
Care United States Bureau of Reclamation,
Yakima, Washington.

My Dear Doctor:

In Re proposed Economic Survey in connection with proposed Carquinez Dam.

I understand that Engineer Young is practically ready to report upon the proposed barrier at four different sites between Army Point and Point Richmond. Naturally the next question will be whether or not the benefits derivable from such barrier at each respective site will justify the cost of construction and the expense of maintenance and operation. To determine these benefits in each instance an economic survey obviously is necessary. For some time past we have put before you, in various ways, our desire to have this further survey made by the Bureau of Reclamation by means of funds contributed equally by the Bureau of Reclamation and our own State Department of Public Works, but thus far we have only stated in general terms what the benefits will be and what factors must be examined and appraised in such a survey. We wish, therefore, now to be more specific. We will take each proposed site in turn.

Army Point Site.

This site is just above Benicia, between Army Point at the Arsenal on the north shore and Bull's Head Point opposite on the south shore. A barrier here presents the following factors for study and appraisement:

(a) One of the natural and most feasible routes for vehicular traffic between the west side of the Sacramento Valley and the cities of Oakland and Berkeley on the east shore of San Francisco Bay is along the edge of the marsh lands from Suisun to Benicia, thence across the straits to Martinez, thence to Concord and Walnut Creek and then by the Tunnel Road into Berkeley and by Redwood Canyon into Oakland. The route by the Tunnel Road has long been open. For the several past months much work has been in progress to make this route even more usable than it has been for many years. They are straightening and widening the road on the Contra Costa County side of the hill. Plans are under discussion to cut a tunnel at a much lower level and to widen, straighten and lower the road on the Alameda County side of the hill. Recently, in Oakland, $5000 was appropriated and arrangements made to plan a highway from Oakland through Redwood Canyon to Walnut Creek. There are several other suggested routes for additional roads through this range of hills to connect these East Bay communities with the back country; and every route now existing or suggested is tributary directly to any highway from Martinez to the north. So it is clear that in conjunction with a dam at this site, a bridge, as a part of such a north-going highway, will be very important. It is the duty of our State Highway Commission to provide just such main highways. No doubt the Commission could be interested in this feature of the project; and it might well be that the Commission, through moneys especially provided for it by our present two-cent gas tax, or through other moneys which likely will be provided for it by several measures which will be on the ballot in November, will be willing and anxious to join in the expense of construction, maintenance and operation. But only an economic survey can possibly inform us as to what extent, on the basis of benefits to vehicular traffic both now and in the future, the state's Highway Commission should participate.

(b) The main line of the Southern Pacific Railroad, both from the east and from the north, crosses the straits at Benicia. It is my information that the monthly cost to the railroad to maintain and operate its ferry (it runs two large boats with frequent crossings) is well above $100,000. But it is my understanding that a railroad bridge may well be built in conjunction with the barrier. If so, the railroad will be greatly interested to determine how far it should contribute, on the basis of present and future benefits, towards the construction, maintenance and operation of such a barrier. But here again an economic study or survey must be made. I wish to add that the railroad itself has done considerable to ascertain the feasibility of constructing a bridge at this point; and Mr. Young told me that he had gotten the railroad's data for his use.

(c) Above this dam site, and below the delta area, there are a number of very important industries which use very large supplies of water. These industries at present are the Shell Oil Company, which has a refinery near Martinez; Tide Water Associated Oil Company, formerly the Associated Oil Company, which has its refinery at Avon east of Martinez; Columbia Steel Company, which has a very large steel mill at Pittsburg; Paraffine Paint Company, which has one of its paper factories at Antioch; Great Western Electro-Chemical Company, which has a large plant for the manufacture of chemicals situated near Bay Point; Pioneer Rubber Mills, which has a large plant between Pittsburg and Antioch, and Coos Bay Lumber Company, which has a large yard and factory near Bay Point. Most of these industries use very large quantities of water and customarily they pump it at a very low expense—about one cent per 1000 gallons, I believe, from the neighboring channel. Needless to say, it is fresh water and not salt water that they use and must have. Salt water, even were the quantity of salt in it small, is very damaging to machinery and greatly increases the cost of the maintenance as well as cost of operation. The diluted salt water conditions which now prevail for several months in the summer time in this stretch of channel makes the water situation for these industries a very severe one. They have an industrial association which for a long time has been actively in search of relief, and they have been considering several different methods of bringing water to their industries by means of aqueducts from other sources. Any of these means of relief will be very costly and will greatly increase the expense of water. The fact is that cheapness of water supply is one of the reasons which greatly induced these industries to locate where they did many years ago. Here then is an instance where the construction of this barrier will have a very beneficial result for these industries and one of the purposes of an economic survey must be to ascertain the comparative values of this proposed barrier as a means of furnishing fresh water to these industries and of the alternative projects for the bringing of water to this area for these industries by means of aqueducts from distant sources. There is one large user of water, namely, the California-Hawiian Sugar Refining Corporation, whose plant is at Crockett, below this particular dam site. At present it expends large sums of money annually to barge water to its plant during the critical months. If this dam is constructed a pipe line might be provided of very short length by which this company would be relieved of the expense of bringing water to its plant by barges. So this element also would enter into the proposed economic survey.

(d) East of Martinez, in Contra Costa County, there are considerable areas of farming lands where additional supplies of water for irrigation and domestic uses are already needed and will be more largely needed in the future. Several thousand acres are involved. The time must come when this area will have to provide itself with additional water either from a distant source of from the channel between Martinez and Bay Point. Certainly an economic survey should consider this factor.

(e) There are also a number of small and yet important towns and urban communities which are in much need of additional water supplies for all purposes. I refer particularly to Pinole, Vallejo, Crockett, Martinez, Benecia, Walnut Creek, Concord and Suisun. Mare Island Navy Yard is situated at Vallejo. The United States Army has a large arsenal at Benicia and there are several large tanning plants and a canning plant located at Benicia. Martinez is the county seat of Contra Costa County. Vallejo, for the development of its water supply, has just completed a project whereby it stores the water of Gordon Valley on a tributary of Suisun Creek and proposes to pipe such waters to Vallejo. The city of Vallejo was driven to this course by the demands of the Navy Yard. But this project of Vallejo interferes seriously with the water rights and needs for water of some nine or ten thousand acres of very rich farming land in Suisun Valley west of the town of Suisun. Consequently, the whole of this farming community is united to prevent Vallejo diverting these waters from Suisun Creek, from which it percolates into the farming territory. If Vallejo should get a domestic water supply from the main channel above this proposed barrier the situation in Suisun Valley would be entirely relieved. At Benicia the situation is more desperate as no possible outside source of supply is available. The fact is that the investigation which has thus far been conducted concerning the feasibility of the construction of a salt water barrier is to be attributed directly to a report prepared by Captain Clarence Jarvis of the United States Army when he was stationed at the arsenal at Benicia with specific instructions to devise, if possible, a way to increase the water supply for the arsenal. I presume that the United States Army is still interested in any effort to increase the fresh water supply of Benicia. If the other towns which I have mentioned are to get water supplies they must obtain them by pipe lines which will conduct the waters to them from far distant sources at great expense or this salt water barrier must be built. Here then are other factors which must be considered in the proposed economic survey.

(f) Several years ago nine of the East Bay cities united in forming what is known as the East Bay Municipal Utility District. These cities are: Oakland, Berkeley, Alameda, San Leandro, Emeryville, Albany, Piedmont, all in Alameda County, and Richmond and El Cerrito in Contra Costa County. You will note that among these cities is the city of Alameda, where the Navy Department desires to construct a huge naval station. The purpose which these cities had in organizing this district was to provide an additional water supply for the territory comprised within the district. The water situation in this territory is extremely serious and has been so for the last few years. At present there is barely enough water in sight to carry the territory for the next five months. This assumes that the present wells south of Oakland will continue to yield as well as they are yielding at the moment. But engineers are saying that there is grave danger that these wells will fail because of the tremendous demands which are being made upon them. In some of them there is already a trace of infiltration of salt water. This district, after some investigation, decided to build a large reservoir on the Mokelumne River east of Stockton to conduct the waters by a huge aqueduct from that reservoir to the East Bay communities to supplement the present water supply furnished by the East Bay Water Company. This project is under construction. This district must get its water from the Mokelumne River or some other distant source. The trouble with the present project is that it will do a great deal of harm to the farming communities along the lower reaches of the Mokelumne River. In consequence a very bitter fight is now being waged between the district and the farming communities. What the outcome of this battle will be it is not possible to say. The farming communities are going to continue to do everything they can to prevent the district taking their water supply. If this salt water barrier were constructed a great deal of the present trouble between the district and the farming communities could be removed and perhaps the whole trouble could be entirely alleviated. I would think that it would be a part of the economic survey to take this whole problem into consideration.

(g) Between Benicia and Antioch on both sides of the channel there are considerable areas of marsh lands which, if the salt could be kept out of them and if the salt in them could be leached out with fresh water, would constitute some of the richest farming land in the State of California. Personally I think it would be richer than any of the land in the Sacramento and San Joaquin Delta. It would have more silt in it than does the land in the San Joaquin Delta and it would have more peat in it than does a larger part of the land in the Sacramento Delta. I would judge that some fifty to sixty thousand acres are involved. A barrier of this kind is the only hope for the future which this marsh land area has and certainly the value which the barrier would have for this land is a factor for investigation in an economic survey.

(h) The thing which most immediately instigated the present investigation was the existing battle between the Delta territory and the Sacramento Valley over the large diversions of water from the Sacramento River above Sacramento whereby, as we of the Delta claim, the influx of salt water into the Delta channels has been produced and thereby has endangered the rich farming communities in the Delta. The fact is that 75 per cent of the lands of the San Joaquin Delta are lower than high tide and most of them are lower than low tide in San Francisco Bay. In the Sacramento Delta a very large part of the lands are lower than high tide and a considerable portion of them are lower than low tide in San Francisco Bay. Tidal effects occur in all channels of the Delta even above Stockton and above Sacramento. The channels of all streams in the Delta are much below low tide and in some instances obtain a depth of 50 or 60 feet. Now, in the remote past, the great flow of water rushing through the Delta to the sea from the Sacramento and San Joaquin River stream systems has kept these channels clear of salt water and has stored such quantities of fresh water in San Pablo Bay, Carquinez Straits, Suisun Bay and Honker Bay and channels connecting with them that the inflow of salt water into the Delta territory has been prevented. In recent years, however, the greatly increased storage of water on the tributaries of the Sacramento and San Joaquin rivers and the greatly increased diversion of water from these two stream systems for the irrigation of vast areas of lands in the Sacramento and San Joaquin valleys, combined with ten or more years of shortage of rainfall, have brought it about that in such years as 1920 and 1924 the fresh water barrier of which I have just spoken has been entirely done away with and salt water has gone far into the many stream channels in the great Delta territory. This condition caused the Delta interests to organize Delta Land Syndicate and River Lands Association and to institute suits and to take other measures to prevent diversions above us which operated to prevent formation of the fresh water barrier below the Delta territory. Hard battles have already been fought and hard battles are still to be fought. It is obvious that the construction of this barrier will remove the cause of this trouble and permit development to continue unhampered in the Sacramento and San Joaquin valleys and upon the upper reaches of the Sacramento and San Joaquin river stream systems. Obviously the economic factors are many and of enormous consequence to the future welfare of this state. All of the great power companies of the state are involved and a great majority of the irrigation districts. Likewise, there is involved the Hetch Hetchy project of the city of San Francisco as well as the project of the city of Sacramento. Then, too, there are many public utility canal systems which are involved. Any economic survey must take all of these things into account in appraising the economic values which arise or are involved in the construction of this barrier.

(i) Something must be said also on the subject of the ravages of the teredo, or marine borer. Before salt water conditions were brought about in the channels between Benicia and Antioch through the causes therefor which I have described, the piling on the wharves in this area was not treated for protection against the teredo. The reason was that the piling always was in fresh water and the teredo would not invade fresh water areas. The salt water condition came to prevail in this area long before anyone realized that the change had occurred. In consequence many wharves collapsed in use and wharfingers and warehouse owners first became aware of the condition when such accidents happened. There is extant a report on the invasion of the teredo into this area and into the straits between Benecia and Vallejo and it is estimated that the losses through damage to piling by the teredo between Vallejo and Antioch has exceeded $15,000,000. Even piling which has been treated to withstand the teredo eventually succumbs and has to be replaced; but piling in fresh water has an extremely long life and therefore there is an economic factor here which must be taken into consideration in any economic survey. This, of course, related to shipping and commerce along this channel between Sacramento, Stockton and San Francisco and other bay points.

(j) From your long residence in California you are quite familiar with the fact that the San Joaquin Valley has a very much greater irrigable acreage than there is water to irrigate it and the Sacramento Valley has a much greater supply of water than there are irrigable acres to use it. You are likewise aware of the very desperate situation which prevails in the lower end of the San Joaquin Valley where many thousands of acres are going backwards through lack of water due to overexpansion and to lowering of water tables under extensive pumping. These conditions have been getting more acute year by year. Those in touch with the water condition in northern California have anticipated what has happened and the last several legislatures have made large appropriations of moneys for water resources investigations and, as based thereon, for the formulation of a scheme for the comprehensive development of the water resources of the Sacramento and San Joaquin valleys with their tributary systems. At the legislative session of 1925 a report for such a comprehensive development of these water resources was submitted to the legislature and is known as "Bulletin No. 9—Supplemental Report on Water Resources of California—A report to the Legislature of 1925." I am enclosing a map which is part of that bulletin whereon is delineated the comprehensive scheme. You will note from this map that the dam in Carquinez Straits at some as yet unascertained point is a crucial factor in this scheme. In other words, the whole economic situation in the San Joaquin Valley, so far as that situation depends upon an adequate supply of water for irrigation, is involved in this project for the construction of a barrier below the mouths of the Sacramento and San Joaquin rivers. Here is an economic factor which is worthy of more than usual attention because it extends in so many directions and any economic survey in connection with the proposed barrier must certainly consider this factor.

(k) I must also note that an improvement in navigation would arise, as I see it, from the construction of this barrier. At present, in the summer time, there is such a low flow in the Sacramento River during several months, particularly in such excessive dry years as were 1920 and 1924, that navigation even to Sacramento at times is impossible and is entirely impossible for a considerable period of time over the stretches of the river immediately above Sacramento where a considerable commerce otherwise would originate. There have been numbers of occasions when the river at Sacramento has been so low that the boats had to stop several miles below Sacramento. The federal authorities who are concerned with navigation have given considerable thought and study to this condition and have made reports to the higher officials at Washington concerning the same. They have proposed, in fact, that a lock should be built across the river at Freeport, a considerable distance below Sacramento, for the express purpose of maintaining navigable conditions as far up the river as Sacramento and somewhat beyond. I understand, however, that the army engineers have definitely recommended against the construction of a lock at Freeport and have proposed other means to help the situation. However, this is one of the factors which must be considered in any economic survey.

(l) In view of what I have now said it seems to me conclusive that another economic factor must be studied in any economic survey. For, as I see it, the construction of this barrier through the various beneficial results which I have indicated will cause great developments to occur along the straits, and in the delta and in the Sacramento and San Joaquin valleys and even in the mountain areas and in Contra Costa and Alameda counties. These developments will extend to an increase in intensive farming, to an increase in irrigated areas, to the growth of cities, and to the development of manufactures of every sort and thereby will steadily promote the development of commerce throughout northern California. No man can say how great this additional production of wealth will be. You are aware that both the city of Sacramento and the city of Stockton have deep water projects afoot where they propose to construct deep water channels from the upper reaches of San Francisco Bay to their respective localities in order thereby to create inland ports for deep sea-going vessels. Surely no man can foretell, if the developments occur which I have suggested, how great will be the growth of sea-borne commerce as well as commerce by rail.

Now I do not mean to say that there will be no disadvantages arising from the construction of this barrier. I am referring now to economic disadvantages. There will be some. For example, construction of this barrier will make it necessary for vessels operating on the rivers between bay points and river points to use locks during several months of the year. In a way this use of locks will hinder commerce and consequently an economic survey must consider this question. Moreover, the barrier will have the effect to increase seepage conditions in large portions of the Delta and will make necessary, as I see it, the construction of larger levees or stronger levees. These things mean increase in maintenance and operation as well as in capital expenditures and must be taken into consideration in any economic survey. As far as commerce may be hindered the federal authorities will be deeply interested. Therefore, as I see it, the construction of a barrier at this particular site will involve many elements in which the federal government must take a great interest.

So we unhesitatingly appeal to the United States Bureau of Reclamation to contribute additional sums to provide jointly with the state the means for conducting an economic survey to consider the many economic factors which I have now suggested in connection with this particular dam site.

Dillon Point Site.

This site for a dam is some distance below the Army Point site and approximately in the middle of what we call Carquinez Straits. Everything which I have said with reference to the first site may be properly said with reference to this site, except that there may be some question about the feasibility of providing for a railroad crossing in conjunction with a highway crossing on the dam. However, I have no doubt that Mr. Young's report will go into this feature of the matter.

Crockett Site (not reported on).

I do not know what this site is called in Mr. Young's report. It is near the bridge which is now being constructed across Carquinez Straits immediately west of Crockett. There would be no possibility, as I see it, of using a dam at this place as a railroad crossing. Also the making of a highway crossing at this point would seem to be an unreasonable duplication of the crossing which is now under construction. Moreover, a highway crossing on the low summit of the dam would be much too low and would not be as near as advantageous for a highway crossing as the bridge under construction will be. Aside from highway and railroad crossings, what I have said about the first dam site is equally applicable here.

San Pablo Site.

This site will easily furnish an appropriate highway crossing which, as the years pass, will become more and more important to the development of the coast counties through easy vehicular communication with the east bay communities. Likewise a dam at this place will offer a proper crossing for a railroad, although in this respect the advantages will not be as great as they would be at the first site. Likewise large areas of additional marsh and tide lands could be brought under cultivation through the use of fresh water. Virtually the whole of San Pablo Bay would be reclaimable as would the marshes which fringe this bay on the north side. There would be several other large industries to receive benefits, notably the large Standard Oil Company plant at Richmond and the Union Oil Company plant at Oleum. Otherwise, everything which I have said in connection with the first dam site is applicable here.

I have said nothing herein concerning who should bear the cost of construction, maintenance and operation of such a barrier. But from what I have said it is clear that many factors must be carefully considered before there can be any appropriate determination of this question. In my judgment, there must be a careful, thorough, unbiased, economic survey of every factor which I have suggested before we undertake to determine upon whom the cost of construction, operation and maintenance shall be imposed. It is easy to see how the Federal and State Governments, the Highway Commission, and the Southern Pacific Railroad could be brought together to construct, operate and maintain this barrier. It is not so easy to see how the numerous industries and towns and cities and the various distinct farming communities and territories should be brought together to bear each a definite portion of such cost. But this only demonstrates the necessity for an economic survey, wherein all of these things will be given consideration and appraisement and whereby, no doubt, concrete suggestions can be evolved as to how such costs should be borne or distributed.

I have written this letter as though I were speaking personally and alone. however, I am really representing a committee which has had in charge the prosecution of this investigation. This committee represents the irrigation interests in the San Joaquin Valley through Mr. Hultman, who is president of the Board of Directors of the Turlock Irrigation District, and through Mr. Harris, who is connected or has been connected, at least, with the Madera Irrigation District, and this committee likewise represents the irrigation districts in the Sacramento Valley through Mr. Durbrow, who is manager of the Glenn-Colusa Irrigation District and president of the Irrigation Districts Association of California, and through Mr. Jesse Poundstone, who is president of Reclamation District No. 108 and is a member of the executive committee of the Irrigation Districts Association, and this committee likewise represents the Delta area through me, the chairman of the executive committee of Delta Land Syndicate, an organization of the owners of the lands in the Delta for the purpose of attempting to find a solution for the salt water menace which looms larger before us year by year as the developments in the mountains and the two great valleys continue. Please, therefore, accept this letter as coming from the committee as well as from me.

If there are any points here which need further elaboration, I will be glad to go into them at your suggestion.

I am

Yours very truly,

D. HADSELL.

Exhibit 11

REPORT ON PROPOSED SITES FOR A SALT WATER BARRIER IN THE LOWER REACHES OF SACRAMENTO AND SAN JOAQUIN RIVERS, CALIFORNIA

By KIRK BRYAN, Geologist in the U. S. Geological Survey, August 20, 1924

Bearing of Geology on Proposed Structures.

The geologic characteristics of the part of California in which the Salt Water Barrier is to be built are considered at some length in a later section of this report. Briefly, the region is known to geologists as one of crustal instability where earth movements of considerable magnitude and complexity have taken place within comparatively recent time. These earth movements and the violent vibrations of the earth's crust or earthquakes which are likely to accompany them, have an important bearing on the location and design of large engineering works. It is, however, equally important to consider how far such considerations may properly be taken into account, and to what extent the possible damage to engineering structures due to such earth movements must be included in the unavoidable hazards of any human enterprise.

Geologic investigation can define the nature and general trend of earth movement. For any area the direction of movement, whether up or down, with respect to sea level, or the kind of movement, whether accomplished by mass deformation or by the rupture of the earth crust along definite lines of fracture or faults, can usually be determined. But such investigation has so far not attained sufficient refinement to warrant prediction as to the direction or magnitude of the next movement. For the region of San Francisco Bay the general type of deformation is known, and from the recency of past movements—some of which have taken place in historic time—it may be predicted with confidence that these movements will continue, but the time at which they may occur is unknown. However, the historic and geologic record in this and other regions indicates that earth movements take place in small amounts, separated by intervals of time that are long in respect to the life of man. Some of these movements, amounting to tens of feet only, are of no consequence in the life of the community, others, which can be conceived of, might have results of far reaching or even disastrous importance. It seems obvious that if earth movements are separated by considerable intervals of time, and when they occur may be inconsiderable in amount, that many engineering structures of relatively short life may be built without regard to such risk. The phenomenal growth of the bay cities with the accompanying construction of large works is proof that to many minds this risk is inconsiderable. That larger earth movements, or movements causing a disastrous rearrangement of land and water may occur, can not be denied, but such an event would cause a complete readjustment of the cultural complex of the region. In this readjustment any engineering structure, even though it escaped physical damage, might become valueless because the interests for whose benefit it had been built had themselves been destroyed. It follows, therefore, that engineering structures should be undertaken to meet present conditions and contengencies that may be reasonably predicted during the life of the structure, without regard to the risk of earth movement which is inherent in the region and is a part of man's life in the area.

Attendent consequences of earth movements are vibrations of the earth's crust or earthquakes. Earthquakes, in themselves, produce damage to engineering structures, and earthquakes of destructive violence may accompany earth movements of inconsiderable amount and they may affect areas at a considerable distance from the center of propagation. Thus, earthquakes may be considered as an irregularly recurrent hazard to structures. The history of the region records two earthquakes separated by an interval of 30 years. This interval is doubtless purely fortuitous but probably indicates that earthquakes of considerable magnitude may be expected at intervals measured in tens, rather than in hundreds of years. That structures should be designed to avoid the effect of earthquake shake seems a reasonable requirement.

In the foregoing review of the risks natural to the region due to earth movement and earthquake shock, it may be seen that the science of geology can contribute little to assist the engineer in estimating the risk, or in the location of structures. It can only point to the lines of past movement and recommend the avoidance of these lines with, however, no guarantee that new lines of weakness in the earth's crust may be developed. The effect of earthquake shock is recorded in a large literature and is subject to mathematical analysis.

On the bearing power of foundations, and the probable character of rocks in proposed excavations, a few general suggestions can be made.

General Geology of the Region.

The coast ranges of California which generally form the western border of that state, and project into the Pacific Ocean along its coast, are low at San Francisco. Here, in a great cross-depression in the ranges, the sea extends inland in the connecting bays of San Francisco, San Pablo and Suisun. Through these bays is discharged the drainage of the Great Central Valley of California where alluvial floor constitutes one of the great agricultural areas of the world. Flowing from the adjacent and surrounding high mountains the waters of the region are gathered into two great rivers, the Sacramento and San Joaquin, which, flowing respectively from north and south, unite in a maze of andstomosing channels in the island country or delta region. Flowing through this region, and subject to the tidal fluctuations of the sea, the rivers discharge into Suisun Bay, and thence through the connecting bays and straits to the Golden Gate and the Pacific. It is this delta region which was once bathed wholly by fresh water carried by the rivers that is now menaced by incursions of salt water from the tidal bays. The proposed barrier must therefore be built either in the delta region or in the bay region. Sites in the narrower parts of the bay region are considered in this report.

The coast ranges of California have a complex history, involving compression and differential uplift in comparatively recent geologic time. The complete history of their building, though interesting as part of the natural setting and as an explanation of many of the features of the region, has only academic interest. The coast ranges are now a series of irregularly parallel ridges having a northwest southeast trend. In part these ridges are due to the superior resistance of hard rocks to erosion and the valleys to easy erosion of soft rocks. This parallel outcrop of hard and soft beds is due to successive folding of the ranges during periods of compressive strain that seems to have been largely completed in Pliocene time. In addition the ranges are composed of parallel fault strips, or blocks, which have been uplifted differentially along faults or fractures. These movements are more recent than those referred as strictly compressive and have continued down to the present time. This regional structure is of importance and will be considered at some length. (See Plate 3-1.)

The Montara block forms the western portion of the San Francisco Peninsula. Its eastern boundary passes out to sea south of the Golden Gate but the block is continued in the Reyes Peninsula, the eastern boundary lying in the depression marked by Tomales Bay. The Marin–San Francisco block forms the Santa Clara Valley, most of San Francisco Bay and the Marin Peninsula. Its eastern boundary is the Hayward fault zone at the base of the Berkeley Hills in the eastern part of the cities of Oakland and Berkeley, and extends across San Pablo Bay into Petaluma Valley. The Berkeley Hills block forms the hills of the same name. The eastern boundary is not well defined but lies in the depression between the Berkeley Hills and Mt. Diablo, in the valley of Walnut Creek. The boundary crosses Suisun Bay east of Army Point, near Avon and Goodyear. It has not been traced northward into the hills between Napa and Vaca mountains. The Mt. Diablo block, north of Suisun Bay, may continue into the Vaca Mountains. It has an undefined boundary that separates it from the Great Valley. These relations, however, have been only imperfectly worked out.

Each of the fault strips or blocks, thus defined, has, in spite of a complex interior structure, acted more or less as a unit. The Montara block is tilted to the northeast and is relatively uplifted. The Marin–San Francisco block is depressed to the southeast and uplifted to the northwest of San Francisco Bay. The Berkeley Hills block is generally uplifted more on the southwest than on the northwest so that the hills are higher and steeper on the southwest face of the block. The Mt. Diablo block has had a more intermediate uplift and the relations to the depression of the Great Valley is still a field for inquiry.

The lines of greatest earth weakness along which earth movements have recently occurred, and where they are most likely to recur, are on the boundaries of these blocks. The San Bruno fault zone, which separates the Montara block from the Marin–San Francisco block, lies outside the Golden Gate. The Haywards fault zone, which separates the Marin–San Francisco and Berkeley Hills block, crosses San Pablo Bay east of San Pablo Point at a place where the bay is wide and at a distance of several miles from any proposed site. The fault zone which separates the Berkeley Hills block from the Mt. Diablo block is less well defined. It has been named, in unpublished papers, the Calaveras fault and, though traced and defined through the upper part of Walnut Creek Valley, is concealed by swampy ground and alluvium in its northern extension. It seems probable, however, that it passes through, or near, Avon and Goodyear, about three miles east of Army Point, the eastern entrance to Carquinez Strait.

Compared to these main fault zones the faults within the blocks are of minor importance. Most of these faults were active in the periods of compressive strain of Pliocene and earlier times. Movements along these faults are unlikely and, except for shattered and brecciated belts of rock which occur along them, they have little effect on the character of sites for the barrier. In general, it may be the part of prudence to avoid such faults in the location of the barrier. Known faults of this character are described under each site.

The group of bays and straits which form the outlet of Sacramento and San Joaquin rivers are a remarkable feature of the local geography. Considered with the valleys of tributary streams the bays and straits form a valley system now submerged beneath the sea. Such a system being at right angles to the main structural features of the coast ranges is evidently antecedent to the uplift of the ranges. An ancestral river draining the Great Valley must have existed and across this river the mountains were uplifted, but at so slow a rate that the river cut a valley and maintained its course in spite of the uplift. Through various vicissitudes, some of which are imperfectly known, this valley persisted and finally assumed its present form when it was submerged below sea level. There have, however, been minor oscillations of land and sea and differential movements of the several fault blocks in which the region is divided. Thus, the Golden Gate has the simple form of a river gorge, but San Francisco Bay has been relatively more depressed and the rock floor is doubtless, in places, deeper than in the Golden Gate, and more or less filled by late Quaternary deposits. Carquinez Strait is like the Golden Gate, a simple drowned river gorge, but San Pablo Bay and Suisun Bay have doubtless been carried somewhat deeper beneath the sea.

Carquinez Strait (See Plate 3-2).

Carquinez Strait is cut across the general strike of the formations which consist of sand stones and shales. Several faults of the older and probably inactive type cross the strait with a northwest trend and more or less parallel to the general strike of the rocks. The northern continuation of the Franklin fault approaches Vallejo Junction from the southwest and, passing to the west of Mare Island, is lost in San Pablo Bay. The Carquinez fault emerges on the shore of the strait two miles west of Martinez and, passing to the east of Port Costa, follows the depression of Southampton Bay. An unproved fault is thought to lie in a valley just east of Eckley and to pass into Glen Cove. All of these faults are of the older type and are considered to be no longer active.

Dam Sites.

Dillon Point–Eckley Site. The narrow part of the strait between Dillon Point and Eckley is a proposed site. The rocks are sandstone and shales of the Chico formation and dip at angles of 45° to 70° to the southwest. Numerous small fractures and minor faults cut the rocks. The Carquinez fault passes to the east of the site and there is a suspected fault to the west. The general trend of these faults and the strike of the rocks is about north 25° west.

The sand stones and shales should form a suitable foundation for structures of ordinary size and identical material is being so used for the support of the land piers of the Volona Bridge 1½ miles west. There seem to be no objectional features to this site.

Army Point–Suisun Point Site. The proposed site at Army Point crosses the strait in a northwesterly direction parallel to the general trend of the rocks. The rocks at Army Point and Suisun Point are sandstones and shales having a northwest strike and dipping 50° to 75° to the southwest. These rocks belong to the Monterey formation and rest uncomformably on the similar sandstones and shales of the Chico formation. The contact lies just east of Army Point but is well exposed on Suisun Point.

Slight deformation of the beds on minor fractures is evident but no fault of large displacement passes through this area. The rocks are similar to those at Dillon Point in bearing power and there are no objectional geologic features.

Point San Pablo–Point San Pedro Site. San Pablo Strait connects San Pablo and San Francisco bays, but this strait is formed by two projecting head lands and bears little resemblance to Carquinez Strait. Both points, or headlands, are composed of rocks of the Franciscan group, here undifferentiated into formations. The Franciscan group is older, harder, and has been more disturbed than the formations represented at the other dam sites. The structures bear little relation to existing crustal blocks and the rocks of the group form a unit wherever they occur, which acts as a resistant mass in the movements of the region. Thus, details of the structures at sites in this group of rocks are of little moment.

The rocks exposed are massive, dark blue, fine grained quartzite with associated shales and thin beaded sandstones and cherts. The massive sandstone dips 45° southwest at Point San Pablo and on Point San Pedro stands at various angles in the numerous quarries of this headland.

The rocks of this site are exceptionally good as foundation material. The quartzite will probably stand the maximum loading of a granite, and the shaly parts of the formation are probably stronger than most sandstones.

The northwest trend of the site, parallel to the Hayward fault to the east, is a favorable feature. There seems to be no geological objections to this site.

Point Richmond–Bluff Point Site. The narrow part of San Francisco Bay, between Point Richmond and Bluff Point, is a proposed site. The rocks at both points belong to the Franciscan group and are suitable for foundation purposes equally with those at the San Pablo–San Pedro site. It should be noted, however, that Richmond Point belongs to a belt of Franciscan rocks which forms Brooks Island, Potrero San Pedro and the part of Marin Peninsula northwest of San Pedro Point. Bluff Point belongs to the belt formed by Goat Island, Angel Island and the Tiburon Peninsula. It seems unlikely that these two belts of Franciscan rocks are continuous under the bay and more than probable that a belt of one of the later and softer formations intervenes and would be encountered in drill holes.

The rocks of the two ends of the site are satisfactory, but there is a possibility of unsatisfactory rock along the line of the barrier. The direction of the proposed structure at this site crosses the trend of all the fault lines of the region and though no fault line is known to exist in the area covered by the water of the bay, the site seems somewhat less advisable than other proposed sites.

Construction Material.

The massive quartzites of the Franciscan group have long been used for riprap, macadam and concrete aggregate for which purposes they are sold under the name of "blue stone." The two lower sites have the advantage of proximity to large supplies of this material. Excavation of this rock both above water level or in under water work is, however, relatively expensive because of its hardness.

The sandstones and shales of the Chico and Monterey formations exposed at the two sites on Carquinez Bay have suffered much from surface weathering. The sandstones are yellow and in places incoherent. At a number of points along the strait landslides occur. Below the surface and at places at the surface the sandstones are unweathered. In this condition they are blue or gray in color, dense and hard. Many of the beds are 20 to 40 feet thick. These parts of the formation would make excellent stone for riprap or might be crushed for concrete aggregate. Large scale quarrying is, however, difficult for the relatively thin beds must be followed into the hillside and much waste material handled.

In deep excavations the sandstone will be hard and resistant and will probably have similar qualities under the waters of the bay. As material for embankments under water it seems likely that the shales and fragments of sandstone from the thinner beds will fill the voids of the larger stones derived from the massive sandstone beds and form a tight and relatively stable structure.

Drilling Operations.

It is obvious that the proposed sites have been chosen largely on topographic conditions. Fortunately no faults of consequence cross these sites and the rocks exposed present no insuperable difficulties. No minor shifts in proposed sites seem warranted on geological grounds. Similarly it is beyond the possibility of geologic prediction to indicate in advance the depth of bedrock below the water of the straits.

Exhibit 12

LOGS OF DEEP WELLS DRILLED

"A" CALIFORNIA & HAWAIIAN SUGAR REFINING CO. WELL

Well drilled in Recreation Park—135 feet south of north fence and 51 feet west of east fence. Work done between October 23 and December 18, 1916.

Depth	*Thickness*	*Character of strata*
0	5 ft.	Adobe
5	47	Red shale
52	30	Loose red shale
82	25	Coarse shale
107	51	Coarse hard shale
158	59	Hard shale and quartz
217	3	Boulder—granite
220	4	Hard rock
224	4	Soft rock
228	24	Hard shale
252	18	Blue clay with broken gravel
270	4	Boulder and clay
274	19	Very hard blue clay
293	18	Loose black shale
311	23	Very hard blue clay
334	13	Shale
347	10	Clay and boulder
357	41	Shale
398	5	Rock
403	12	Shale
415	10	Blue clay
425	25	Hard shale
450	60	Soft shale
510	20 ft.	Blue clay
530	30	Hard shale and rock
560	39	Boulder and blue clay
599	28	Hard shale
627	6	Rock
633	9	Tough blue clay
642	8	Rock
650	11	Blue clay
661	28	Rock
689	47	Shale and streak of clay
736	12	Rock
748	6	Hard tough clay
754	14	Shale
768	25	Hard blue clay
793	84	Hard shale
877	6	Rock
883	13	Hard rock
896	64	Clay
960	16	Shale
976	6	Clay
982	13	Shale
995	5	Clay
1000		

"C" JOYCE ISLAND GUN CLUB—Finished in June, 1923

Depth	*Thickness*	*Character of strata*
0	2 ft.	Tule roots
2	18	Black mud
20	92	Hard blue clay
112	10	Black sand
122	96	
218	16	Black sand, large quantity mica
234	117	
351	14	Black sand
365	133	
498	20 ft.	Quartz sand
518	205	
723	29	Sandy and hard
752	9	
761	14	Sandy, coarser and harder
775	20	
795	15	
810	30 in.	Quartz sand which contained fresh water
	17*	
832*		

* Discrepancy.

"D" REES WELL

Depth	Thickness	Character of strata
0	2 ft.	Tule roots
2	68	Tule mud
70	40	Soft blue clay
110	15	Sediment soil and soft sand
125	15	Black mud
140	15	Soft yellow clay
155	16 ft.	Yellow clay and sand
171	40	Soft blue clay
211	15	Dry blue hard clay
226	16	Black sand
242	27	Coarse sand, light in color
269		

"E" SEYMOUR GUN CLUB WELL

Depth	Thickness	Character of strata
0	2 ft.	Decayed tule
2	28	Bluish black mud
30	10	Yellow clay, dry
40	37	Yellow clay, soft
77	2	White sand
79	20	Blue clay, hard and dry
99	19	Greenish clay
118	4	Blue clay
122	14 ft.	Sand and gravel
136	17	White beach sand
153	20	Light blue clay, stratas white rock
173	20	Blue clay, sandy layers rock
193	97	Light gray clay, hard and dry
290	40	Blue shale, very hard
330	10	Blue shale, almost rock
340	11	Medium coarse gravel (Fresh water and gas this strata)
351		

"F" OTIS WELL

Depth	Thickness	Character of strata
0	1 ft.	Decayed tule
1	47	Soft gray clay
48	10	Yellow clay
58	58	Light yellow clay, medium hard
116	15	Light gray clay, medium hard
131	5	Dark gray clay, medium hard
136	10	Dark lead clay, medium hard
146	30	Light yellow clay, hard
176	1 ft.	Redwood log
177	20	Medium fine gravel and a little sand
197	20	Coarse gravel
217	20	Yellow clay, soft
237	20	Light green clay, layers of sand
257	14	Gray clay
271	25	Yellow clay, hard
296	20	Fine gravel and coarse sand
316		

"G" FRANK MASKEY WELL

Depth	Thickness	Character of strata
0	2 ft.	Tule root
2	40	Decayed vegetation
42	20	Soft blue clay
62	19	Yellow clay
81	10	Black sand
91	98 ft.	Sand and fine clay
189	4	Dry blue clay
193	35	Sand
228	7	Sand
235		

Exhibit 12—Continued

LOGS OF DEEP WELLS DRILLED

"H" N. V. C. MURDOCK WELL

Depth	*Thickness*	*Character of strata*
0	2 ft.	Tule roots
2	43	Decayed vegetation
45	10	Soft blue clay
55	5	Soft yellow clay
60	15	Red sand
75	10	Soft yellow clay
85	20	Soft blue clay
105	35	Black mud
140	15	Dark clay and sand
155	32	Black mud
187	15	Decayed vegetation
202	1	Old wood and log
203	5	Dark sand and clay
208	25 ft.	Soft blue clay
233	83	Black mud
316	43	Soft blue clay
359	10	Medium blue clay
369	4	Medium hard clay
373	11	Clay and grit
384	15	Fine black sand
399	5′-3″	Clay and grit
404′-3″	36 ft.	Hard blue clay
440′-3″	11	Soft blue clay
451′-3″	5	Sand and clay
456′-3″	12	Fine black sand
468′-3″		Total
468′-3″		

"I" THRELKELD & SCOTT WELL

Depth	*Thickness*	*Character of strata*
0	55 ft.	Peat
55	13	Brown clay
68	15	Clay and gravel
83	7	Brown clay
90	15	Yellow sticky clay
105	50	Sticky clay, blue
155	20	Sandy clay
175	12	Tough sticky clay, yellow
187	8	Sticky clay
195	18	Yellow clay
213	17	Sandy clay, yellow
230	26	Yellow clay
256	8	Clay and sand
264	8	Clay
272	19	Clay and sand
291	8	Sand, hard
299	53	Clay
352	18	Tough sticky clay
370	11	Sandy clay
381	12	Blue clay
393	30*	Clay
523*	16 ft.	Tough sticky clay
539	16	Clay
555	8	Tight gravel, made [illegible] in 9 hours
563	2	Tight sand
565	2	Lava
567	33	Clay
600	42	Lava
642	23	Clay
665	78	Lava
743	132	Clay
875	16	Tough sticky clay
891	167	Clay
1058	30	Hard lava
1088	14	Soft lava gravel, [illegible] water
1102	8	Soft lava
1110	5	Hard lava
1115	35	Lava water
1150	8	Soft blue shale
1158	23	Hard blue shale
1181	31	Blue sand, some water
1212		

* Discrepancy.

"J" FRANK HOWELL WELL

Depth	Thickness	Character of strata	Depth	Thickness	Character of strata
0	2 ft.	Tule roots	60	40	Yellow clay
2	50	Blue mud	100	200	Yellow sandstone
52	8	Yellow sand (brackish water)	300	400	Blue shale (pockets of oil)
60			700		

"K" WARD WELL—Bored in September, 1924

Depth	Thickness	Character of strata	Depth	Thickness	Character of strata
0	3 ft.	Soil	126	4 ft.	Yellow clay
3	2	Coarse gray sand	130	2	Yellow sand
5	20	Peat	132	3	Yellow clay
25	40	Soft blue mud	135	3	Yellow sand
65	40	Fine blue sand	138	1	Yellow clay
105	2	Blue clay	139	2	Yellow sand
107	18	Yellow clay	141	½	Yellow clay
125	1	Yellow sand	141½		
126					

Exhibit 13

ACTION OF SALT SOLUTIONS ON CONCRETE

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

WASHINGTON

San Francisco, California, May 26, 1925.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
110 Agriculture Hall,
Berkeley, California.

Dear Mr. Young:

In reply to your letter of May 22d regarding points of interest to you concerned with use of concrete in the proposed Salt Water Barrier:

Briefly discussing the points in the same rotation you presented them numerically, the following comments are offered:

1. The most desirable characteristic in a concrete projected for exposure to menacing salt solutions is a low permeability factor.

2. How such a concrete of low permeability factor can be fabricated the most economically at any given job can only be determined through experimentation with available aggregate. It is likely considerable care will have to be exerted in selection of aggregate, fabrication and placement to insure a low permeability factor in the structure. Therefore, the assumpton that such a concrete in place will prove more expensive than the ordinary run of concrete used with safety where service conditions are less exacting, is at least a reasonable one.

3. Though cautious practice always favors the use of fresh water in concrete gaging, there are reports that salt water has on occasions been used for the same purpose without apparent detriment to the job. This may indicate that a fresh water gaged concrete can be placed under salt water with the same engineering difficulties and limitations such operations can be successfully accomplished under fresh water. After the conditions most favorable for development of law permeability concrete have been determined, then the question of practicability of the tremie system far handling and placing that prescribed concrete mixture will require attention. This appeals more as an engineering problem involving the

proper physical placing of a prescribed concrete mixture than as a chemical consideration of possible salt water hazards present during placement operation.

4. There are at least two constituents normal to salt water regarded as deleterious to concrete. To the magnesium salts is attributed the power to replace calcium in the portland cement complex with weakening effects. Water-soluble sulphate acts both chemically and physically upon concrete, the latter action largely confined to zones of wetting and drying. Neither magnesium salts nor water-soluble sulphates are present in salt water to the extent dire results must follow the admixture of some salt water with the green concrete. Assuming that all the salts thus presented for combination with the portland cement actually went through the chemical cycle, the tolerance of the cement for the limited dosage available should be manifested.

Real and serious trouble may occur, however, when the accumulative effect of the equivalent of an over-dosage of salts has been administered through the agency of percolating salt water continuously carrying into the concrete structure a fresh supply of harmful salts. The reaction between set cement and sea water is roughly quantitative, and like most chemical reactions, the rate of action is determined by the relative area exposed to such action, assuming the supply of attacking reagent is without limit. Therefore, when attack is limited to structure facing only, the rate of attack will be much slower as compared to a honeycomb condition in the concrete where the contact of attacking reagent with concrete surface is proportionately increased. It is obvious then that a nonporous concrete, that is, a concrete of low permeability factor, will exhibit the greater durability under the exposure conditions found in salt water.

5. Percolating water carrying in sodium chloride to reinforcing steel starts the chemical change of transposing steel to iron chloride, likely mixed with iron oxide, etc. Suffice to state that such chemical changes or corrosion are attended with marked increase of volume over the space originally occupied by the reinforcing features, resulting in the rupture and scaling of the concrete within the pressure area developed. A structure once fractured and split by such action offers no barrier against infiltration of the salt water to work over a relatively large surface of concrete. (See latter part of Paragraph No. 4.) The distance from the facing to place the reinforcing steel to insure against contact with salt water is not readily answered. If the concrete is porous, the salt water may find extensive penetration of the concrete mass. A policy of placing reinforcing steel close to the surface of facing seems justified only where there is assurance the concrete will serve as a barrier against salt water penetration

Yours very truly,

IRVING FURLONG,
Associate Chemist.

Exhibit 14

THE ACTION OF SEA WATER ON CONCRETE STRUCTURES IN AND ADJACENT TO SAN DIEGO BAY

STANDARD OIL COMPANY

SALES DEPARTMENT

SAN DIEGO

In making this investigation and report it has been thought advisable to accumulate and summarize the results of similar investigations, not only on this coast, but wherever it has seemed that the data contained or the conclusions reached would be of value, not only in determining what conditions we might be expected to encounter, but in aiding us to arrive at the proper conclusions from such conditions.

To this end we have summarized and included in this report the following reports on sea water concrete:

1. CONCRETE IN SEA WATER: Rudolph J. Wig and Lewis R. Ferguson.
2. CONCRETE IN SEA WATER: J. L. Harrison.
3. FAILURE OF THE SANTA MONICA PIER: J. H. Quinton, W. [illegible] Barnard and F. H. Olmsted.

Following these summarizations, we have given a general statement of the conclusions reached by these investigators, and have followed this with the report on San Diego Bay conditions.

NOTE.—The detail report on San Diego Bay conditions is not included in this Exhibit. The conclusions are included at the end.—W. R. Y.

I

CONCRETE IN SEA WATER

By Rudolph J. Wig, of The Bureau of Standards, and Lewis R. Ferguson, of The Portland Cement Association, published in Engineering News Record, September 20, 1917, October 4, 1917, October 11, 1917, October 18, 1917, and October 25, 1917.

Objects of the Investigation: To determine the extent, character and causes of failures in concrete structures, plain and reinforced, subject to the action of sea water.

Nature and Scope of Investigation: Personal examination of all the important concrete structures subject to the action of sea water, on both coasts of the United States, and in Canada, Cuba and Panama.

Number of structures examined	130
Number on the Pacific Coast	49
Number in California	34
Number in Southern California	19

Plain Concrete.

Condition of Structures Investigated: The condition of the structures investigated indicated a universal progressive decomposition of concrete structures subject to the action of sea water.

Causes of Decomposition: This decomposition has as its principal cause the chemical action of magnesium sulphate on the interior mass of the concrete above low water line; access to the interior being rendered possible by abrasion of the protective insoluble lime carbonate skin on the concrete. This abrasion is due to the following causes:

(a) Frost.
(b) Ice.
(c) Wave action.
(d) Sand.
(e) Drift.
(f) Vessels.

Corrective Measures:

(a) Rich mixture.
(b) Smooth surface.
(c) Absence of sharp edges.
(d) Avoidance of seams.
(e) Protective coverings—
    1. Wood.
    2. Steel.
(f) Fenders.

Remarks: Deterioration is much more rapid in the North than in the South, due to the action of water freezing and thawing in the surface of the concrete; also to the more violent wave action.

Reinforced Concrete.

Condition of Structures Investigated: Investigation indicated an almost universal tendency of reinforced concrete structures to crack along the lines of reinforcement.

Causes: This action is caused by expansion resulting from corrosion of reinforcing bars due to the chemical action of oxygen and chlorine, which penetrate the concrete above high water line, doing no damage to the concrete, but immediately attacking the steel reinforcement.

Corrective Measures Suggested:

(a) Reduction of the amount of reinforcing to a minimum above high water line.
(b) Placing of reinforcement deeper in the concrete above high water line.

Remarks: Deterioration is more rapid in warm, humid climates than in the North.

Materials Recommended.

Cement: Any standard brand whose specifications fall within the following limits will make satisfactory sea water concrete:

Silica	19 to 25 %
Alumina	4 to 9 %
Iron oxide	2 to 6 %
Lime	60 to 65 %
Magnesia	1 to 5 %
Sulphuric tri-oxide	1 to 2 %

Beach Sand:

Aggregate:

(a) Lime stone.
(b) Gravel.

Water: Investigation indicated that no damage results from the use of sea water in gaging concrete.

Waterproofing Compounds: Waterproofing compounds are not recommended.

Workmanship.

Forms:

(a) Forms should be made tight enough to prevent the leakage of concrete.
(b) Forms should be oiled with a mineral oil.

Mixing Concrete:

(a) A richer mixture than for land work should be used.
(b) Mixture should be proportioned by an actual test of the materials to be used, rather than by an arbitrary ratio.
(c) Mixture should be dry enough to permit light tamping.

Placing Concrete:

(a) Where possible, construction seams should be avoided.
(b) In case of the occurrence of construction seams or joints, surface should be thoroughly cleaned before work is resumed.

Conclusions.

First: Well made concrete, properly placed, if not subject to mechanical abrasion or erosion, is permanent in sea water. Disintegration by chemical action will be very slow unless there is frost action or appreciable mechanical abrasion.

Second: Reinforcing Concrete. No definite conclusions are stated as to methods to be pursued and designs to be adopted to prevent deterioration of reinforced concrete in sea water. Suggestions in regard to possible corrective measures have been stated.

II

CONCRETE IN SEA WATER

By J. L. Harrison, published in "Concrete," November and December, 1919.

A summary of the results of an investigation made of all the important concrete structures in the Philippine Islands which were subject to the action of sea water, the investigation extending over a period of three years, from 1916 to 1919.

Plain Concrete.

Condition of Structures Investigated: The condition of structures investigated indicated a considerable decomposition of plain concrete structures subject to the action of sea water.

Cause of Decomposition: The cause of this decomposition was the chemical action of magnesium sulphate on the interior mass of the concrete; access to the interior being rendered possible in most cases by the porosity or permeability of the concrete.

Reinforced Concrete.

Condition of Structures Investigated: The condition of the structures investigated indicated a considerable amount of disintegration and cracking of reinforced concrete structures.

Cause: This action is caused by expansion resulting from corrosion of reinforcing bars due to the chemical action of chlorine.

Indications pointed to the fact that the presence of chlorine in the interior of the concrete was due, not so much to percolation or capillary attraction, as to the inclusion of sea water and other saline materials in the preparation of the concrete.

Conclusions.

The conclusions of these investigators differ from those of Wig and Ferguson in that the former did not consider that the protective coating of lime carbonate on the surface of concrete structures was sufficient protection against action of the magnesium sulphate contained in the sea water. It is considered that the only protection against such action is a method of construction which will insure practically impermeable and nonporous concrete.

Reinforced Concrete: These investigators disagree with the conclusions of Wig and Ferguson in that they include as a contributing cause of the corrosion of the reinforcing steel, the inclusion of sea water and beach material in the preparation of the concrete, and lay less stress on the matter of the introduction of the chlorine through capillary attraction.

III

THE FAILURE OF THE SANTA MONICA PIER

Engineering New Record, March 25, 1920.

Summary of the report of the Board of Engineers to the City Commission.

Board of Engineers: J. H. Quinton, of Quinton, Code & Hill; Frank H. Olmsted, of Olmsted & Gillelen; W. K. Barnard, of Lees & Barnard.

Description of Structure: This pier, which was built in 1908 and 1909 as a combination pleasure pier and support for municipal outfall sewer, was 1600 feet long and 36 feet wide, and was made up of a concrete floor on timber stringers, supported on concrete floor beams, which rested on concrete caps cast in place on precast reinforced concrete piles, sunk by jetting.

Nature of the Failure: Disintegration of concrete and cracking of the piles; the majority of cracking being above high water line.

Causes of Failure: Chemical disintegration and mechanical fracture of piles, brought about by the penetration of salt water into and through porous and permeable concrete, and the resultant corrosion of the steel reinforcing.

Possible Contributory Causes:

(a) Storms during the erection of the pier.
(b) Electrolysis.

Criticism of Design and Construction:

(a) Steel was not imbedded to a sufficient depth in the concrete.
(b) Beach sand, containing more or less salt, was used in the mixing of the concrete.

In concluding their report the Board of Engineers advised that the substructure of the pier be rebuilt, using creosoted timber piles and creosoted timber caps.

CHEMICAL ANALYSIS OF GOOD AND DISINTEGRATED CONCRETE TAKEN FROM THE PILING OF THIS PIER

	Good concrete	Disintegrated concrete	Loss or gain
Total concrete	142.7547 gr.=100.000%	35.9182 gr.=100.000%	
Insoluble in acid (Rock, sand and SiO_2 in original cement)	115.0721 gr.= 80.608%	25.2734 gr.= 70.364%	
Soluble in acid	27.6826 gr.= 19.392%	10.6448 gr.= 29.636%	
The acid soluble portion consists of:			
Fe_2O_3	1.1120 gr.= 4.017%	0.4473 gr.= 4.202%	0.185% g
Al_2O_3	3.7360 gr.= 13.495%	1.6691 gr.= 15.680%	2.185% g
CaO	11.1480 gr.= 40.271%	1.8256 gr.= 17.150%	23.121% l
SO_3	0.3691 gr.= 1.333%	0.1834 gr.= 1.723%	0.390% g
MgO	0.3980 gr.= 1.438%	1.1715 gr.= 11.005%	9.567% g
H_2O of hydration CO_2 and alkalies	10.9195 gr.= 39.446%	5.3479 gr.= 50.240%	10.794% g

This analysis illustrates very clearly the results of the action of the magnesium sulphate in sea water on the lime in the concrete, the products of this chemical reaction being soluble calcium sulphate and magnesium oxide which is precipitated in the concrete probably in the form of hydroxide.

Conclusions.

The conclusions of the investigators making this report are practically the same as those reached by Wig and Ferguson.

The latter, in their investigations, did not reach any definite conclusions as to means whereby the failure of reinforced concrete structures could be absolutely prevented.

The Board of Engineers, in making their report to the City Commission in regard to the failure of this pier, by their recommendation that the pier be rebuilt with creosoted piling, take in effect the same position.

General Conclusions to be Drawn from Foregoing Reports.

In seeking to reach some definite conclusions from the foregoing reports, we find that while there is considerable difference of opinion as to the cause of certain phenomena, there is a practical agreement on the following points:

1. Good, rich, unreinforced concrete, properly mixed and placed, and protected from abrasive action and from structural stresses,, will give a very long life in sea water.

2. Failure of plain concrete is due to the chemical action of magnesium sulphate, which obtains access to the interior of the concrete, either through abrasion of the surface or by percolation, due to the porosity or permeability of the concrete surface.

3. With present methods of construction, steel reinforced concrete will not give satisfactory service in sea water.

4. Failure of such reinforced concrete is due to the corrosion of the reinforcing steel, caused by the chemical action of chlorine, which obtains access to the steel either by percolation, capillary attraction, or by the use of sea water and saline materials in the preparation of the concrete.

IV

THE ACTION OF SEA WATER ON CONCRETE STRUCTURES IN AND ADJACENT TO SAN DIEGO BAY

Conclusion.

In the three reports which we have summarized it will be noted that emphasis has been laid chiefly on chemical causes of the disintegration and failure of concrete structures. It appears to us that the matter of physical causes should also be considered.

Any failure in concrete structures, whether plain or reinforced, will be due to one of two reasons:

1. The chemical action of magnesium sulphate or of chlorine on the interior mass, or on the steel reinforcement of the structure.

2. Fractures in those members of the structure in which the elastic limit of the materials composing them has been exceeded by stresses, caused by exterior forces, which may be either in the nature of moving loads carried by the structure, or the action of waves, or the swell of the open sea.

Various means for effecting the exclusion of the chemical elements injurious to concrete and the reinforcement have been enumerated in this report.

In the case of plain, unreinforced concrete, it is our opinion that the injurious chemical element of magnesium sulphate can, by proper methods of construction and with the aid of good workmanship, be excluded to a sufficient degree to produce a structure, which, with a reasonable amount of maintenance, will be practically permanent in local waters.

In regard to steel reinforced concrete the problem is more difficult, as the exclusion of the chlorine from the steel reinforcement must be practically absolute in order to prevent the corrosion of the steel and its resultant expansion and the fracture of the concrete.

In the summaries of the reports which we have included in this report special emphasis has been laid on the necessity of rich mixtures, the deep burying of the reinforcement and the exclusion of saline materials in the preparation of the mixture. It is possible, that with all these precautions taken, and with an excellent quality of workmanship, concrete might be made which would entirely exclude the chlorine, but in order to accomplish this result, the most favorable conditions would be necessary.

Taking all these facts into consideration, it is our opinion that the element of risk connected with construction of this sort is too great to make it advisable to use reinforced concrete in structures subject to the action of sea water.

In regard to the physical causes of failure: It may be noted in our report on the condition of local structures, that the two examples of reinforced concrete construction in local waters which show no sign of failure, are both located at points where protection from the action of the open sea is afforded, and that the one example of reinforced concrete construction which is at the present time showing indications of failure, is subject to a very violent wave and swell action from the open sea.

It is our opinion that numerous cases of failures in reinforced concrete structures, the responsibility for which has been laid to chemical causes, have had as the initial cause of failure, minute fractures, due to physical stresses which we have described above, these fractures affording a means of entrance to the injurious chemical elements.

We would say then, in conclusion, that in the protected and comparatively warm waters of San Diego Bay, plain unreinforced concrete structures are practicable, but that even with these favorable conditions, the construction of reinforced concrete structures is not, with present methods of construction, advisable.

Comments on Sea Water

Memorandum, October 25, 1920

Mr. C. O. Van Valer:

H. Le Chatelier (International Association for Testing Materials) finds that the active ingredients of cement (lime aluminates, silicates) are decomposed by the magnesium salts of sea water, yielding soluble calcium chlorides and lime sulphates. The latter, with lime aluminate, forms a compound whose crystalization tends to swell and crack the material.

The substitution of iron for alumina in cement removes one of the most active reagents in the deteriorating effects of the salts in sea water.

The disintegration of concrete in salt water appears to be due less to the action of the water itself than to physical action from outside sources. Cement mortar has remained in perfect condition for 15 to 20 centuries in Italian harbor works although exposed to the constant actions of sea water.

The above confirms Mr. Brown's conclusions.

The experience of the writer while in the service of Velie, Blackwell & Buck, on the East coast, is also in confirmation of Mr. Brown's article, i. e., Monolithic Concrete work with very little or no reinforcement showed no signs of failure when exposed to salt water, while heavily reinforced work such as bridge abutment, wingwalls, etc., deteriorated rapidly.

D. D. Purrington.

Exhibit 15

This exhibit, shown in the original report, is in the form of a pamphlet entitled "Tides and Currents in San Francisco Bay." Copies of this pamphlet may be obtained by application to the United States Coast and Geodetic Survey.

Exhibit 16

CORRESPONDENCE REGARDING DATUM

DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

WASHINGTON

October 16, 1924.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
110 Agriculture Hall,
Berkeley, California.

Dear Sir:

Your letter of September 25, 1924, to Inspector H. C. Denson, U. S. Coast and Geodetic Survey, San Francisco, California, has been referred to this office for reply.

The table of tide planes accompanying your letter has been examined and new values based on the latest information at hand have been supplied. The table is returned herewith. The new values, tabulated on a separate sheet, are also enclosed. (Copied below.)

You will note on the new sheet that standard sea level and standard lower low water correspond to mean sea level and mean lower low water on the old sheet.

Standard sea level was adopted as the standard datum for the precise level net as referred to on page 7 of the U. S. Coast and Geodetic Survey Special Publication No. 22. It is based on 16 years of hourly readings, 1898 to 1913, and reads 8.519 feet on tide staff of 1897 at Presidio. I am informed that the elevation of the U. S. Geological Survey bench marks are now being adjusted and soon will be published, the reference being standard sea level.

Standard lower low water, corresponding to a reading of 5.55 feet on tide staff of 1897 at Presidio, was adopted as a standard datum for hydrographic work by the U. S. Coast and Geodetic Survey on March 23, 1907. It agrees closely with the value for mean lower low water as derived from 26 years of automatic gage record, 1898 to 1923. Standard lower low water is 2.969 feet below standard sea level at Presidio.

With reference to the second paragraph of your letter, you are advised that the relation of mean lower low water to the mean sea level varies as the half range and low water inequality of the tide vary at the different places. For practical purposes mean sea level is considered to be in the same equipotential surface at all points, while mean lower low water would present a warped surface. This explains why different lower low water datums were used for work in the lower harbor and in Suisun Bay, as referred to by Mr. Perkins.

The Coast and Geodetic Survey is always glad to be of service, and if there is any further information you desire, do not hesitate to let me know.

Very truly yours,

R. L. FARIS,
Acting Director.

PRESIDIO, CALIFORNIA

Elevation of tidal datums and mean range of tide in accordance with the best information at hand October 14, 1924, the plane of reference being standard lower low water.

	On 1897 tide staff feet	Above plane of reference feet
City datum, San Francisco	17.385	11.835
Highest tide observed (26 years 1893-1923)	13.7	8.15
Datum of Southern Pacific Railroad	11.650	6.100
Mean higher high water (26 years 1898-1923)	11.16	5.61
Mean of all high waters (26 years 1898-1923)	10.58	5.03
Mean lower high water (26 years 1898-1923)	10.00	4.45
Mean half tide level (26 years 1898-1923)	8.61	3.06
Standard sea level (16 years 1898-1913)	8.519	2.969
Mean higher low water (26 years 1898-1923)	7.80	2.25
Mean of all low waters (26 years 1898-1923)	6.65	1.10
Standard lower low water (adopted in 1907)	5.55	0.00
		Below plane of reference feet
Datum of Central Pacific Railroad	5.183	0.367
Datum of State Engineering Department	----	----
Lowest tide observed (26 years 1898-1923)	3.2	2.35
Mean range of tide (26 years 1898-1923)	3.93	----

110 Agriculture Hall,
Berkeley, California, June 6, 1925.

The Director,
U. S. Coast and Geodetic Survey,
Washington, D. C.

Refer 41/HMA

Dear Sir:

Please refer to letter dated October 16, signed by Mr. R. L. Faris, acting director, addressed to the writer with reference to datum planes in San Francisco Bay. There are points on which I am not yet clear.

For a time subsequent to 1907, the difference in elevation between mean lower low water and mean sea level was 3.102 feet, based on 10 years of observation on what is designated as the fixed tide staff. In the letter from Mr. Faris, the observations are made on what is designated as the tide staff of 1897 and the difference in the low water and standard sea level planes is given as 2.969 feet. Are these two different tide staffs or are they identical, at least so far as the elevation of the "0" is concerned?

Apparently the elevation of the plane of standard lower water, fixed in 1907, has been held constant and the absolute position of the plane of mean sea level has been dropped 0.133 feet. Is this assumption correct?

In the enclosed table, which is copied from a table accompanying Mr. Faris' letter, there is a greater change in the elevation of the datum planes of the Central Pacific and Southern Pacific R. R. than is represented by the 0.133 feet above. Have the elevations of these two planes been changed, as represented in column three of the table, or were there errors in the elevations as shown in column one?

At places situated like Collinsville, at the mouth of the Sacramento River, and the head of Suisun Bay, is it probable or possible for the elevation of the mean tide plane, assuming it has been correctly determined by sufficient observations, to be appreciably higher than mean sea level, due to the influence of a heavy constant flow of fresh water?

Respectfully,
WALKER R. YOUNG, *Engineer.*
Bureau of Reclamation.

Exhibit 16—Continued

U. S. Coast Geodetic Survey
August 13, 1907.
Tidal Division

Presidio, California

The tide planes given below were obtained from the records for the 10 years, 1897-1907, at Presidio, California.
(See note)

	Column 1 On fixed tide staff, feet	Column 2 Above plane of reference, feet	Column 3 On tide staff of 1897, feet	Column 4 Above plane of reference, feet
City datum, San Francisco	17.318	11.768	17.385	11.835
Highest tide observed	13.718	8.168	*13.70	8.15
Datum of Southern Pacific Railroad	11.178	5.628	11.650	6.100
Mean higher high water	11.320	5.770	*11.16	5.61
Mean of all high waters	10.694	5.144	*10.58	5.03
Mean lower high water	10.068	4.518	*10.00	4.45
Mean half tide level	8.694	3.144	*8.61	3.06
Mean sea level; this is U. S. G. S. Datum (=Standard sea level)	8.652	3.102	**8.519	2.969
Mean higher low water	7.910	2.360	*7.80	2.25
Mean of all low waters	6.694	1.144	*6.65	1.10
Mean lower low water: C. & G. S. datum also datum U. S. Army Engineers, and State Harbor Commission, San Francisco, California (=Standard lower low water)	5.550	0.000	#5.55	0.00
		Below plane of reference		Below plane of reference
Datum of Central Pacific Railroad	4.678	0.872	5.183	0.367
Datum of State Engineer Department	4.438	1.112	----	----
Lowest tide observed	2.958	2.592	*3.20	2.35
Mean range of tide	4.000	----	*3.93	----
Zero of Mission Rock tide staff, 1872	2.909	2.641	----	----
Zero of Union Iron Works tide staff	2.617	2.933	----	----
Zero Powell Street tide staff, 1895	2.497	3.053	----	----
Zero Sausalito tide staff, 1877-1897	0.129	5.421	----	----
Zero Presidio tide staff, 1897	0.000	5.550	----	----
Zero Fort Point tide staff, 1854-1877	0.291	5.841	----	----
Zero Mission Street tide staff, 1889	3.556	9.106	----	----

* For 26 years.
** For 16 years.
\# For 10 years.

According to Mr. Pond, Assistant Engineer in the office of Colonel Deakyne, this datum plane is used for work in the lower harbor, but for work in Suisun Bay they use the same datum plane as the Debris Commission, which is 3.6 below mean sea level. (This note added by W. A. Perkins, Sacramento Valley Investigations, August, 1924.)

Columns 3 and 4 by U. S. C. & G. S., Washington office, brought up to October 14, 1924. See their letter of October 16, 1924.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
WASHINGTON

June 16, 1925.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
110 Agriculture Hall,
Berkeley, California.

Dear Sir:

With reference to your letter of June 6, 1925, requesting further information relative to datum planes at San Francisco, Calif., the following statements are submitted:

The value for mean sea level as given in the first column of the table accompanying your letter and that given in the third column of the table are both referred to the zero of the staff of 1897. The difference in the elevation of this datum as given in the two columns is due to the difference in the length of series on which these values are based. Mean sea level varies from day to day, from month to month, and from year to year due to variations in meteorological conditions. There is a rough periodicity in these variations but they can not be accurately foretold. A good determination of mean sea level requires several years of observations. While from time to time a number of different tide staffs have been used at the Presidio tide station through their connection to the same primary bench mark, all of the observations have been referred back to the staff of 1897.

Standard lower low water adopted in 1907 has, as you have inferred, been held constantly at the same elevation, while mean sea level as adopted since that date and based on 16 years of observations from 1898 to 1913, inclusive, has been lowered 0.133 foot. These datums have been referred to a number of standard bench marks in the vicinity of the tide station and recovery through these bench marks will be much more reliable than through the tide staff itself, which has been renewed from time to time. This Bureau will be glad to furnish descriptions and elevations of these bench marks upon request any time they are desired.

In regard to the datum planes of the Central Pacific and Southern Pacific railroads, this office is unable to say whether the elevations of these two datums have been changed or not. The elevations given for these datums in the first and third columns of your table are evidently based on statements submitted to this office at different times. The values given in the third column are based on a sketch furnished by Assistant Chief Engineer J. R. Barlow of the Southern Pacific Railroad Company on December 22, 1910, and also on the descriptions and elevations of several bench marks furnished by Mr. Barlow on February 7, 1911.

At places situated like Collinsville, where there is a considerable outflow of fresh water, the local mean tide level must necessarily be higher than the ocean mean sea level. After the local mean tide level has been determined from a series of tidal observations, the difference in elevation of the two datums can best be determined by leveling to the nearest bench mark, which is referred to mean sea level.

It is hoped the above statements will give you the information you desire, and this Bureau will be glad to be of service to you at any time.

Very truly yours,

R. L. FARIS,
Acting Director.

Exhibit 17

EXTRACTS FROM JOURNAL OF THE CALIFORNIA STATE SENATE FOR 1863

THE FLOOD OF 1861 AND 1862

"During the prevalence of the floods of last winter, while the incidents connected with them were fresh in the memory of all, copies of the following circular, the object of which is explained by itself, were addressed to each of the county surveyors throughout the state. At the same time, letters were addressed to responsible persons in different parts of the state, requesting them to furnish this office with any reliable information regarding the destruction by the late flood of any old landmarks or evidences of antiquity, which would tend to show the extent of the floods of 1862, as compared with those of former years:

Surveyor-General's Office,
Sacramento, February 13, 1862.

Sir:

It is deemed of utmost importance to preserve in concise form in the state archives, for future reference, as much statistical information as possible in regard to the recent floods throughout the state.

The most proper method of obtaining such information seems to be through the surveyors of the several counties, acting under instructions from the Surveyor-General.

There is no appropriation out of which such services can be paid, but it is hoped that an interest in the general welfare will prompt each of the county surveyors to as efficient a performance of this duty as possible.

You will, therefore, whenever opportunity occurs, so far as it can be done without expense to the state, collect all possible information upon the points indicated below, and any other information you may deem of importance in this connection, and report to this office in July next:

First: The extreme height above low water at any well designated points upon streams in your county.

Second: Date of highest water.

Third: The general depth over the adjacent lands.

Fourth: The approximate quantity of land overflowed in your county.

Fifth: If the banks of the streams have been seriously affected, state in what manner and to what extent.

Sixth: If any bars were formed, or considerable change of channel occasioned, state the facts and circumstances.

Seventh: If there was much deposit upon submerged lands, state the general depth and character of it.

Eighth: Upon swamp and overflowed lands, state the depth of water and general direction of the current, depth of deposit, etc.

It is suggested also, that all persons having facilities for doing so, should be requested to mark distinctly, upon large trees, or other objects not liable to removal, the point of highest water.

The value of this information will readily suggest itself to the surveyors of counties containing swamp lands belonging to the state, in reference to their future reclamation.

Very respectfully, your obedient servant,
J. F. Houghton, Surveyor-General.

To ——————,
County Surveyor.
—————— County, California."

The following quotations are from the report of the Surveyor-General:

"The result, so far as answers have been received, has been highly satisfactory, and the testimony furnished in the report of Amos Matthews, county surveyor of Yolo, and of Dr. Louis M. Booth of Stanislaus, furnish strong circumstantial evidence that the flood of 1862 is without parallel in centuries past.

In Yolo County, Indian mounds of great depth, formed of the lightest material, which would almost float in still water, bearing unmistakable evidence of great antiquity in the large oaks growing upon them, have been almost entirely carried away, trees and all, leaving strewn along the course of the current, numberless skulls and other bones of the tribes who once inhabited the valley of the Sacramento, and who made these mounds, at the same time the home of the living and the resting place of the dead.

Reliable information has reached me of the destruction by the rising of the waters melting the sun-dried bricks of which it was constructed, of an old adobe house in Solano County, built 25 years since, in a position which had never before been above the rise of the waters. Evidence which is believed to be reliable has been received of a similar disaster to an old adobe, built in the valley of Russian River 50 years since.

By the report of Dr. Booth, it will be seen that the Stanislaus River, which, to all appearances, had for centuries discharged its waters through its proper channel, and allowed alluvial deposits to accumulate upon its banks to the depth of 10 or 12 feet, and upon the top of this deposit oaks from 5 to 10 feet in diameter to grow undisturbed for more than 300 years, during the great flood of 1862 tore away its old banks, carried away considerable tracts of land well grown over with timber, and uprooted and carried down its swollen stream the trees which its waters had so long nourished, and in some places left its old bed, and formed a new channel entirely away from it.

The report of Mr. Drew, county surveyor of San Joaquin, in answer to the circular, contains full statistics of the flood in the vicinity of Stockton, and the county, which will be valuable in reference to the reclamation of the great body of swamp lands bordering the San Joaquin and other rivers in that county.

The county surveyors of Lake and Fresno have also furnished valuable information respecting the flood in their counties.

An erroneous impression prevails to a considerable extent, created chiefly by a series of well written articles published last spring in several public journals of the state, that the Straits of Carquinez, connecting Suisun and San Pablo bays, have, by incapacity to discharge a sufficient amount of water, contributed largely to the overflow of the Sacramento Valley.

It is a well admitted and self-evident principle in hydraulics, that when an obstruction to the free passage of any current of water occurs, it is accompanied by a corresponding rise in the water. Had the writer of these articles applied this simple test to the Straits of Carquinez, no complaints would have been made of their want of capacity

The highest water ever known at Benicia was occasioned by an extraordinary high tide, being eight inches higher than any previous spring tide, and occuring about the 5th or 6th of January, 1862, or several days before the highest flood, and at no time afterwards was the water so high as on that day.

Upon the swamp lands bordering the Suisun Bay on the north, at a distance of about a mile below Collins' Landing, hogs lived all winter with no floating islands to flee to, showing that there could not have been two feet of water at any time on the marsh.

Ascending the Sacramento, at a distance of a mile above Collins', the water was about four feet over the marsh, and at Rio Vista it has increased to about eight feet."

"Also I am under many obligations to Dr. Thomas M. Logan of Sacramento for valuable information which he has allowed me to compile from his most complete and reliable records; also, for a chart showing the oscillations at Sacramento, extending over a period of 13 years. * * * During the later part of the month of November, and the first few days of December, 1861, large quantities of snow fell in the mountains to the east and north of us.

The average temperature of the month of December for eight years, at Sacramento is forty-six and thirty-one hundredths degrees (46 deg. 31) December, 1862, being forty-three degrees (43 deg.); while the average of December, 1861, reaches the high figures of fifty and ninety-eight one hundredths degrees, (50 deg. 98), and the few days preceding the flood still higher, as follows: December 7th, fifty-six degrees (56 deg.); December 8th, fifty-seven and sixty-six one hundredths degrees (57 deg. 66); December 9th, fifty-one and sixty-six one hundredths degrees (51 deg. 66).

On each of these days a warm rain was falling, which rapidly melted the large accumulations of snow in the mountains, and the rivers, already high, receiving these accessions of rain and melted snows of the 7th and 8th of December, reached here on the 9th of December, with the result already too well known. * * *

The flood of January, 1862, which reached its highest point at Sacramento about 9 o'clock p.m. of the 10th of said month, combined all the unfavorable circumstances of that of the previous month, with the most remarkable downfall of rain ever recorded. * * *

Mr. Begole reports from December 23 to December 30, seven and fifty one-hundredths inches of rain; December 30 to January 9, six and sixty-five one-hundredths inches; January 10, five and eighty-two one-hundredths inches; January 11, five and fifty one hundredths inches; being a total of twenty-five and forty-seven one-hundredths inches in 19 days, or eleven and thirty-two one-hundredths inches in 48 hours, ending with January 11. This includes 10 inches of snow, which is reduced to rain, being about equal to one inch; and also shows a total of forty-five and three one-hundredths inches falling in that locality from December 23 to January 23.

Dr. Logan's report shows that on the 8th of January there fell at Sacramento, six hundred and eighty-one thousandths inches rain; January 9, one and four hundred one-thousandths inches; January 10, seven hundred and sixty-one thousandths inches; January 11, nine hundred and ninety-six one-thousandths inches; and a total for the month, of fifteen and thirty-six one-thousandths inches. The nearest approach to which was in December, 1849, in which fell 12½ inches; and next, in March, 1850, in which month fell 10 inches."

"December 3, 1862.

* * * I have received a circular from your office, propounding eight questions having reference to the floods of last winter. By personal examinations and inquiry I have endeavored to collect such information as was possible, and will give you only such as may be reliable, as in many cases it is so conflicting as to be unavailable.

First: The highest water in Stockton was on the 24th day of January, 1862, being 12 feet 1 inch above the low tide of this date; December 3, 10 feet 6 inches above the high tide of this date, and 3 feet 6 inches above the highest water in the flood of 1852. About 15 miles northwest from this city, in Township 3, North, Range 5, East; the highest water was on the 24th day of January, being 14 feet higher than the summer low tides.

In Township 1, South, Range 5, East, 12 miles from this city, in a southwesterly direction, and near the forks of the San Joaquin River, the highest water was on the 24th day of January, 12 feet above the summer low tides, and 5 feet above the highest water of 1852.

Second: The first heavy flow of water, from the east or mountain streams, occurred on the 26th day of December, on which day the city was slightly submerged. On the 28th day of December, the water in the city was a few inches higher than on the 26th.

On the 11th day of January occurred the greatest overflow of the country to the northeast, east and southeast, caused by the water from the mountain streams. The highest water in this city and on the land to the west, was on the 24th day of January, being 24 inches higher than on the 11th of January. This was back water, and came from the north, or Sacramento River; no current near the city. A short distance to the west of the city, on this and several subsequent days, there was a strong current running past the city from the north, and running nearly due south, to a point six miles south from this city, there meeting the waters of the San Joaquin, and changing the direction of the current to a northwest course.

Third: It is difficult to answer this question satisfactorily. I believe about two-thirds of our entire county was inundated. Of the agricultural and grazing portion, about one-half. Over this portion the water would average one and a half to two feet in depth.

Fifth: The banks of the streams have not been seriously affected.

Sixth: No considerable bars or changes of channel have been occasioned by the flood.

Seventh and Eighth: There was no large amount of deposit left on the agricultural portion—perhaps an average of two inches except at a few points on the river bottoms. This deposit was a very fine sand or slum, and to the most of our land was an advantage. It is impossible to tell the amount of deposit there may be on the tule lands, as they are still submerged.

The greatest danger we have of a recurrence of the events of last winter is from the waters of the Sacramento and American rivers breaking over the plains to the north, as it was the waters from these rivers which caused the greatest amount of damage in this vicinity. Aside from the Sacramento water, the damage in this vicinity would not have exceeded $10,000. * * *

GEORGE E. DREW,
County Surveyor of San Joaquin County."

"December 10, 1862.

* * * As to the height of the waters above low water mark in the last flood, it was impossible for me to keep any memorandum of it; but I have been told that at the head of the Cache Slough, at a place called Main Landing, the water was 10 feet above the ground, which would make it about 18 feet above low water mark. In the marshes around Suisun City, the greatest height attained was only about two feet six inches, which would give about nine or ten feet above low water mark. In the islands in Suisun Bay the water did not rise more than six inches above the marsh, and that only at the highest tides. All these islands were covered with cattle, and they continued on them all winter without the least inconvenience, and have been doing all the time exceedingly well.

In your letter of the 28th of November, last, accompanying your circular, you mention the washing away of Baca's house on Putah River. I never heard of it, but, however, it is possible, as that house was built very near the bank and immediately below a ford, and the least overflow of the river would wash any adobe building.

JOHN PEABODY,
County Surveyor, Solano County."

"December 2, 1862.

* * * Am of the opinion that such a flood as the last has not occurred within the last hundred years, and, perhaps, never since the Great Flood receded from the land. The evidence upon which I found my opinion, in part, is the undoubted fact, that many years ago, the banks of the Sacramento were inhabited by populous tribes of Indians, who have disappeared from the face of the earth. In witness, we see the numerous mounds scattered along the river bank through the whole valley. These mounds must be very old; some of them had large oak trees, grown from acorns carelessly thrown aside by this extinct race. These mounds, till within a year, retained their shape as left by the aborigines; there could be seen the excavation scooped out where stood the principal hut, with numerous smaller cavities, used for like purposes. Now the flood has destroyed the original shape of the mounds, and we see but a heap of earth strewed with the skulls, which, for centuries, had lain covered with the light ashes and mould of which the mounds were composed. Some say the Indians did inhabit the valley, but were destroyed by a great flood, wherefore we do not find their descendants; but all of us have seen just such mounds on high lands, where no modern flood has ever reached; and the apparent age of these mounds indicates their inhabitants to have been coeval with those who lived along the river. The mounds are of the lightest material, and accumulated slowly, in long years, from ashes and decayed vegetable matter. In my opinion, if floods had often occurred, they would have been washed away ages ago. In one place on the river I saw an innumerable number of skulls, the mound in which they were buried having been almost entirely swept away. In many places great oak trees, centuries old, have been uprooted and carried away. The Indians have no knowledge of any disaster which happened to their ancestors by reason of floods, and their traditions must certainly extend back a hundred years, as many of them have lived three-quarters of that time.

In reply to your request for statistics of the late flood, I can state, perhaps, but little not generally known. This county was pretty generally overflowed, either by the river or by the rush of water from the coast mountains. The greatest depth of water in the tule, west from Sacramento, was about 15 feet. Considerable quantities of sediment were deposited. I think we should ask to know how the water stood at different points with reference to the river when its banks were full, with no regard to height above low water mark. The river, at this point, rose about two feet above its banks; 15 miles farther down, about three feet; and at Rio Vista, where the incline plane of the river meets the horizontal plane of the bay, it rose nearly eight feet. There was but little current in the river during the flood. The water, as is natural, ran where was the greatest fall, that is, where there is a fall of 1 in 16 by the tortuous course of the river, there may be a fall of 1 in 4 on a direct line. In one instance, the counter current carried a barn two miles up the river, and deposited it on the opposite bank, where it now stands.

AMOS MATHEWS,
County Surveyor."

"December 26, 1862.

Hon. J. F. Houghton,
Surveyor-General.

Dear Sir:

In response to your questions in relation to the late flood, I have obtained from Mr. J. D. Morley, of Stanislaus County, the following replies in relation to the effects of the flood in that county, and also certain other information which is thereto appended:

First: The extreme height above low water mark at well designated points upon the Tuolumne and Stanislaus rivers, was 20 feet, but where the Tuolumne River flows through the mountains, the extreme height was 50 or 60 feet. The extreme height above low water mark at well designated points on the Merced River and Dry Creek. was 15 or 16 feet.

Second: The water attained its greatest height on the 10th or 11th of January, 1862.

Third: The lands in Stanislaus County adjacent to the Tuolumne, Stanislaus and San Joaquin rivers, and Dry Creek, were overflowed to the depth of 8 or 10 feet.

Fourth: All lands bordering upon streams in Stanislaus County were overflowed. The Tuolumne and Stanislaus rivers overflowed land to the width of about a mile; the San Joaquin, in Stanislaus County, overflowed lands to the width of from 5 to 20 miles. Persons living upon lands overflowed by that stream only saved their lives by fleéing to the mountains and high lands. Dry Creek overflowed lands to the width of from one-quarter to two miles.

Fifth: The banks of the Tuolumne and Stanislaus rivers have been very seriously affected by washing; in some places the width has been increased from 200 to 1500 feet; and whenever those rivers rise five or six feet, there will be three or four channels at different points, all occasioned by the washing of the late floods. The banks of the San Joaquin are very little changed, the river retaining its original channel. Tuolumne River, by changing its channel and overflowing its banks, has destroyed many ranches by washing away the soil.

Sixth: The Tuolumne and Stanislaus rivers have changed their channels in many places, and large sand bars have been formed in those rivers. The San Joaquin retains its original channel, and there are no bars to obstruct the navigation.

Seventh: There was a deposit of light, sandy material upon most of the submerged lands in Stanislaus County, varying in depth from six inches to four feet.

Eighth: Upon the swamp and overflowed lands in Stanislaus County the depth of water was about 10 feet, the current running west-northwest. The deposit was less than upon some of the higher lands, varying in depth from four inches to two feet, the deposit upon submerged lands near the mountains and low hills being always greater than upon the lower lands. The deposit upon the swamp lands was more of a vegetable character than that upon the higher lands.

Nine-tenths of the crops upon the Tuolumne and Stanislaus rivers were destroyed, and many houses were swept off; a general destruction of fencing occurred; many cattle and horses perished in the flood; the destruction of timber was very great, caused entirely by the soil being washed away from the roots of the trees by the immense volume and velocity of the water. Many of the ferryboat landings were entirely destroyed by washing of the banks, changes of channel and formation of bars.

In relation to Merced County, on the Merced River the effects of the flood were very similar to those occasioned by the Tuolumne and Stanislaus rivers.

The effects of the flood in Mariposa County, generally, in consequence of the face of the country being more hilly, were that so great an area was not overflowed, and the injuries were confined principally to mining improvements upon the banks of the Merced River and various creeks, the water rising as much as 50 or 60 feet above low water mark.

At such times as I receive information in relation to the flood, I will send it to you.

Yours respectfully,

W. H. Lyons."

"Branche's Ferry, Stanislaus County,
December 5, 1862.

W. H. Lyons, Esq.

Dear Sir:

In answer to your note of the 1st instant, I would state that it gives me great pleasure to impart any information in my power regarding the subjects mentioned in the Surveyor-General's circular:

First: On the Tuolumne River, at this point (Section 35, 3, South, 13, East), the extreme height was about 30 feet above low water mark, and about seven feet higher than the high water mark of the flood of 1851 and 1852.

Second: About meridian, on the 10th of January, 1862. On Saturday, the 11th, at 12 o'clock, it having fallen three or four feet in the interval, it was a few inches lower.

Third: From 7 to 20 feet.

Fourth: All the bottom lands on the Tuolumne River, from bluff to bluff. I should think that 10 times as much land was submerged as lies within the United States meandering posts.

Fifth: The banks of the river have all been washed away; in some places to the extent of five or six rods.

Sixth: Old bars were washed away, and new ones formed. The channel was changed every half mile, in many instances sweeping away all the bottom lands, in others, cutting a new channel through the center of a ranch.

Seventh: In some instances the flood left large deposits on the land of a light sandy character, unfit to sustain vegetable life. The flood appears, in most cases, to have swept off the soil and original deposits to the depth of from 5 to 20 feet, and as the water subsided, to have deposited sand and loose gravel of various depths.

Eighth: I can only state that I believe that nearly every acre of overflowed land within the United States meandering lines on the Tuolumne River has been swept away, or rendered valueless by a deposit of sand, as the water fell.

In reply to the concluding clause of your letter I would state that no flood of like character and extent has occurred on the Pacific slope for many hundred years. The evidences in support of this conclusion are to be found in the facts that the land washed away along the river banks was originally formed from alluvial deposits, in some places 10 or 12 feet above the bed rock, where the Indians had for years bruised the acorns and seeds for food, forming dozens of small and large holes in the rock. The period of time occupied in forming 10 or 12 feet of deposit, including a foot or two of soil, geologists can determine. Upon that deposit grew oak trees from 5 to 10 feet in diameter, washed up and carried down the stream. Some of them must have been more than 300 years old. In some places the hearts of large oak trees can now be seen lying on the bed rock where 10 or 12 feet of the original deposit has been washed down stream.

My ranch, as well as those of many of my neighbors, was rendered nearly valueless by the sweeping away of the soil and depositing afterwards of loose gravel and fine sand, which the wind blows hither and thither as it changes.

In a hurried manner I have given you all the information thought of at this moment; any further questions answered with pleasure.

I should estimate the damage caused by the flood on the Tuolumne River, from Jacksonville to its mouth, at not less than $150,000.

Yours respectfully,
Louis M. Booth, M. D."

Exhibit 18

PRECIPITATION AND SACRAMENTO RIVER STAGES

Preceding and During the Storm of January, 1914

Date	Rainfall in inches			Sacramento River
	United States Weather Bureau	Mountain Copper Company	Southern Pacific Railroad	United States Weather Bureau
	Sacramento, California	Suisun Point, California	Suisun, California	Sacramento gage at 7:00 a.m.
November 1 to December 30, 1914	----	Total for November, 1913—4.97 Total for December, 1913—6.63 Total for January, 1914—9.63 Total, July 1913 to June, 1914—26.15 Seasonal rainfall largest for period 1905 to 1925	8.26	----
December 31	----		3.25	----
January 1	.04		1.32	26.4
January 2	.36		.40	23.6
January 3	----		.30	24.1
January 4	----		----	23.5
January 5	----		----	23.4
January 6	----		----	23.2
January 7	.50		.27	23.0
January 8	----		.32	23.0
January 9	----		----	23.0
January 10	----		----	22.9
January 11	----		----	22.8
January 12	.57		.16	22.2
January 13	.24		1.60	21.8
January 14	.78		.71	22.4
January 15	----		.45	23.8
January 16	.03		----	23.6
January 17	.48		.23	23.0
January 18	.05		.76	24.3
January 19	.03		.14	24.3
January 20	----		----	24.2
January 21	.74		.43	24.1
January 22	.50		3.14	23.9
January 23	.31		----	25.4
January 24	.56		1.06	25.5
January 25	.76		.30	26.0
January 26	.02		.99	27.2
January 27	----		----	27.7
January 28	----		----	27.5
January 29	----		----	27.2
January 30	----		----	26.8
January 31	----		----	26.3
Total	5.97		----	----

Maximum for month—27.8 at 9 a.m., January 27th

Exhibit 19(a)

HIGH WATER IN THE DELTA

CALIFORNIA DELTA FARMS, INC.

Pacific Finance Building. Los Angeles.

Belding Building. Stockton.

Stockton, California.
October 31, 1924.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
110 Agriculture Hall,
Berkeley, California.

Dear Sir:

In further reply to your letter of October 16th regarding the elevation of water surface in the Delta territory during extreme high tide.

The extreme high tide to which you refer on January 25, 1914, occurred in the Delta territory as you describe in your letter and was primarily the result of a severe storm on the ocean. I have not all the details of the figures relating to that tide. The peak of it, however, gave the highest water level in the lower Delta around the junction of Old River with the San Joaquin that has ever occurred so far as we know, with the exception of the high water of 1907.

At the top of this tide the water stood in this territory at an elevation of practically 9.5 U. S. E. D., or 5.9 U. S. G. S. datum. The high water in the flood of 1907 during the latter days of March stood at an elevation of 10.3 U. S. E. D. This high level of the water on January 25, 1914, was undoubtedly contributed to by the flood waters that were coming down the Sacramento and San Joaquin rivers.

It is interesting to note, however, that this date was three or four days earlier than the peaking of the flood of the Sacramento and San Joaquin rivers in this territory. You probably have the records from the Sacramento Weather Bureau showing the daily flood elevations of the Sacramento at Rio Vista and the San Joaquin at Lathrop during all of the flood period. A reference to those tables for the period about January 25, 1914, will show that the flood waters peaked at Rio Vista and Lathrop along about the 28th or 29th of January.

The storm on the ocean in the interval between the 25th and the 29th had abated, yet notwithstanding the fact that the flood waters adjacent to the junction of the San Joaquin with Old River were raising, the peak of the tide in this territory was steadily lowering. I have not the exact figures on the rate of this dropping, but I have very clearly in mind that during these three or four days the peak of the high tide at this junction of the rivers dropped somewhere between 1.0 and 1.5 feet and this drop removed the serious menace under which our levees existed on January 25.

There was on the peak of this tide on the afternoon of January 25 in the San Joaquin Delta only one mishap which did not turn out seriously. On the Webb Tract for a distance of something over 700 feet the inside half of the levee dropped vertically, as a result of a longitudinal crack in the levee, a distance of from two to five feet, putting the interior half of the levee far below the elevation of the top of the tide. Fortunately a narrow strip of the levee next to the water side ranging from two to five feet wide on top held and continued to hold until the tide receded. It may be said in this connection too, that the peak of the tide was of probably about one hour's duration. This recession of the tide relieved the pressure and we were enabled with dredgers to strengthen the levee materially before the next tide came, which was on the afternoon of the 26th and, incidentally, this tide was about four inches lower than the one of the 25th.

Following this, as I said before, the tide continued to recede each day and in the meantime we had strengthened the levee so that no serious damage resulted.

Regarding the high water of February 25, 1917, I have no record covering this water. I do have in mind that about that time there was a high tide, but it was not of such moment that we paid any attention to it, possibly because our levees were better and it did not interest us.

Another fairly high tide that caused us some misgiving occurred on February 11, 1919, at which time the top of the tide went to 8.5 U. S. E. D., and my remembrance is that there was no material flood water coming down the river. We were particularly interested in the situation at that time because we had only a short time previously enclosed the new Bouldin Island levees and of course a tide of this height was somewhat menacing. So far as our properties were concerned, however, this elevation was not a serious menace, existing as it did only for a very brief period.

Yours very truly,
G. A. ATHERTON.

Exhibit 19(b)

HIGH WATER IN THE DELTA

CALIFORNIA DELTA FARMS, INC.

Pacific Finance Building. Belding Building.
Los Angeles. Stockton.

Stockton, California,
June 27, 1925.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
110 Agriculture Hall.
Berkeley, California.

Dear Mr. Young:

In reply to yours of June 19, I have the following information for you:

On February 20, 1925, the high tide peak was 8.0 feet, U. S. E. D., at the Bouldin Island pump, which is on the west side of Bouldin Island, about a mile upstream from the mouth of the Mokelumne River.

At the same place the water on the 19th was 7.5 feet and on the 21st 7.6 feet. At the King Island pump, which is on the dredger cut between Empire Tract and King Island, at 5 o'clock on February 20 water stood on our U. S. E. D. gauge at 7.9 feet, at the top of the tide. The conditions at this time were evidently abnormal.

Under ordinary conditions the difference in the time of high tide between Ft. Point and Bouldin Island as fixed by general observations that we have made is about six hours. The difference between Ft. Point and Stockton is about eight hours, and we have always estimated that at King Island the difference was about seven hours. On February 20 the high tide at Ft. Point was at 8.50 a.m., which should have brought the high tide at King Island at about 4 o'clock, which would seem to indicate a lag of probably an hour on February 20.

The report that you have from Chipps Island of the tide, 9.2 feet, in connection with the very much lower level up in our territory, is somewhat of a parallel to the conditions that existed in 1909 when the water near Antioch was materially higher, according to reports that we received, than it was in 1907, when we on the upper river had our highest water, and although I have no records of how high the water actually was in our territory at that time, yet it was not sufficiently high to cause us any alarm and was materially lower than it was in 1907.

Yours very truly,
G. A. ATHERTON.

Exhibit 20(a)

MEMORANDUM REGARDING TIDES BY N. B. HUNT

December 22, 1924.

Subject: Tidal characteristics at proposed sites for Salt Water Barrier—Sacramento Valley Investigations.

1. Data relative to tidal characteristics are valuable in connection with various studies to determine the feasibility and type of a Salt Water Barrier below the

confluence of the Sacramento and San Joaquin rivers. Unfortunately, the exhaustive study which this subject merits can not be undertaken at the present time but the information which has been obtained will be an aid, at least, in eliminating uncertainties.

2. Data have been secured at two stations at the Army Point site, one station at the Dillon Point site and one station at the Point San Pablo site and include in each case water surface elevations and velocities at various depths from surface to bottom throughout a tidal cycle. The stations were selected with a view to ascertaining the maximum velocity in the section and with the exception of one station at the Army Point site the measurements were made during Spring tides. A drawing showing elevation and velocity curves has been prepared for each observation station. (Plates 5-1, 5-2, 5-3 and 5-4.)

3. The data may be useful in the following ways:

(a) Velocities are an important factor in the construction of a cofferdam or the rock fill section of the barrier, assuming this type will be recommended.

(b) The tendency to scour may be judged from the velocities near the bottom.

(c) The velocity of flow of the water in the tidal prism computed on the basis of volume of prism and time required to flow in or out, may be checked roughly by means of the measured velocities.

(d) The form of curve corresponding to fluctuation in water surface must be known in order to calculate the discharge through the gates of the barrier during a tidal cycle.

(e) A use for the data may be found in flood–plane studies, especially those concerned with conditions below the barrier.

4. Data should be used subject to the following considerations:

(a) The configuration of the land may be such that the main currents of the flood and ebb are deflected to different parts of the section.

(b) Results are dependent to an uncertain degree upon the flow of the Sacramento and San Joaquin rivers during the measurements.

(c) The direction of flow below surface during measurements D and L at Army Point on September 19 and 20 was not determined with certainty.

5. Velocities were measured from the downstream end of the drill barge with a small Price electric penta meter suspended on a 3/32 in., single strand, galvanized airplane cable which was wound on a reel. One or two 30-pound torpedo weights, as depth and velocity required, were suspended below the meter. The cable was marked at 5 and 10-foot intervals with strips of white and red cloth held in place by wire through the strand of the cable. The barge draws about two feet of water and has a 45-degree overhang at each end.

6. The direction of flow below the surface was determined by the inclination of the meter cable and is doubtful in cases already mentioned because the velocities were too low to cause inclination. The inclination might be misleading in the case of strong cross-currents at different depths but their presence could probably have been detected as the meter was lowered and the cable came under their influence gradually.

7. At Dillon Point the direction of flow fluctuated through an angle of about 30 degrees and often was not the same near the bottom as at the surface. At Point San Pablo the early flood flow at the surface approached the barge from a point between San Quentin and the Marin Islands while the direction of current below the surface was perpendicular to the line of drilling.

8. When the tide was changing from flood to ebb, and vice versa, the flow at the surface was observed to be opposite in direction from that near the bottom in all cases when the latter was determined. According to John R. Freeman, in his report of 1903 on the Charles River Dam, there is an old saying among pilots that "the flood tide comes in first on the bottom." Observations in Boston Harbor under his direction confirmed this statement (p. 403 of his report). He is not so definite in describing the flow at different depths when the flood was changing to ebb but the measurements which are the subject of this memorandum indicate that not only does the flood tide come in first on the bottom but that it is sustained near the bottom after the ebb has begun at the surface, or in other words, that the ebb tide begins first at the surface. From the foregoing it is to be expected that the early flood tide is strongest near the bottom and the early ebb tide is strongest at the surface and it is believed that the velocity curves justify such a conclusion in spite of some inconsistencies. Reference to the drawing shows that the ebb flow continued for about two hours after the water surface had begun to rise and

the flood flow continued for about the same length of time after the water surface had begun to fall.

9. In every case the greatest velocity during a tidal cycle occurs between half tide and higher high water or lower low water. The greatest velocities which preceded the two extreme stages of the tide are given in the following table:

Date, 1924	*Place*	*Max. vel. preceding higher high water (flood)*	*Max. vel. preceding lower low water (ebb)*	*Time of max. vel.*
September, 19-20	Army Point	2.44	2.58	3 hours before lower low
October 1	Army Point	3.47	5.83	1 hour before lower low
October 30	Dillon Point	4.91	4.45	2 hours before higher high
November 26	Point San Pablo	4.34	6.44	2 hours before lower low

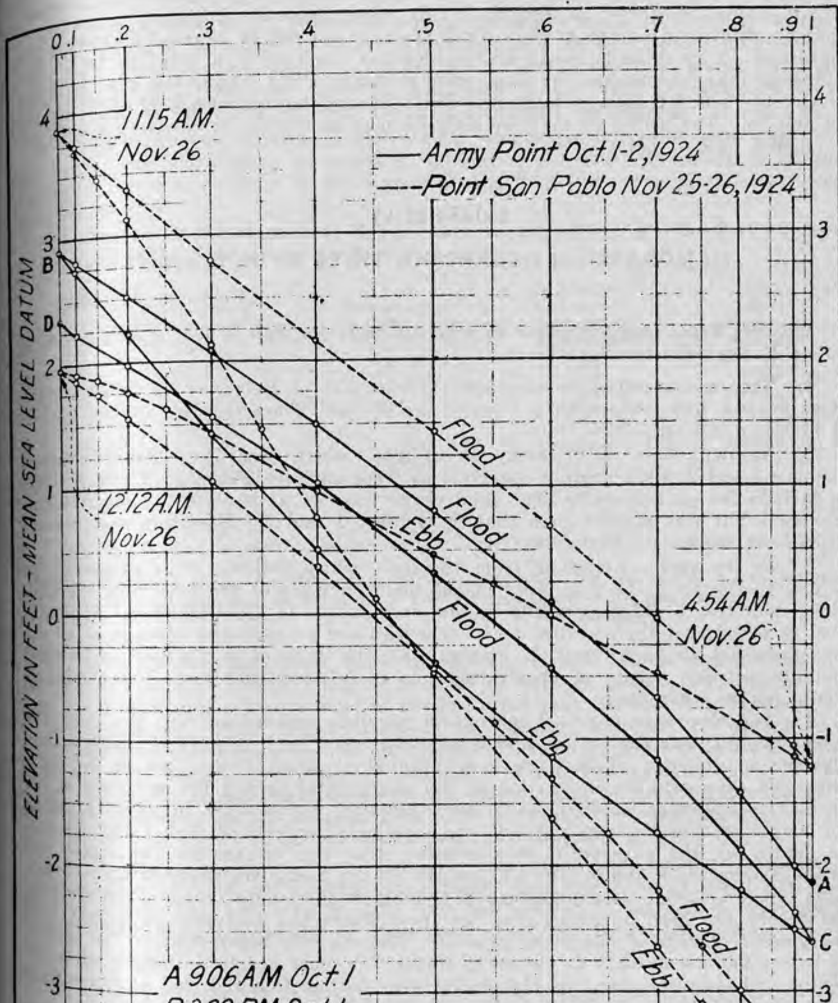
10. A comparison of velocities near bottom shows very little difference between ebb and flood. Actually the average of the ebb velocities at the lowest depth during a tidal cycle is greater than the flood in all cases except the measurements of September 19 and 20 at Army Point. The greatest recorded velocity at the lowest depth occurred during the ebb tide and was 2.92 feet per second. (Measurement 0 at Point San Pablo.)

11. The approximate flow of the rivers into Suisun Bay, in second-feet, for a few days preceeding each current meter measurement is given below, in second-feet. The Mokelumne was measured at Clements; the Cosumnes at Michigan Bar; and the Calaveras at Jenny Lind. No allowance is made for the difference in time required for the water to reach the bay from the various gaging stations nor is the return flow to the river channels below the gaging stations included but it is believed that the results are not affected materially.

Date, 1924	*Sacramento at Sacramento, second-feet*	*San Joaquin at Vernalis, second-feet*	*Mokelumne, Cosumnes, Calaveras, second-feet*	*Combined flow to Suisun Bay, second-feet*
September 16	2,800	412	42	3,254
September 17	2,790	408	96	3,294
September 18	3,010	416	109	3,535
September 19	3,150	422	113	3,585
September 20	3,140	422	32	3,594
September 28	3,520	430	24	3,974
September 29	3,470	416	12	3,898
September 30	3,310	402	8	3,720
October 1	3,370	402	26	3,798
October 2	3,520	402	36	3,958
October 27	5,920	554	34	6,508
October 28	5,950	554	37	6,541
October 29	7,620	554	951	9,125
October 30	11,700	554	737	12,991
October 31	10,200	690	408	11,298
November 22	11,000	1,410	280	12,690
November 23	13,700	1,360	300	15,360
November 24	13,000	1,410	220	14,630
November 25	11,500	1,410	250	13,160
November 26	10,700	1,460	250	12,410
November 27	9,860	1,460	250	11,570

The estimated flow of the rivers during flood has been placed at 750,000 second-feet and the statement has been made that under extreme conditions that flow in Carquinez Strait is always toward the ocean. It is not known with what degree of certainty this continuous ebb flow was determined but it is evident that surface observation is not reliable because of the greater strength of the flood tide near the bottom at certain times.

12. With a reversal of current the river flow is held back during flood tide and the fresh water discharge must vary during a tidal cycle from zero to at least twice the average. Even with no reversal of current it is probable that the discharge of fresh water is comparatively little at high tide and must consequently, at low tide, be greatly in excess of the average. This range in fresh water discharge during a tidal cycle will not necessarily be increased by the barrier since the increase in head may balance the reduction in waterway area and maintain the same rate of discharge at high tide.



—Army Point Oct. 1-2, 1924
---Point San Pablo Nov 25-26, 1924
11.15 A.M. Nov. 26
12.12 A.M. Nov. 26
4.54 A.M. Nov. 26
5.18 P.M. Nov. 25
6.12 P.M. Nov. 26
Flood
Ebb
A 9.06 A.M. Oct. 1
B 3.20 P.M. Oct. 1
C. 9.50 PM Oct. 1
D 4.38 A.M. Oct. 2
ELEVATION IN FEET - MEAN SEA LEVEL DATUM
FRACTIONS OF TIME INTERVAL BETWEEN HIGH & LOW WATERS
SEMI SINUSOIDAL COORDINATES
N.B.H. - H.U.W. 12-22-24

13. The gage readings for each tidal cycle has been plotted on semisinusoidal coordinates to show the silimarity of the tidal wave to a true sinusoid, which plots in the form of a straight line. A close approximation to the true sinusoid would justify using the latter as typical in all calculations involving the tidal wave, thereby effecting a saving in time, since the sinusoid can be drawn by plotting the elevations of crest and trough and connecting them with a straight line. The following curves represent the tidal wave at Army Point during the measurements of October 1 and 2 and at Point San Pablo during the measurements of November 25 and 26. The utility of the true sinusoid may be decided in connection with the particular case at hand.

Exhibit 20(b)

MEMORANDUM REGARDING TIDES BY N. B. HUNT

February 17, 1925.

Subject: Tidal characteristics at proposed sites for Salt Water Barrier—Sacramento Valley Investigations.

1. This memorandum is supplementary to that of December 22, 1924, on the same subject and deals with a comparison of tidal characteristics during periods of high and low run-off.

2. At drill hole 3550, Army Point site, which was the station occupied October 1 and 2, 1924, further observations were made on February 7 and 8, 1925, to include the peak run-off. The tidal range was not at its monthly maximum at this time but was greater than that of October 1 and 2. Elevation and velocity curves are shown on Plate 5-5.

3. In drawing conclusions from the data which follows, it is necessary, as before, to recognize the possibility of the main currents of the flood and ebb tides being deflected to different points in the cross-section of the waterway. It should also be noted that the so-called mean velocities are actually the average of all the measurements in each vertical, disregarding the lack of uniformity in vertical distance between points of observation. It is believed that more exact methods would not be warranted.

4. The observations failed to confirm previous indications that the flood tide comes in first near the bottom and is stronger near the bottom in its early stages. Changes in direction of flow are more gradual at Army Point than at the other sites and there was no inclination of the meter cable during the reversals at the surface to indicate the direction below. Allowing for changes in velocity during the elapse of time between the first and last measurements of each vertical series as shown by the subsequent measurement near the surface as the meter was raised, the curves F and K indicate that the change took place nearly simultaneously from top to bottom. In explanation of this discrepancy with previous observations the theory has been advanced that the fresh water has increased in weight with the greater amount of silt in suspension. The ebb tide began first at the surface as before but its strength in the early stages was more nearly uniform at different depths and it is probable that the change near bottom followed that at the surface more closely.

5. A comparison of the tidal curves for the two periods of observation at drill hole 3550 shows the more recent to be higher in actual elevation than the predicted tides, while the former are generally lower and resemble in this respect most of the observations at other sites. Great reliance should evidently not be placed on the evidence of the predicted tides but the inference that abnormal conditions prevailed on February 8 is unavoidable and is strengthened by other peculiarities of the curve for this date. The water surface is generally higher in elevation than at any previous time for which records have been obtained. Lower high water is at very nearly as high as the preceding higher high water and higher low water is at mean sea level elevation. It it is not known to what degree the height of tide is subject to the influence of the wind but it seems probable that its effect is secondary to that of the run-off through a period of large variation such as occurred from October 1 to February 8. This belief if justified by observations at Army Point on

September 19, 1924, during a strong upstream wind when the observed higher high water was nearly one foot lower than predicted. (The above does not refer to severe storms on the ocean.)

6. The maximum velocity recorded during the tidal cycle (5.19 feet per second) occurred about 2¾ hours before lower low water and agreed approximately as to time with previous observations at this site. Notwithstanding more favorable conditions for high velocities, however, with respect to run-off and range of tide, it was less than the maximum on October 1 (5.83 feet per second).

7. The maximum velocity at the bottom occurred during ebb and was 3.14 feet per second, the highest measured at bottom at any site. Contrary to earlier measurements, the velocities at the bottom during flood were generally much lower than for the ebb.

8. The flow of the rivers into Suisun Bay, in second-feet, for the first 10 days of February, 1925, is given in the following table:

Date, Feb., 1925	*Sacramento at Sacramento, second-feet*	*San Joaquin at Vernalis, second-feet*	*Mokelumne* Calaveras, Cosumnes, second-feet*	*Combined** flow to Suisun Bay, second-feet*
1	20,400	1,180	660	22,240
2	21,500	1,220	530	23,250
3	21,700	1,260	550	23,510
4	28,900	1,260	2,000	32,160
5	60,200	1,360	11,500	73,060
6	83,000	6,770	38,100	127,870
7	111,400	16,260	11,400	139,060
8	133,200	11,360	8,020	152,580
9	128,900	8,910	6,170	143,980
10	121,200	6,530	4,440	132,170

* Mokelumne at Clements, Calaveras at Jenny Lind, and Cosumnes at Michigan Bar.

** No allowance made for difference in time required for the water to reach the bay from the various gaging stations. The figures do not include drainage water from areas not gaged, but the percentage of error is not large.

9. The statement previously made, to the effect that surface observations do not furnish reliable evidence that no reversal of current takes place, appears to have less significance in the absence of further proof that the flood tide is strongest at the bottom at certain times. Data is too meager, however, to warrant an assumption that this phenomenon is entirely eliminated during floods and assurance must still rest upon a knowledge of conditions at all depths. The effect of the run-off on the tide at the different observation stations may be judged approximately from the following tabulations, making due allowance for the uncertainty in direction of flow below the surface which generally prevailed at slack tide.

10. In conclusion, it appears that the tidal characteristics are maintained during variable run-off with greater uniformity than might be expected and the effect of the flood of February 8, 1925, was not sufficiently marked to serve as a measure of the volume necessary to cause continuous flow toward the ocean.

RELATIVE DURATION OF FLOOD AND EBB TIDES

Place	Date	Length of flood, hours			Length of ebb, hours			Ratio, flood to ebb
		Lower low to lower high water	Higher low to higher high water	Total	Lower high to higher low water	Higher high to lower low water	Total	
Army Point	Sept. 19-20	6.5	*6.0	12.5	5.0	6.8	11.8	1.06
Army Point	Oct. 1- 2	5.9	5.2	11.1	*5.3	7.8	13.1	0.85
Dillon Point	Oct. 30-31	5.3	6.1	11.4	*5.4	8.3	13.7	0.83
Point San Pablo	Nov. 25-26	6.4	6.3	12.7	4.8	*7.7	12.5	1.02
Army Point	Feb. 7- 8	5.4	4.3	9.7	6.6	*8.4	15.0	0.65

RELATIVE MAXIMUM MEAN VELOCITIES DURING FLOOD AND EBB

Place	Date	Velocity, feet per second		Ratio, flood to ebb
		Flood	Ebb	
Army Point	Sept. 19-20	2.2	2.0	1.10
Army Point	Oct. 1- 2	2.8	3.8	0.74
Dillon Point	Oct. 30-31	4.1	4.0	1.02
Point San Pablo	Nov. 25-26	3.8	5.2	0.73
Army Point	Feb. 7- 8	2.4	4.3	0.56

* Estimated.

Exhibit 21(a)

CORRESPONDENCE REGARDING EXTREMELY HIGH TIDES

DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

WASHINGTON

January 13, 1926.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
Department of the Interior,
2054 University Ave., Berkeley, Calif.

Dear Sir:

Your letters of December 28, 1925, and January 2, 1926, relative to high tides in San Francisco Bay, and addressed to the Inspector, U. S. Coast and Geodetic Survey Field Station, San Francisco, Calif., have been referred to this office for reply.

With regard to the fourth paragraph of your letter of December 28, 1925, it will be noted that the tidal data for the period 1878–1896 are given on pages 41 and 42 of U. S. Coast and Geodetic Survey Special Publication No. 115, Tides and Currents in San Francisco Bay. (See Exhibit 15.) The records show that the highest tide at Sausalito during this period occurred on January 16, 1878, the height being 3.1 feet above mean high water, 5.1 feet above mean sea level. This height is very close to the height of highest high water at Presidio on November 18, 1918, which was 5.2 feet above standard sea level.

With reference to the fifth paragraph the records on file in this office show that the highest tides at Fort Point in 1861 and 1862, respectively, occurred on December 31, 1861, and January 1, 1862, the heights being 4.6 and 4.1 feet, respectively, above mean sea level. Although these are not the highest tides observed at Fort Point, the record being 4.9 feet above mean sea level on November 5, 1869, it is found that the water surface in January, 1862, was materially raised as indicated by the following:

Sea level for January, 1862, was the highest observed during the period 1860-1876, being 0.6 foot above mean sea level. Mean low water for that month was the highest obtained at Fort Point. Mean high water for the month was unusually high, and was only exceeded by the monthly means for September, 1876, and this was but 0.01 foot higher. The mean range for January, 1862, was the smallest range obtained for any month during the period 1860–1876, indicating that the tide was materially affected by meteorological conditions. As Fort Point was the only station in San Francisco Bay or tributaries where tidal observations were made during the period December, 1861–January, 1862, we are unable to furnish you with corresponding elevations at any other station for this period.

Referring to your letter of January 2, 1926, the extreme high water on November 18, 1918, may be attributed to a combination of astronomical and meteorological causes. The moon was in perigee on November 17 and on November 18 it was full, the combined effect of which would tend to give a large range of tide.

The predicted astronomical high water on the 18th was 6.7 feet above mean lower low water, or 3.8 feet above standard sea level, which leaves a difference of 1.4 feet to be accounted for by meteorological causes.

The following data relative to the weather on November 18, 1918, were obtained from the San Francisco office of the U. S. Weather Bureau:

The 18th was rainy, with 0.06 inch of rain on the 17th, and 2.34 inches on the 18th. A low pressure was to the northward of San Francisco, with a minimum of 29.70 inches at 8.45 a.m., 18th, at San Francisco. Winds commenced from the southeast at 7 p.m. on the 17th and continued through the 18th, reaching a velocity of 45 miles an hour at 8.34 a.m.

In connection with this subject a letter from the inspector of the U. S. Coast and Geodetic Survey Field Station, San Francisco, Calif., dated December 6, 1918, stated that there was a strong southerly wind and heavy seas outside on November 18, 1918.

Should you desire further meteorological data, it is suggested that you communicate with the San Francisco office of the U. S. Weather Bureau, as this subject does not come within the purview of this survey.

Very truly yours,
E. Lester Jones, Director.

Exhibit 21(b)

CORRESPONDENCE REGARDING EXTREMELY HIGH TIDES

Department of Commerce
U. S. Coast and Geodetic Survey
Washington

February 23, 1927.

Mr. Walker R. Young,
Construction Engineer,
Department of the Interior,
Bureau of Reclamation,
Ellensburg, Washington.

My dear Sir:

Your letter of February 9, 1927, requesting tidal data for the Golden Gate and addressed to the U. S. Coast and Geodetic Survey, San Francisco, California, has been referred to this office for reply.

The predicted higher high water for San Francisco for December 31, 1861, is 2.8 feet above mean sea level, and that for January 1, 1862, is 2.6 feet above mean sea level.

At Presidio the observed sea level for January, 1914, was 0.5 foot above mean sea level.

Very truly yours,
R. L. Faris, Acting Director.

Exhibit 21(c)

CORRESPONDENCE REGARDING EXTREMELY HIGH TIDES

Department of Commerce
U. S. Coast and Geodetic Survey
Washington

March 2, 1927.

Mr. Walker R. Young,
Construction Engineer,
Department of the Interior,
Bureau of Reclamation,
Ellensburg, Washington.

My dear Sir:

Your letter of February 21, 1927, requesting the elevation of sea level at Presidio for the month of November, 1918, and addressed to our San Francisco office has been referred to this office for reply.

Our records show that the observed sea level at Presidio for November, 1918, was 0.4 foot above mean sea level.

Very truly yours,

R. L. FARIS, Acting Director.

Exhibit 21(d)

CORRESPONDENCE REGARDING EXTREMELY HIGH TIDES

UNITED STATES DEPARTMENT OF AGRICULTURE
WEATHER BUREAU
WASHINGTON

March 5, 1927.

Mr. Walker R. Young,
Bureau of Reclamation,
Department of the Interior,
Ellensburg, Washington.

Dear Sir:

Receipt is acknowledged of your letter inquiring as to the meteorological conditions existing in the vicinity of San Francisco, Calif., on December 31, 1861, and January 1, 1862.

The nearest weather reporting station to San Francisco in operation at the time indicated was at Benicia Barracks, about 25 miles northeast of San Francisco, and we are furnishing herewith a statement of the weather conditions existing at that point on the dates indicated.

In addition to the data for Benicia Barracks, we are sending herewith a statement concerning the weather conditions at Ft. Bragg, which is located apparently about 135 miles northwest of San Francisco, for January 1, 1862. No record was made at that place during the latter part of 1861. As of possible interest we are also inclosing a statement from Fort Crook, which is located in the interior portions of northeastern California. None of these reports seem to indicate the presence of any particular storm on the Pacific Coast at the time indicated by you.

Respectfully,

P. C. DAY, Meteorologist,
In Charge of Division.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
CLIMATOLOGICAL DIVISION

Washington, D. C., March 3, 1927

Copy of the original record of observations made by observers of the Army Medical Force at places in California named on the dates and at the hours specified below.

1861-1862 (December 31 and January 1) Presidio (gap in record from October 9, 1861, to January 11, 1862)

Benicia Barracks, 25 miles northeast of San Francisco

Date	Temperature, degrees fahrenheit		Precipitation			Wind force and direction		Character of sky
	Hour	Thermometer	Hygrometer		Total (inches) 24 hours ending	Force	Direction	
1861—								
December 31	7 a.m.	52	50	Not stated	0.08	1	E.	Cloudy
December 31	2 p.m.	58	55			2	NE.	Fair
December 31	9 p.m.	53	51			1	E.	Cloudy
1862—								
January 1	7 a.m.	51	49	----------	none	1	E.	Fair
January 1	2 p.m.	56	53	----------		2	W.	Fair
January 1	9 p.m.	51	48	----------		2	W.	Fair

Exhibit 21 (d)—Continued

Fort Bragg, on coast, 135 miles northwest of San Francisco

1861, December, no record latter part of month, after 7 a.m., 19th

1862— January 1----------	7 a.m.	48	52	----------	none	1	NW.	Fair
January 1----------	2 p.m.	61	58	----------		2	NW.	Fair
January 1----------	9 p.m.	50	50	----------		2	NW.	Fair

***Fort Crook, in interior northeastern California**

(See below)

1861— December 31--------	7 a.m.	35	32	----------	none	2	NW.	Cloudy
December 31--------	2 p.m.	43	39	----------		2	NW.	Cloudy
December 31--------	9 p.m.	29	27	----------		1	NW.	Cloudy
1862— January 1----------	7 a.m.	25	23	----------	none	1	SE.	Fair
January 1----------	2 p.m.	40	36	----------		1	SE.	Fair
January 1----------	9 p.m.	28	26	----------		1	SE.	Fair

NOTES:—No readings of pressure are found. "Hygrometer" reading seems to mean a stationary wet-bulb moistened by wick, save in freezing weather, when wet for each observation. "Force" of wind may be on scale 1-10 or instead the "Beaufort", 1-12. No entry above 8 is noted and very few above 5.

*Fort Crook not in present day atlases. Latitude and longitude are entered 41° 10′ or 40° 10′, and 121° 20′. (Even where entered consistently we find these latitudes and longitudes not always approximately right). If 41° 10′ the fort was probably near Pitt River, between Redding and Alturas. If 40° 10′, the fort was probably near Feather River, between Oroville and Quincy.

Exhibit 22

MECHANICAL ANALYSIS OF SILT

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

Report of Mechanical Analysis of Sediment Submitted by Bureau of Standards, San Francisco, California, for U. S. Engineer's Office, San Francisco, Calif.

Mare I'd. Strait

Air Analyzer (per cent blown off)

Lab. No.	0.01 mm	0.02 mm	0.04 mm
50132	28.6 %	40.9 %	97.0 %

The sizes of separations are as determined by two dimensional microscopic measurements of cement particles—Specific Gravity 3.1 to 3.2.

The sediment was disintegrated by soaking in water and then dried in very thin cakes. These cakes were crushed with the hands until all of the material passed through a No. 70 sieve. It is probable that the sediment is finer than indicated by the 0.01 mm and 0.02 mm separations—the action of the air being too gentle to break up agglomerations of particles. It is believed that the 0.04 mm separation indicates the true fineness of the material.

By the same system of measurements described above, the maximum size of separation of the standard No. 200 sieve is about 0.11 mm. Comparatively, then, the 0.01 mm, 0.02 mm and 0.04 mm determinations correspond approximately to 0.1, 0.2 and 0.4 the size of separation of the standard No. 200 sieve. That is, they approximate separations of No. 2000, No. 1000 and No. 500 sieves, if such sieves could be constructed.

W. H. SLIGH,
Div. VII-2, Bureau of Standards.

Washington, D. C., January 22, 1925.

Exhibit 23

THE CONTROL OF SEA WATER FLOWING INTO LAKE WASHINGTON SHIP CANAL

The exhibit accompanying original report was in form of a pamphlet by E. Victor Smith and Thomas G. Thompson, reprinted from Industrial and Engineering Chemistry, Vol. 17, No. 10, page 1084, October, 1925. It has not been reproduced in the printed report.

Exhibit 24

CORRESPONDENCE AND TABLES RELATIVE TO FRESH WATER ABOVE LAKE WASHINGTON SHIP CANAL

W. J. Barden, Colonel,
Corps of Engineers,
District Engineer,
602 Burke Building,
Seattle, Wash.

110 Agriculture Hall,
Berkeley, Calif.
July 6, 1925.

Reference: Your letter of March 30, File No. 161.51/54.

Dear Sir:

1. Relative to the last paragraph, which discusses the quantity of fresh water necessary to keep the lakes at Seattle fresh, are data available which show the surface area and storage capacity of the lake created by the dam and which show approximately the flow of fresh water entering the lake required to keep the chlorine below 250, 500 and 1000 parts per million under conditions of present average traffic through the locks.

2. It is assumed that the quantity of fresh water required is considerably in excess of the 100 to 200 second-feet which is discharged continuously through the salt water conduit at the locks. It occurs to me that if water in excess of that passed through the salt water conduit were entering the lake, its passage through a conduit in the dam at as low an elevation as practicable would result in drawing off the more concentrated salt water near the bottom of the canal.

3. Although in case of the proposed Salt Water Barrier there will undoubtedly be seasons during which all water should be conserved for use upriver, it may be necessary for the accomplishment of the purpose of the barrier to use some of the river discharge for the purpose of controlling salinity in the lake. We are concerned over the feasibility of keeping the lake sweet and hope that you have data suggested in paragraph 1 above.

Respectfully,

WALKER R. YOUNG,
Engineer, Bureau of Reclamation.

Exhibit 24—Continued

WAR DEPARTMENT
UNITED STATES ENGINEER OFFICE
SEATTLE, WASHINGTON

WJB/EVM.
July 20, 1925.

Refer to File No. 161.51/62.

Mr. Walker R. Young, Engineer,
Bureau of Reclamation,
Department of the Interior,
110 Agriculture Hall,
Berkeley, Calif.

Dear Sir:

With reference to your letter of July 6, Mr. A. W. Sargent, Assistant Engineer, in charge of the Lake Washington Ship Canal, submits the following memorandum:

"The area of Salmon Bay, Lake Union and Lake Washington is approximately 25,000 acres. The following table shows the average discharges per day, July 19, 1924, to May 18, 1925, over the spillway dam and through the lock culverts, not including that required for lockages or that passing through the salt water conduit."

AVERAGE DISCHARGE IN CUBIC FEET PER SECOND, PER DAY

Date	*Lock culverts*	*Spillway dam*
July, 1924		
19	0	0
to		
November		
10	0	0
11	1500	0
12	1800	0
13	100	0
14	1800	0
15	900	0
16	400	0
17	1200	0
18	400	0
19	1200	0
20	1800	0
21	1100	0
22	1600	0
23	1800	0
24	800	0
25	700	0
26	0	0
27	700	0
28	0	0
29	0	0
30	0	0
December		
1	0	0
2	0	0
3	300	0
4	1600	0
5	2400	0
6	400	0
7	1100	0
8	1100	0
9	1100	0
10	2400	0
11	2400	0
12	1800	0
13	900	0
14	2100	0
15	1800	0
16	1600	0
17	1800	0
December, 1924—Continued		
18	600	0
19	900	0
20	900	0
21	700	0
22	900	0
23	900	0
24	300	0
25	2100	0
26	1300	0
27	1200	0
28	2400	0
29	1700	0
30	400	0
31	400	0
January, 1925		
1	300	0
2	0	0
3	0	0
4	1700	0
5	1600	0
6	600	0
7	600	0
8	400	0
9	0	0
10	900	0
11	0	0
12	300	0
13	300	0
14	1200	0
15	800	0
16	400	0
17	600	0
18	1200	0
19	1200	0
20	400	0
21	900	200
22	1800	800
23	1000	800
24	400	800
25	1800	800
26	600	800
27	1800	800
28	1200	800

Exhibit 24—Continued

AVERAGE DISCHARGE IN CUBIC FEET PER SECOND, PER DAY

Date	Lock culverts	Spillway dam
January, 1925—Continued		
29	1800	800
30	400	800
31	1700	1500
February		
1	2000	3200
2	2400	9700
3	1800	2100
4	1800	1200
5	2400	1200
6	1800	2800
7	1800	1200
8	1600	5600
9	600	4000
10	900	1600
11	1800	1600
12	900	1200
13	900	300
14	700	0
15	900	0
16	600	800
17	1800	800
18	1800	800
19	1200	1140
20	1800	2850
21	2400	4800
22	1500	980
23	2400	995
24	500	920
25	400	1100
26	0	450
27	900	0
28	1800	0
March		
1	1800	0
2	900	0
3	800	0
4	1200	0
5	0	0
6	0	0
7	0	0
8	400	0
9	900	0
10	600	0
11	700	0
12	300	0
13	0	0
14	300	0
15	2300	0
16	1200	0
17	700	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0

Date	Lock culverts	Spillway dam
March, 1925—Continued		
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0
31	0	0
April		
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	700	0
7	1200	0
8	900	0
9	900	200
10	900	800
11	300	800
12	100	800
13	0	800
14	0	800
15	0	800
16	0	800
17	0	800
18	0	1190
19	0	1800
20	0	1800
21	0	1800
22	0	800
23	0	800
24	300	800
25	0	800
26	0	800
27	0	200
28	0	0
29	0	0
30	0	0
May		
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	1200	0
10	1200	0
11	1200	0
12	600	0
13	500	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	

Exhibit 24—Continued

Dates when salinity tests were made and lake elevations at time of test 1924-1925	*Number of times large lock was filled during period*	*Approximate average discharge during period, cubic feet per second* Lock culverts	Spillway dam
July 19 (23-10) August 19 (23-6)	254	0	0
August 19 to September 13 (23-3)	402	0	0
September 13 to October 20 (23-7)	530	0	0
October 20 to November 10 (25-1)	242	0	0
November 10 to December 13 (24-10)	438	1009	0
December 13 to January 10 (24-9)	244	1004	0
January 10 to February 14 (25-1)	442	1177	1270
February 14 to March 14 (24-10)	372	924	540
March 14 to April 11 (25-3)	332	326	64
April 11 to May 18 (25-3)	690	134	422

"The small lock was filled 800 to 1000 times per month. The discharges are approximate and are based on a record which is kept of the length of time each spillway gate is open, height of opening, and times when water is discharged through large lock culverts. The formula for discharge given in U. S. Geological Survey Water Supply Paper No. 200 was used."

Conclusions.

"Our condition here would be much improved if the salt water sump above the locks were enlarged. This would allow more of the salt water to be held near the discharge culvert where it could be carried away before it raised to a point where it would overflow and travel up through the canal to the lakes.

The bottom of our sump is four feet lower than the upper mitre sill of the large lock and the intake of the salt water conduit two feet above the bottom of the sump. The area of the sump is about 400,000 square feet. A sump two or three times larger, six or eight feet deep, with the intake of the salt water conduit a little above the bottom, would probably keep the lakes reasonably clear of salt under our present conditions of discharge and lockages with 200 or 300 second-feet continuous discharge through the salt water conduit.

If part of the water passing over the spillway were carried through the dam at as low an elevation as practicable, instead of all over the spillway, some additional salt would be carried off."

Yours very truly,

W. J. Barden,
Colonel, Corps of Engineers. District Engineer.

1 Encl. Copy of Salinity Test.

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	Oct., 1914	Jan., 1917	June, 1917	July, 1917	July, 1919	Feb., 1920	March, 1921	Oct., 1921	June, 1922	May, 1923	Dec., 1923
Lake Washington, Madison street	0		2			2	3		3	3	3	2
	50		3			2	3		3	3	3	3
	100		3			2	3		3	3	3	3
	150		3				3		3	3	3	3
	175								3		3	
	200		2			3	3		3	3	3	3
Light, Laurelhurst Point	33								16			
Union Bay (at Foster Island)	0								4			
	10								5			
	20								18			
	25								182			
Portage Cut	0					5	3		6	3	3	3
	10					3	3		14	2	3	3
	20					4	3		173	2	4	3
	25			3		3			378	3	5	
	27											3
	29								505			
University Bridge	0		3	3		6	3	3	36	3	3	7
	10		3	3		7	3	3	37	3	3	7
	20		3	4		7	3	3	178	3	3	151
	25								1,210			
	30					650	3	3	1,985	4	3	309
	35								2,400			
	40					770	3		2,507	4	4	356
	43							3				
Lake Union Gas Plant	0		7	7		13	7	3	70	4	14	32
	10		17	7		15	9	3	111	3	16	56
	20		25	7		32	9	3	145	5	23	225
	25								1,350			
	30		1,092	15		1,690	9	3	2,875	10	26	1,625
	35								3,760	26	110	
	40		5,195	1,721		3,608	4,149	3	4,710	420	1,030	3,935
	45						5,040	5	5,830	3,995	3,565	4,390
	47										4,210	4,450
	50		5,268	5,221		5,260		9			4,040	

19 70686

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	July, 1924	Aug., 1924	Sept., 1924	Oct., 1924	Nov., 1924	Dec., 1924	Jan., 1925	Feb., 1925	March, 1925	April, 1925	May, 1925
Lake Washington, Madison street	0	----	----	----	----	----	----	----	----	----	----	----
	50	----	----	----	----	----	----	----	----	----	----	----
	100	----	----	----	----	----	----	----	----	----	----	----
	150	----	----	----	----	----	----	----	----	----	----	----
	175	----	----	----	----	----	----	----	----	----	----	----
	200	----	----	----	----	----	----	----	----	----	----	----
Light, Laurelhurst Point	33	----	----	----	----	----	----	----	----	----	----	----
Union Bay (at Foster Island)	0	----	----	----	14	3	3	3	----	----	----	----
	10	----	----	----	22	7	3	3	----	----	----	----
	20	----	----	----	68	9	3	3	----	----	----	----
	25	----	----	----	141	174	5	4	----	----	----	----
Portage Cut	0	3	3	8	101	70	3	3	3	3	3	4
	10	3	3	11	140	79	3	3	3	3	3	3
	20	3	3	38	196	294	3	3	3	3	4	3
	25				248							
	27	3	4	205		372	3	3			4	3
	29									3		
University Bridge	0	7	5	26	95	75	3	3	3	3	3	4
	10	6	4	27	104	75	3	3	3	3	3	4
	20	6	4	328	375	340	3	3	3	3	3	3
	25											
	30	131	10	895	785	505	3	3	3	3	3	3
	35											
	40	265	430	990	865	515	3	3	3	3	3	3
	43	265										
Lake Union Gas Plant	0	29	71	120	167	295	15	9	6	8	3	7
	10	30	70	121	202	302	17	9	7	8	3	8
	20	92	70	390	340	345	40	20	12	8	3	11
	25											
	30	1,380	1,280	2,380	1,925	977	94	20	17	9	7	13
	35						180	23			11	
	40	3,740	2,940	3,810	3,140	3,360	2,545	2,205	19	16	28	850
	45	3,905	3,970	4,302	3,885	3,695	3,220	3,210	19	435	920	1,675
	47	3,915	3,960			3,750	3.520	3,385	2,065	2,275	2,255	2,130
	50											

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	Oct., 1914	Jan., 1917	June, 1917	July, 1917	July, 1919	Feb., 1920	March, 1921	Oct., 1921	June, 1922	May, 1923	Dec., 1923
Lake Union Brick Yard	0		18	8			9		123	3	27	128
	10	354	20	9			10		121	3	26	145
	20	363	21	10			9		175	7	29	241
	25								1,660			
	30		29	24			9		2,885	35	38	1,250
	35								3,810			
	40	440		384			2,275	16	4,730		1,245	3,980
	42		4,200									
	43								5,090			
	45										4,235	4,330
	48										4,385	
East Side, Lake Union	0											
	10											
	20											
	30											
	35											
	40											
	45											
	47											
Brace and Hergert Lumber Mill	0			9					123		28	
	10			9					124		27	
	20			8					150		29	
	30			10					2,620		50	
	35								3,780		76	
	37								4,285		258	
Lake Union, Stone Way	0		17	8		17	6					
	10		17	7		17	7					
	20		21	8		23	6					
	30		1,012	14		1,975	6					
	40		3,082	959		3,675	2,170					
Fremont Avenue Bridge	0		19	10		20	9	3	128	3	14	68
	10		20	9		21	12	3	127	3	15	79
	20		23	19		93	15	4	135	4	18	197
	30		1,634	18			13	3	2,940	20	84	1,010
	32			33		2,450			3,125	28	85	

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	July, 1924	Aug., 1924	Sept., 1924	Oct., 1924	Nov., 1924	Dec., 1924	Jan., 1925	Feb., 1925	March, 1925	April, 1925	May, 1925
Lake Union Brick Yard	0	29	83	155	200	383	75	23	10	12	5	9
	10	28	83	164	205	430	85	23	11	12	5	10
	20	37	96	260	345	460	110	34	13	14	7	15
	25	----	----	----	----	----	----	----	----	----	----	----
	30	1,245	1,387	2,040	1,860	830	115	36	15	15	9	17
	35	----	----	----	----	----	500	----	----	----	----	----
	40	3,255	3,255	3,520	3,520	3,030	3,140	1,795	28	23	32	740
	42	----	----	----	----	----	----	----	----	----	----	----
	43	----	----	----	----	----	----	----	----	----	----	----
	45	3,340	3,288	3,710	3,525	3,520	3,226	2,805	3,045	2,550	2,320	3,000
	48	3,370	3,380	3,750	3,655	3,488	3,325	3,102	3,327	3,350	2,875	3,090
East Side, Lake Union	0	30	81	141	188	310	33	30	14	12	6	7
	10	32	81	141	200	330	47	30	15	13	6	8
	20	44	81	340	307	375	65	30	15	13	8	12
	30	1,238	1,335	2,210	1,890	1,185	125	31	19	14	12	52
	35	----	----	----	----	----	550	----	----	----	----	----
	40	3,490	3,320	3,670	3,405	2,988	3,340	1,420	20	60	21	865
	45	3,880	3,945	4,115	3,900	3,680	3,400	2,595	2,050	2,375	810	1,925
	47	3,905	3,945	----	----	----	----	----	----	----	1,800	2,200
Brace and Hergert Lumber Mill	0	----	----	----	----	----	----	----	----	----	----	----
	10	----	----	----	----	----	----	----	----	----	----	----
	20	----	----	----	----	----	----	----	----	----	----	----
	30	----	----	----	----	----	----	----	----	----	----	----
	35	----	----	----	----	----	----	----	----	----	----	----
	37	----	----	----	----	----	----	----	----	----	----	----
Lake Union, Stone Way	0	----	----	----	----	----	----	----	----	----	----	----
	10	----	----	----	----	----	----	----	----	----	----	----
	20	----	----	----	----	----	----	----	----	----	----	----
	30	----	----	----	----	----	----	----	----	----	----	----
	40	----	----	----	----	----	----	----	----	----	----	----
Fremont Avenue Bridge	0	40	78	125	260	285	25	18	11	12	5	10
	10	40	83	148	260	330	30	18	11	14	5	13
	20	228	87	416	445	460	45	18	12	17	5	42
	30	1,750	1.435	2,470	1,355	680	137	20	13	80	5	60
	32	1,790	----	----	----	----	275	21	14	----	5	----

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	Oct., 1914	Jan., 1917	June, 1917	July, 1917	July, 1919	Feb., 1920	March, 1921	Oct., 1921	June, 1922	May, 1923	Dec., 1923
Northern Pacific Bridge	0	45		15	6	31	16	3	169	3	28	134
	10	49		16		79	15	4	171	4	29	139
	20	51		54	68	239	16	4	315	7	31	279
	30	165			370	3,207	14	6	2,920	75	460	1,350
	32										610	
	33											1,410
	35				1,997							
Ballard Bridge	0			12	10	37	16	5	193	6	27	156
	10			12	25	42	16	4	198	8	35	154
	20			38	58	146	26	5	360	13	38	285
	28				470							
	30			911		4,633	55	5	3,555	600	945	1,100
	32						130	4			2,430	
Salmon Bay, Standard Oil Dock	0		35	55			21	6	244	10	50	238
	10		35	59			41	5	237	9	51	259
	20		36	200			35	12	310	33	53	301
	30		495	1,109			35	20	2,315	325	645	589
	35										1,565	
	40							1,000	7,800			6,110
	46							6,740	9,075			7,760
Inlet of salt water discharge pipe	0		26									
	10		69									
	20		518									
	30		904									
	40		6,376									
Outlet of salt water discharge pipe	0			3,300	Before lockage							
				7,355	After lockage							
Middle of large lock, lock empty, lower gates open	0			24								
	5			27								
	15			53								
	25			319								
	35			5,502								
	40			7,145								

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	July, 1924	Aug., 1924	Sept., 1924	Oct., 1924	Nov., 1924	Dec., 1924	Jan., 1925	Feb., 1925	March, 1925	April, 1925	May, 1925
Northern Pacific Bridge	0	51	96	213	335	345	53	15	11	26	5	17
	10	52	107	224	360	370	54	15	12	27	6	20
	20	174	146	480	370	495	70	18	12	31	6	37
	30	1,695	1,730	2,360	2,045	3,180	95	18	12	995	9	265
	32	----	3,245	----	----	----	----	----	----	----	----	560
	33	1,695	----	----	----	----	----	23	----	2,030	10	----
	35	----	----	----	----	----	----	----	----	----	----	----
Ballard Bridge	0	66	132	270	390	405	79	18	14	53	7	27
	10	71	146	270	430	400	84	18	16	54	9	28
	20	230	200	415	435	540	78	19	18	88	11	52
	28	----	----	----	----	----	----	----	----	----	----	----
	30	3 810	4,535	3,680	2,450	5,845	81	184	20	2,845	5,010	3,500
	32	3,066	5,207	----	----	----	90	255	136	2,465	765	----
Salmon Bay, Standard Oil Dock	0	90	144	311	370	450	95	31	26	74	8	34
	10	94	160	335	375	460	95	31	28	75	12	48
	20	227	217	600	515	470	110	45	550	115	13	145
	30	3,070	4,780	3,360	3,290	4,495	220	505	2,560	3,545	417	4,205
	35	----	----	----	----	----	----	----	----	----	----	----
	40	10,267	10,050	10,160	9,160	10,375	5,958	5,500	7,910	7,745	6,010	9,560
	46	10,720	11,023	10,230	9,190	11,815	8,855	8,770	8,405	9,550	8,460	9,120
Inlet of salt water discharge pipe	0	----	----	----	----	----	----	----	----	----	----	----
	10	----	----	----	----	----	----	----	----	----	----	----
	20	----	----	----	----	----	----	----	----	----	----	----
	30	----	----	----	----	----	----	----	----	----	----	----
	40	----	----	----	----	----	----	----	----	----	----	----
Outlet of salt water discharge pipe	0	----	----	----	----	----	----	----	----	----	----	----
Middle of large lock, lock empty, lower gates open	0	----	----	----	----	----	----	----	----	----	----	----
	5	----	----	----	----	----	----	----	----	----	----	----
	15	----	----	----	----	----	----	----	----	----	----	----
	25	----	----	----	----	----	----	----	----	----	----	----
	35	----	----	----	----	----	----	----	----	----	----	----
	40	----	----	----	----	----	----	----	----	----	----	----

Exhibit 24—Continued

LAKE WASHINGTON SHIP CANAL LOCKSITE

Parts of Chlorine 1,000,000 Parts of Water

	Depth in feet	Oct., 1914	Jan., 1917	June, 1917	July, 1917	July, 1919	Feb., 1920	March, 1921	Oct., 1921	June, 1922	May, 1923	Dec., 1923
Middle of large lock, lock full, upper gates open	0			66								
	10			128								
	20			244								
	30			573								
	40			7,186								
	55			10,809								
Puget Sound	0			14,446								
	200			16,589								
	500			16,727								

	Depth in feet	July, 1924	Aug., 1924	Sept., 1924	Oct., 1924	Nov., 1924	Dec., 1924	Jan., 1925	Feb., 1925	March, 1925	April, 1925	May, 1925
Middle of large lock, lock full, upper gates open	0											
	10											
	20											
	30											
	40											
	55											
Puget Sound	0											
	200											
	500											

Exhibit 25

A SALT CLEARING SHIP LOCK

By W. M. MEACHAM, Seattle, Wash.

It follows that if the difference of head is .55 feet of water with a height of a fresh water column of 55 feet above the opening below the wall, that the mean specific gravity is 1.01, or that the difference of height of the two columns of water is a measure of the mean specific gravity of the salt water. This pressure is 944 pounds per foot of wall length. This explanation of pressure is not to show what pressure the siphon wall must take care of, but to show the actual head and pressure produced by the salt water.

For the purpose of a simple explanation it was assumed that the dense salt water was on one side of the wall and below the line of its lower edge on the other side. The actual condition at times would be a quantity of salt water of varying density on the fresh water side of the wall above its lower edge. A similar head exists against the upper gate of the lock just before it is opened to the canal above, after a lockage from below.

The salt siphoning spillway has been described as working with locks of the type now in use in the Lake Washington Canal at Seattle and at Panama. A limited water supply was assumed.

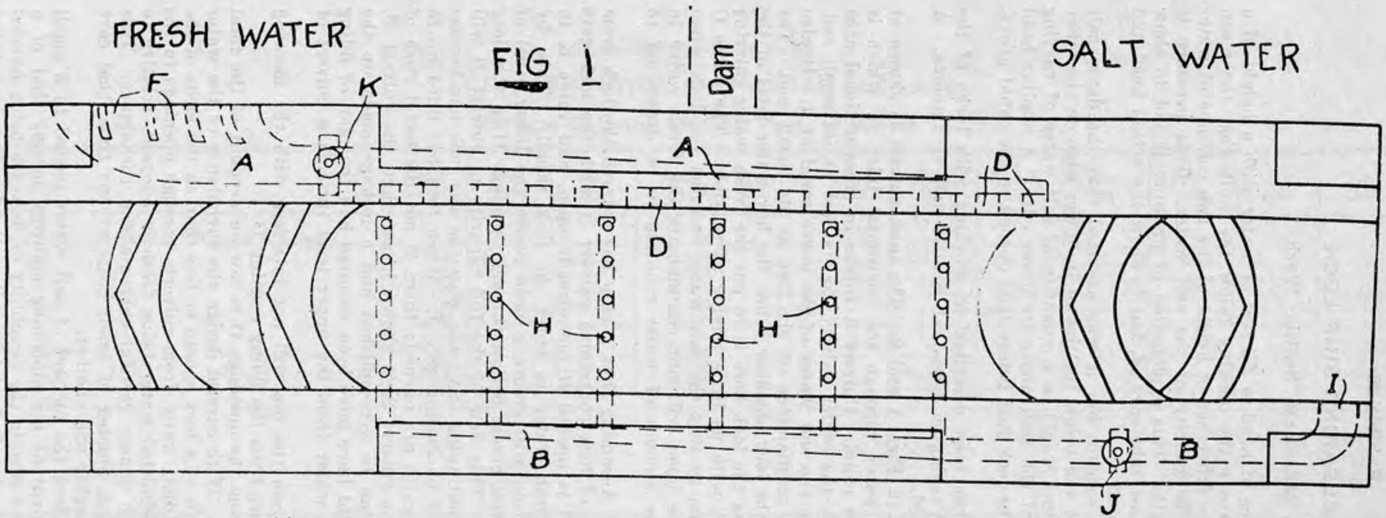
A salt clearing lock is shown in Figs. 1 and 2. The inlet culvert is shown at A. It is connected with fresh water through the horizontal inlet F, which is shown below the surface of upper canal. Culvert A tapers in cross-sectional area from an area of twice that of B, the outlet culvert, to six feet at its small end. The outlet culvert B empties into the salt water of the lower canal at 1. It also tapers in cross-sectional area to a diameter of six feet at its small end. The ducts C connect culvert A with the lock chamber below the low water level of the lock. The object of their entering the lock here is to put the fresh water entering the lock on top of the salt water with as little mixing as possible. The ducts C leave the conduit A at the bottom so that the salt water entering the lock when the lock gates at lower level are open will not contaminate the fresh water in culvert A, thereby increasing the amount of water required to be drawn off to freshen the lock.

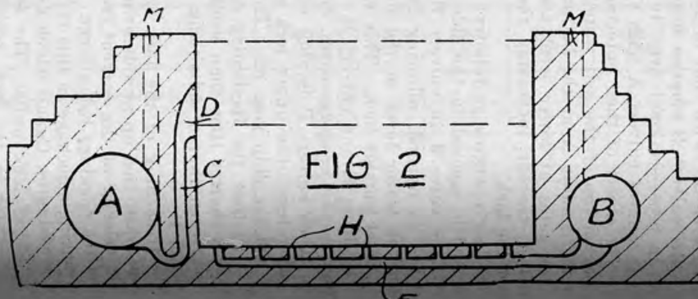
The lock operates as follows: Assuming that a ship has entered the lock from below and is moored to the side of lock containing culvert B with the lock gate closed; the valve J in culvert B is opened if not already open, and valve K in culvert A is opened, allowing fresh water to enter the lock rapidly. This, by raising the water level in the lock, will create a head above the lower level of canal water outside lock. This will create a flow through openings H in the floor of lock; ducts E and culvert B. This flow of the full capacity of culvert B will increase as the head increases, continuing until the water in the lock has become fresh. Then culvert B is shut off by closing gate J. When lock has filled up to the higher level, the upper lock gates are opened; there is not the usual rush of water and the ship goes on. The culvert A is shown larger than the culvert B. This is so that the freshening can be accomplished and a lockage made up the canal in a shorter time than would have have been required had the plan of filling the locks been that of admitting water from the upper level through a culvert of the size of B.

The freshening of the lock from the top will not interfere with the mooring of ships when tied up at side away from the filling opening D.

The velocity of the current from the openings D is low on account of the total area of the openings being large. With careful design the turbulance of the water when making a lockage in this type of a lock should be less than in the locks of the Lake Washington Canal, which admit water from culverts through openings in the lower edge of lock walls. The admitted water being fresh is buoyant, relative to the salt water in the lock, which causes vertical currents and turbulance. This makes it necessary, when raising a number of small boats at one time, that care be taken to keep them from damaging one another.

A lock of this type would reduce the amount of salt water passed to a small quantity, making the work required of the siphoning spillway largely that of a safety device. There would always remain the possibility of lockages being hurried or of a lockage being improperly handled and a lock full of salt water being emptied into the higher level.





A SALT CLEARING SHIP LOCK

Proposed by

Mr. W.M. Meacham

Seattle, Wash.

SV-170 193-D-26

LAKE WASHINGTON SHIP CANAL

Seattle, Washington

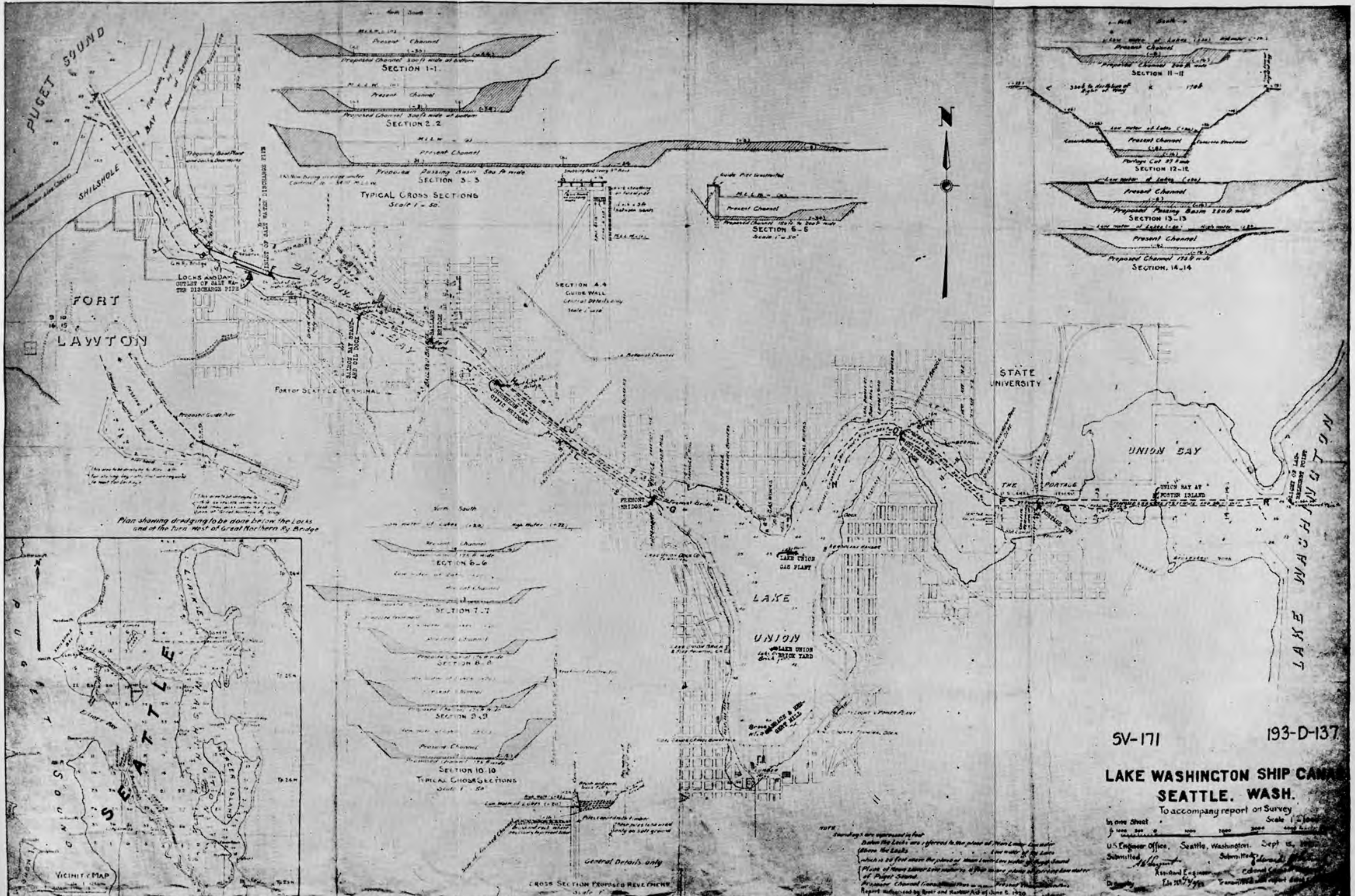

PUGET SOUND
SHILSHOLE BAY
SALMON BAY
FORT LAWTON
Port of Seattle Terminal
Locks and Dam
Section 1-1.
Section 2.2
Section 3-3
Typical Cross Sections
Section 4.4
Guide Wall
Section 6-5
Section 11-11
Section 12-12
Section 13-13
Section 14-14
Present Channel
Section 6-6
Section 7-7
Section 8-8
Section 9-9
Section 10-10
Typical Cross Sections
Plan showing dredging to be done below the Locks and at the turn west of Great Northern Ry Bridge
Fremont Bridge
LAKE UNION
STATE UNIVERSITY
UNION BAY
THE PORTAGE
LAKE WASHINGTON
General Details only
Cross Section Proposed Revetment
Vicinity Map
SEATTLE
LAKE WASHINGTON
MERCER ISLAND
SV-171
193-D-137
LAKE WASHINGTON SHIP CANAL
SEATTLE. WASH.
To accompany report on Survey
U.S. Engineer Office. Seattle, Washington.

TABLE 5-1

DISTANCES BETWEEN POINTS ALONG SAN FRANCISCO BAY

(Along average flow line of tides, not by shortest shipping routes) Distance in miles

Location	Point Richmond	Point San Pablo	Mare Island Light	Crockett	Mare Island	Dillon Point	Army Point	Bay Point	Chipps Island (lower end)	Collins-ville	Rio Vista Bridge	Sacra-mento	Stockton
Presidio	8.0	13.1	25.4	27.5	28.4	29.0	33.8	39.4	45.7	50.8	63.6	106.6	92.9
Point Richmond	-----	5.1	17.4	19.5	20.4	21.0	25.8	31.4	37.7	42.8	55.6	98.6	84.9
Point San Pablo	-----	-----	12.3	14.4	15.3	15.9	20.7	26.3	32.6	37.7	50.5	93.5	79.8
Mare Island Light	-----	-----	-----	2.1	3.0	3.6	8.4	14.0	20.3	25.4	38.2	81.2	67.5
Crockett	-----	-----	-----	-----	-----	1.5	6.3	11.9	18.2	23.3	36.1	79.1	65.4
Mare Island	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Dillon Point	-----	-----	-----	-----	-----	-----	4.8	10.4	16.7	21.8	34.6	77.6	63.9
Army Point	-----	-----	-----	-----	-----	-----	-----	5.6	11.9	17.0	29.8	72.8	59.1
Bay Point	-----	-----	-----	-----	-----	-----	-----	-----	6.3	11.4	24.2	67.2	53.5
Chipps Island (lower end)	-----	-----	-----	-----	-----	-----	-----	-----	-----	5.1	17.9	60.9	47.2
Collinsville	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	12.8	55.8	43.5
Rio Vista	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	43.0	-----
Sacramento	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Stockton	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

These distances do not agree exactly with distances shown on page 73 U. S. G. S. Professional Paper 105, Hydraulic Mining Debris in the Sierra Nevada by G. K. Gilbert. Discrepancies due to differences of interpretation as to path of body of tidal waters.

TABLE 5-2

AREAS OF SUISUN AND SAN PABLO BAYS AND CARQUINEZ STRAIT

Areas in acres in Suisun Bay from line of borings at Army Point to a line from Point San Joaquin through lower end of Chain Island (near Collinsville). Distances are from Army Point site.

Location		Low water	High water to marshline	Marshes	Total, including marshes
Radial distances	Flow distances				
0 miles to 2 miles	----------	2,080	2,120	1,520	3,640
2 miles to 4 miles	----------	3,410	3,570	3,260	6,830
4 miles to 6 miles	6.6 miles	4,480	4,650	2,070	6,720
6 miles to 8 miles	9.13 miles	6,380	6,980	3,590	10,570
8 miles to 10 miles	11.7 miles	5,140	5,910	5,490	12,400
10 miles to 12 miles	13.8 miles	2,730	4,940	6,470	11,410
12 miles to 14.3 miles	17.0 miles	2,600	2,720	6,090	8,810
Totals	----------	26,820	31,890	28,490	60,380

Areas in acres in Carquinez Strait from a line between Mare Island Light and nearest point at Selby to line of borings at Army Point site.

Location	Low water	High water to marshline	Marshes	Total, including marshes
Mare Island Light to Dillon Point	1,190	1,270	----------	1,270
Dillon Point to Army Point	2,940	3,650	160	3,810
Totals	4,130	4,920	160	5,080

Areas in acres in San Pablo Bay between line of borings at San Pablo site and line from Mare Island Light to nearest point on shore at Selby.

Location	Low water	High water to marshes	Marshes	Total, including marshes
0 to 2 miles, in bay	3,680	4,640	----------	4,640
0 to 2 miles, in creeks	----------	----------	----------	----------
2 to 4 miles, in bay	7,580	9,480	1,540	11,020
2 to 4 miles, in creeks	----------	----------	----------	----------
4 to 6 miles, in bay	9,540	11,770	1,260	13,030
4 to 6 miles, in creeks	----------	50	430	480
6 to 8 miles, in bay	13,300	14,510	210	14,720
6 to 8 miles, in creeks	----------	----------	----------	----------
8 to 10 miles, in bay	13,870	16,750	590	17,340
8 to 10 miles, in creeks	----------	50	70	120
10 to 12.35 miles, in bay	9,830	15,400	190	15,590
10 to 12.35 miles, in creeks	260	580	760	1,340
12.35 to 15 miles, in creeks	1,100	2,020	2,800	4,820
15 to 17 miles, in creeks	830	1,455	3,200	4,655
17 to 19 miles, in creeks	620	1,285	3,300	4,585
19 to 21 miles, in creeks	520	1,110	2,950	4,060
21 to 23 miles, in creeks	430	920	820	1,740
Above 23	200	350	700	1,050
Totals	61,760	80,370	18,820	99,190

TABLE 5-3

LAG OF SLACK WATER FROM CURRENT METER OBSERVATIONS

Army Point Site, September 19-20, 1924, Apogee and Neap

Time	High water	Low water	Slack water	Maximum velocity** Time	Maximum velocity** Feet per second	Lag of slack water, minimum
Sept. 19, 6.00 p.m.	1.80		8.00 p.m.	9.45 p.m.	−2.1	120
Sept. 20, 12.58 a.m.		−2.70	2.47 a.m.	6.52 a.m.	+2.07	109
Sept. 20, 7.30 a.m.	0.75		9.20 a.m.	11.35 a.m.	−1.38	110
Sept. 20, 12.40 p.m.		−1.25	2.17 p.m.	5.33 p.m.	+2.22	97

Army Point Site, October 1-2, 1924, Perigee, Half Spring

Time	High water	Low water	Slack water	Maximum velocity** Time	Maximum velocity** Feet per second	Lag of slack water, minimum
Oct. 1, 9.10 a.m.		−2.13	11.00 a.m.	Noon	+2.8	110
Oct. 1, 3.17 p.m.	2.97		4.10 p.m.	8.40 p.m.	−3.80	53
Oct. 1, 9.45 p.m.		−2.57	11.32 p.m.	1.32 a.m.	+2.78	107
Oct. 2, 4.45 a.m.	2.35		5.53 a.m.			68

Army Point, February 7-8, 1925, Spring

Time	High water	Low water	Slack water	Maximum velocity** Time	Maximum velocity** Feet per second	Lag of slack water, minimum
Feb. 7, 12.25 p.m.	3.48			4.40 p.m.	−4.18	
Feb. 7, 7.30 p.m.		2.95	9.53 p.m.	Midnight	+2.38	143
Feb. 8, 2.30 a.m.	3.35		3.17 a.m.	6.45 a.m.	−2.25	47
Feb. 8, 7.22 a.m.		−0.04	9.55 a.m.	11.30 a.m.	+2.07	153
Feb. 8, 1.10 p.m.	3.83		2.15 p.m.	5.30 p.m.	−4.3	65
Feb. 8, 8.17 p.m.		−2.75				

Dillon Point, October 30-31, 1924, Perigee and Nearly Full Tropic

Time	High water	Low water	Slack water	Maximum velocity** Time	Maximum velocity** Feet per second	Lag of slack water, minimum
Oct. 30, 8.24 a.m.		−1.25	9.52 a.m.	12.10 p.m.	+4.1	88
Oct. 30, 2.25 p.m.	3.35		3.57 p.m.	6.05 p.m.	−3.95	92
Oct. 30, 9.37 p.m.		−3.93	*11.45 p.m.	2.07 a.m.	+3.18	*128
Oct. 31, 4.00 a.m.	1.85		5.28 a.m.	7.22 a.m.	−2.92	88
Oct. 31, 9.10 a.m.		−1.80				

Point San Pablo, November 25-26, 1924, Spring and Nearly Perigee

Time	High water	Low water	Slack water	Maximum velocity** Time	Maximum velocity** Feet per second	Lag of slack water, minimum
Nov. 25, 5.20 p.m.		−3.70	7.15 p.m.	10.10 p.m.	+3.75	115
Nov. 26, 12.15 a.m.	1.95		1.40 a.m.	4.30 a.m.	−3.0	85
Nov. 26, 4.50 a.m.		−1.22	6.30 a.m.	9.25 a.m.	+3.80	100
Nov. 26, 11.20 a.m.	3.88		12.50 p.m.	3.20 p.m.	−5.23	90
Nov. 26, 6.15 p.m.		−4.17				

* Time of slack water uncertain.
** Average from top to bottom, not at a single point.

TABLE 5-4

VOLUME IN ACRE-FEET IN TIDAL PRISMS ABOVE ARMY POINT

Volume considered is that between water surfaces at successive slack water periods.

Flood tide, 8.50 p.m., July 6, to 3.00 a.m., July 7, 1925

Time interval	Suisun Bay	Sacramento River	San Joaquin River	Fresh water flow	Opposite tide	Total
8.50 to 9.00 p.m., July 6	+ 4,510	----------	----------	−150	− 50	+ 4,310
9.00 to 10.00 p.m., July 6	+21,230	+ 544	0	−875	−300	+20,600
10.00 to 11.00 p.m., July 6	+35,310	+ 6,873	0	−875	−300	+41,010
11.00 to 12.00 midnight	+35,690	+13,657	+2,083	−875	−310	+50,240
12.00 to 1.00 a.m., July 7	+23,440	+14,455	+5,375	−875	−300	+42,100
1.00 to 2.00 a.m., July 7	+10,070	+12,816	+6,541	−875	−300	+28,250
2.00 to 3.00 a.m., July 7	+ 3,560	+ 9,329	+8,445	−875	−310	+20,150
Total	+133,810	+57,680	+22,440	−5,400	−1,870	+206,660

Ebb tide, 3.00 a.m. to 10.45 a.m., July 7, 1925

Time interval	Suisun Bay	Sacramento River	San Joaquin River	Fresh water flow	Opposite tide	Total
3.00 a.m. to 4.00 a.m.	−45,400	− 2,165	----------	−875	+140	−48,300
4.00 a.m. to 5.00 a.m.	−44,690	−10,320	−505	−875	+220	−56,170
5.00 a.m. to 6.00 a.m.	−37,540	−15,468	−4,372	−875	+290	−57,970
6.00 a.m. to 7.00 a.m.	−30,530	−13,286	−5,100	−875	+310	−49,480
7.00 a.m. to 8.00 a.m.	−21,980	−10,119	−5,466	−875	+220	−38,220
8.00 a.m. to 9.00 a.m.	−13,630	−10,140	−7,045	−875	----------	−31,690
9.00 a.m. to 10.00 a.m.	− 5,330	− 8,500	−6,645	−875	----------	−21,350
10.00 a.m. to 10.45 a.m.	− 3,450	− 6,520	−5,750	−670	----------	−16,390
Total	−202,550	−76,500	−34,890	−6,790	+1,180	−319,550

Flood tide, 10.45 a.m. to 5.00 p.m., July 7, 1925

Time interval	Suisun Bay	Sacramento River	San Joaquin River	Fresh water flow	Opposite tide	Total
10.45 to 11.00 a.m.	+11,570	----------	----------	−220	----------	+11,350
11.00 to noon	+26,310	+ 70	----------	−875	−1,120	+24,385
Noon to 1.00 p.m.	+44,630	+ 5,170	----------	−875	−1,120	+47,810
1.00 to 2.00 p.m.	+33,880	+14,070	+1,430	−875	−1,120	+47,385
2.00 to 3.00 p.m.	+22,620	+11,600	+4,020	−875	−1,120	+36,250
3.00 to 4.00 p.m.	+ 9,160	+10,780	+4,850	−875	− 670	+23,245
4.00 to 5.00 p.m.	+ 3,030	+ 8,590	+5,130	−875	− 450	+15,430
Total	+151,200	+50,280	+15,430	−5,470	−5,600	+205,840

Ebb tide, 5.00 p.m. to 9.50 p.m., July 7, 1925

Time interval	Suisun Bay	Sacramento River	San Joaquin River	Fresh water flow	Opposite tide	Total
5.00 p.m. to 6.00 p.m.	−18,810	− 423	----------	−875	+3,870	−16,240
6.00 p.m. to 7.00 p.m.	−28,310	− 5,565	− 90	−875	+3,570	−31,270
7.00 p.m. to 8.00 p.m.	−23,250	−10,587	−1,732	−875	+1,410	−35,030
8.00 p.m. to 9.00 p.m.	− 6,640	−10,763	−3,900	−875	+ 260	−21,920
9.00 p.m. to 9.50 p.m.	− 1,200	− 5,844	−2,909	−730	----------	−10,680
Total	−78,210	−33,180	−8,630	−4,230	+9,110	−115,140

\+ Indicates flood flow.
— Indicates ebb flow.

TABLE 5-5

VOLUME IN ACRE-FEET IN TIDAL PRISMS ABOVE POINT SAN PABLO

Volume considered is that between the water surface at successive slack water periods.

Flood tide 7.30 pm., July 6, to 0.54 a.m., July 7, 1925

Time interval	San Pablo Bay	Carquinez Strait	Suisun Bay	Delta	Fresh water flow	Opposite tide	Total
July 6—							
7.30 to 8.00 p.m.	+25,720	+ 600	----------	----------	—440	—1,490	+ 24,390
8.00 to 9.00 p.m.	+71,560	+3,790	+ 5,140	----------	—870	—5,190	+ 74,430
9.00 to 10.00 p.m.	+81,170	+5,530	+18,200	----------	—870	—4,040	+ 99,990
10.00 to 11.00 p.m.	+79,480	+5,670	+33,990	+ 1,610	—880	—2,780	+117,090
11.00 to midnight	+61,790	+4,320	+37,560	+ 9,190	—880	—1,920	+110,060
Midnight to 0.54 a.m.	+18,060	+2,400	+28,650	+14,070	—790	—1,230	+ 61,160
Total	+337,780	+22,310	+123,540	+24,870	—4,730	—16.650	+487,120

Ebb tide, 0.54 a.m., July 7, to 9.00 a.m., July 7, 1925

Time interval	San Pablo Bay	Carquinez Strait	Suisun Bay	Delta	Fresh water flow	Opposite tide	Total
0.54 to 2.00 a.m.	— 74,330	—1,290	----------	----------	— 90	+3,870	— 71,840
2.00 to 3.00 a.m.	—125,340	—5,030	—10,140	----------	—870	+3,870	—137,510
3.00 to 4.00 a.m.	—125,690	—7,360	—29,320	----------	—880	+2,580	—160,670
4.00 to 5.00 a.m.	—118,070	—8,090	—43,630	— 1,950	—870	+1,290	—171,320
5.00 to 6.00 a.m.	— 78,720	—6,120	—37,510	— 8,520	—880	+ 650	—131,100
6.00 to 7.00 a.m.	— 30,540	—4,810	—30,420	—11,260	—870	+ 390	— 77,510
7.00 to 8.00 a.m.	— 6,430	—3,790	—23,480	—11,640	—880	+ 250	— 45,970
8.00 to 9.00 a.m.	— 1,090	—1,210	—19,290	—13,690	—880	+ 40	— 36,120
Total	—560,210	—37,700	—193,790	—47,060	—6,220	+12,940	—832,040

Flood tide, 9.00 a.m. to 3.45 p.m., July 7, 1925

Time interval	San Pablo Bay	Carquinez Strait	Suisun Bay	Delta	Fresh water flow	Opposite tide	Total
July 7—							
9.00 to 10.00 a.m.	+ 82,460	+3,480	+ 2,000	----------	—870	—6,340	+ 80,730
10.00 to 11.00 a.m.	+101,440	+6,830	+14,030	----------	—880	—4,660	+116,760
11.00 to 12.00 noon	+ 93,880	+6,290	+23,730	----------	—870	—3,790	+119,240
12.00 to 1.00 p.m.	+ 72,320	+5,940	+39,760	+ 630	— 880	—3,170	+114,600
1.00 to 2.00 p.m.	+ 38,050	+3,730	+33,510	+ 8,490	—870	—2,120	+ 80,790
2.00 to 3.00 p.m.	+ 13,080	+3,140	+22,360	+11,230	—880	—1,060	+ 47,870
3.00 to 3.45 p.m.	+ 490	+ 260	+10,320	+ 9,450	—660	----------	+ 19,860
Total	+401,720	+29,670	+145,710	+29,800	—5,910	—21,140	+579,850

Ebb tide, 3.45 p.m. to 8.42 p.m., July 7, 1925

Time interval	San Pablo Bay	Carquinez Strait	Suisun Bay	Delta	Fresh water flow	Opposite tide	Total
July 7—							
3.45 to 4.00 p.m.	—10,700	— 170	----------	----------	—220	+1,820	— 9,270
4.00 to 5.00 p.m.	—59,010	—2,620	— 2,800	----------	—870	+7,260	—58,040
5.00 to 6.00 p.m.	—68,490	—4,990	—15,430	----------	—880	+6,490	—83,300
6.00 to 7.00 p.m.	—33,800	—4,550	—25,690	— 830	—870	+5,190	—60,550
7.00 to 8.00 p.m.	— 4,640	—2,590	—30,130	—7,030	—880	+3,900	—41,370
8.00 to 8.30 p.m.	— 310	— 330	— 7,730	—5,670	—440	+1,300	—13,180
Total	—176,950	—15,250	—81,780	—13,530	—4,160	+25,960	—265,710

\+ Indicates flood flow.
— Indicates ebb flow.

TABLE 5-6

VOLUMES IN ACRE-FEET IN TIDAL PRISMS ABOVE GOLDEN GATE (PRESIDIO)

Volumes considered are those between water surfaces at successive slack water periods.

This study is approximate, tides being considered as a whole instead of by hourly, two-mile sections.

Flood tide, 6.48 p.m., July 6, to 0.13 a.m., July 7, 1925

Fort Point to Point San Pablo 3.76 x 58,800 and to Hunters Point	+221,0
Hunters Point to San Mateo Point 4.44 x 94,400 + 1 x 8,630	+427,0
San Mateo Point to south end of bay 7.4 x 30,000 + 2 x 31,000	+284,0
San Pablo Point to Dillon Point 4.44 x 77,000 + 1 x 18,820	+360,8
Dillon Point to Army Point 4.30 x 3,480 + 1 x 160	+ 15,2
Army Point to Collinsville 2.70 x 32,640	+ 88,0
Collinsville to end .88 x 10,900	+ 9,57
River flow 5.4 x 875	— 4,7
Opposite tide 0.8 x 22,750	— 18,2
Total	+1,383,24

Ebb tide, 0.13 a.m., to 8.18 a.m., July 7, 1925

Fort Point to Point San Pablo and to Hunters Point 7.4 x 56,600	—419,0
Hunters Point to San Mateo Point 8.0 x 92,600 + 1 x 8,630	—749,0
San Mateo Point to south end of bay 11.2 x 26,000 + 2 x 31,000	—353,0
San Pablo Point to Dillon Point 8.0 x 72,300 + 1 x 18,820	—596,8
Dillon Point to Army Point 7.7 x 3,300 + 1 x 160	— 25,0
Army Point to Collinsville 5.1 x 31,000	—158,1
Collinsville to end 1.9 x 10,900 + .5 x 1,380 + .5 x 3,350	— 23,1
River flow 8.1 x 875	— 7,1
Opposite tide 1.0 x 18,000	+ 18,0
Total	—2,314,3

Flood tide, 8.18 a.m., to 2.33 p.m., July 7, 1925

Fort Point to Point San Pablo and Hunters Point 5.5 x 56,000	+308,0
Hunters Point to San Mateo Point 6.4 x 90,000	+576,0
San Mateo Point to south end of bay 8.0 x 24,000	+192,0
San Pablo Point to Dillon Point 6.4 x 70,300	+450,0
Dillon Point to Army Point 6.3 x 3,200	+ 20,2
Army Point to Collinsville 3.8 x 30,000	+114,0
Collinsville to end .84 x 10,900	+ 9,1
River flow 6.25 x 875	— 5,4
Opposite tide 1.6 x 22,750	— 36,4
Total	+1,628,4

Ebb tide, 2.33 p.m., to 8.00 p.m., July 7, 1925

Fort Point to Point San Pablo and Hunters Point 1.72 x 57,400	— 98,7
Hunters Point to San Mateo Point 2.7 x 93,200	—260,0
San Mateo Point to south end of bay 3.4 x 28,600	— 97,2
San Pablo Point to Dillon Point 2.7 x 75,400	—213,5
Dillon Point to Army Point 3.0 x 3,200	— 9,6
Army Point to Collinsville 1.7 x 30,900	— 52,5
Collinsville to end .5 x 3,350	— 1,6
River flow 5.45 x 875	— 4,7
Opposite tide 1.3 x 30,300	+ 39,4
Total	—699,1

+ Indicates flood flow.
— Indicates ebb flow.

TABLE 5-7

VELOCITY OF TIDE PHASES THROUGH THE BAY

From Simultaneous Tide Graphs

	Station	First low	First high	Second low	Second high	Third low	Average	Data from tide table*
	Presidio to Point San Pablo							
Distance, miles	13.1							
Time, minutes		33	36	30	56	48		55
Velocity, miles per hour		23.8	21.8	26.2	14.0	16.4	19.3	14.3
	Point San Pablo to Dillon Point							
Distance, miles	15.9							
Time, minutes		75	63	99	70	81		75
Velocity, miles per hour		12.7	15.1	9.6	13.6	11.8	12.3	12.7
	Dillon Point to Army Point							
Distance, miles	4.8							
Time, minutes		27	21	28	22	15		20
Velocity, miles per hour		10.7	13.7	10.3	13.1	19.2	12.7	14.4
	Army Point to Collinsville							
Distance, miles	17.0							
Time, minutes		93	87	125	88	102		80
Velocity, miles per hour		11.0	11.7	8.2	11.5	10.0	10.3	12.75
	Collinsville to Rio Vista							
Distance, miles	12.8							
Time, minutes		51	54	72	34	33		80
Velocity, miles per hour		15.0	14.2	10.7	22.6	23.3	15.8	**9.6
	Rio Vista to Sacramento							
Distance, miles	47.9							
Time, minutes		279	210	300	210	279		310
Velocity, miles per hour		10.3	13.7	9.6	13.7	10.3	11.2	9.7
	Collinsville to Stockton							
Distance, miles	45.5							
Time, minutes		231	213	240	193	190		270
Velocity, miles per hour		11.8	12.8	11.4	14.2	14.2	12.8	10.1
	Stockton to Lathrop Bridge							
Distance, miles	12.0							
Time, minutes		180	153	225	195			
Velocity, miles per hour		4.0	4.7	3.2	3.7		3.8	

* Computed from time interval of tide lag as published in the tide tables of the U. S. C. & G. S.

** Discrepancy possibly due to fact that channel has been straightened and enlarged since data were collected.

TABLE 5-8

SUMMARY OF VOLUMES IN ACRE-FEET IN TIDAL PRISMS ABOVE DESIGNATED POINTS FOR THE PERIOD JULY 6-7, 1925

Army Point

First flood	206,660	First ebb	319,550	
Second flood	205,840	Second ebb	115,140	
Total	412,500	Total	434,690	Gross ebb flow
			21,890	River flow
			412,800	Net ebb
			2,300	*Excess of ebb over flood
			410,500	

412,500 and 410,500 should balance.

Point San Pablo

First flood	487,120	First ebb	832,040	
Second flood	579,850	Second ebb	255,710	
Total	1,066,970	Total	1,097,750	Gross ebb
			21,890	River flow
			1,075,860	Net ebb
			7,500	*Excess of ebb over flood
			1,068,360	

1,066,970 and 1,068,360 should balance.

Golden Gate (Presidio)

First flood	1,383,240	First ebb	2,314,300	
Second flood	1,628,490	Second ebb	699,170	
Total	3,011,730	Total	3,013,470	Gross ebb
			22,070	River flow
			2,991,400	Net ebb
			33,600	*Excess of ebb over flood
			2,957,800	

3,011,730 and 2,957,800 should balance.

* Excess of ebb over flood is the quantity represented by the difference in water surface at the beginning and end of the period, the surface at the end being lower than at the beginning.

TABLE 5-9

REDUCTION OF VOLUME OF TIDAL PRISM ABOVE GOLDEN GATE BY CONSTRUCTION OF BARRIER AT ARMY POINT

Tides of July 6-7, 1925

	Volume of present tide acre-feet	Reduction of volume by barrier, acre-feet	Volume of reduced tide, acre-feet	Per cent of reduction
First flood	1,406,170	97,570	1,308,600	7.0
First ebb	2,325,200	181,200	2,144,000	7.8
Second flood	1,670,360	123,160	1,547,200	7.4
Second ebb	733,800	54,200	679,600	7.4
Mean				7.5

TABLE 5-10

REDUCTION OF VOLUME OF TIDAL PRISM ABOVE GOLDEN GATE BY CONSTRUCTION OF BARRIER AT POINT SAN PABLO

Tides of July 6-7, 1925

	Volume of present tide, acre-feet	Reduction of volume by barrier, acre-feet	Volume of reduced tide, acre-feet	Per cent of reduction
First flood	1,406,170	473,570	932,600	33.7
First ebb	2,325,200	803,600	1,521,600	34.5
Second flood	1,670,360	593,360	1,077,000	35.4
Second ebb	733,800	277,300	456,500	37.7
Mean				35.3

TABLE 5-11

VOLUME IN ACRE-FEET PER FOOT OF RANGE IN TIDE

The tidal prisms and graphs of July 6-7, 1925, are the basis of the table. The volumes are the total in the main tidal prism, irrespective of the imme- diate source of water in the prism.

Presidio

Time of high or low water	Water elevation	Range	Elevation half tide	Total volume in prism, acre-feet	Volume per foot of range, acre-feet
July 6—					
5.21 p.m.	—0.38				
		4.31	+1.77	1,406,170	326,0
11.24 p.m.	3.93				
		8.40	—0.27	2,325,200	277,0
July 7—					
6.33 a.m.	—4.47				
		6.38	—1.28	1,670,360	261,5
1.22 p.m.	1.91				
		2.39	+0.71	738,570	318,6
6.09 p.m.	—0.48				
		*5.37			

Point San Pablo

Time of high or low water	Water elevation	Range	Elevation half tide	Total volume in prism, acre-feet	Volume per foot of range, acre-feet
July 6—					
5.54 p.m.	—0.51				
		4.46	+1.72	508,500	114,0
Midnight	3.95				
		8.65	—0.37	838,760	96,0
July 7—					
7.03 a.m.	—4.7				
		6.77	—1.32	606,900	89,7
2.18 p.m.	2.07				
		2.72	+0.71	287,510	105,7
6.57 p.m.	—0.65				
		*5.65			

Army Point

Time of high or low water	Water elevation	Range	Elevation half tide	Total volume in prism, acre-feet	Volume per foot of range, acre-feet
July 6—					
7.36 p.m.	—0.52				
		4.81	+1.88	213,930	44,4
July 7—					
1.24 a.m.	4.29				
		8.19	+0.19	313,940	38,3
9.10 a.m.	—3.90				
		6.70	—0.55	216,910	32,4
3.50 p.m.	2.80				
		3.43	+1.08	120,020	35,0
8.33 p.m.	—0.63				
		*5.78			

* Mean.

TABLE 5-12

PROPERTIES OF VARIOUS CONTROL SECTIONS IN SAN FRANCISCO BAY SYSTEM

Section	Width at water surface	Area, square feet	Hydraulic radius
Army Point to Suisun Point	4,900	204,510	41
Dillon Point to Eckley (tide prism not computed)	2,740	211,600	77
Point San Pablo to Point San Pedro	9,560	489,000	51
Fort Point to Lime Point	5,200	957,000	182
Thru Goat Island	11,500	688,000	59

TABLE 5-13

DISCHARGE CAPACITY OF GATES UNDER VARYING HEADS

Area of gate openings, 50′ x 50′ at sea level; 30 gates.
Entrance loss, 10% of velocity head, equivalent to an efficiency of opening of 95%. Effective area of opening is that which is below the elevation of the downstream water surface. Table below is based on an assumed elevation of tail water=0.0. For any other depth, d, $Q' = d \div 50 \times Q$. $A = 95 \times 75{,}000 = 71{,}250$ square feet. Velocity of approach is based on the velocity in an assumed channel area of 200,000 square feet above the barrier. Velocities in table below include velocity due to head of velocity of approach + the static heads.

Static head, in feet	Velocity, feet per second	Discharge	
		Cubic feet per second	Acre feet per half hour
0	0	0	0
0.05	1.80	127,700	5,280
0.1	2.60	185,250	7,656
0.2	3.81	271,460	11,218
0.3	4.67	332,740	13,750
0.4	5.42	386,180	15,958
0.5	6.07	432,490	17,872
0.6	6.63	472,390	19,520
0.7	7.18	511,580	21,140
0.8	7.68	547,200	22,612
0.9	8.15	580,690	24,000
1.0	8.60	612,750	25,320
1.2	9.40	669,750	27,676
1.4	10.17	724,610	29,942
1.6	10.87	774,490	31,928
1.8	11.52	820,800	33,918
2.0	12.13	864,260	35,714
2.2	12.75	908,440	37,540
2.4	13.31	948,340	39,188
2.6	13.86	987,520	40,808
2.8	14.38	1,024,580	42,338
3.0	14.89	1,060,910	43,840
3.5	16.09	1,146,410	47,372
4.0	17.18	1,224,080	50,582
4.5	18.21	1,297,460	53,614
5.0	19.20	1,368,000	56,530
5.5	20.17	1,437,110	59,386
6.0	21.07	1,501,240	62,036

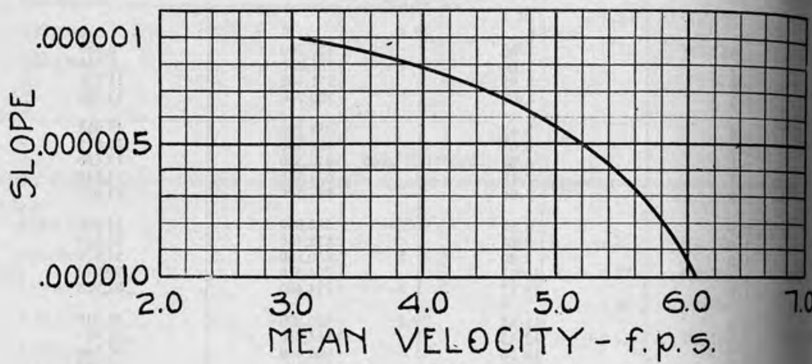
TABLE 5-14

FLOOD DISCHARGE STUDIES. SLOPE THROUGH CARQUINEZ STRAITS

Assuming the section from S. P. test piles near Vallejo (shown on plate 3-15) as typical for straits, the functions are, A=219,200 at mean sea level; p=3234; r=67.7; n=.02; $\sqrt{r}$ =8.23.

Assuming s=.000001, c=370, V=3.05 and Q= 669,000 c.f.s.
Assuming s=.000004, c=296, V=4.88 and Q=1,070,000 c.f.s.
Assuming s= .00001, c=232, V=6.04 and Q=1,323,000 c.f.s.

Slope of .000001=.0053′ per mile, and s of .000004=.021′ per mile.
V necessary to produce a flow of 750,000 c.f.s.=3.42.



From curve, the slope necessary to produce a velocity of 3.42 f.p.s. is .0000014 =.0074′ per mile.

Distance from Army Point to Mare Island Light is 8.4 miles.

For 750,000 c.f.s., the total fall would be .062 ft.
For 1,070,000 c.f.s., the total fall would be .177 ft.

This fall is so slight that it can be neglected because it is far within the range of the limits of error in other factors in the problem.

TABLE 5-15

DISCHARGE THROUGH 30-50′ x 50′ GATES AT POINT SAN PABLO

Discharge through 30-50′ x 50′ gates at Point San Pablo during the tidal cycle 5 p.m. January 24 to 6 p.m. January 25, 1914. Tide record for Point San Pablo interpolated by increasing the record at Presidio by 0.3 of the difference between Presidio and Mare Island, and assuming the time 42 minutes later than Presidio. Quantities are in acre-feet. Flood of 750,000 c.f.s. assumed.

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Mare Island Light	Elevation at Collinsville
Jan. 24, 1914— 5.00 p.m.	—3.25	—1.75	30,980	0			—0.75	+3.45
5.30 p.m.	—3.10	—1.64	30,580	400	0		—0.75	+3.45
6.00 p.m.	—2.87	—1.49	29,500	1,480		400	—0.75	3.45
6.30 p.m.	—2.52	—1.42	26,430	4,550		1,880	—0.69	3.45
7.00 p.m.	—2.10	—1.28	23,000	7,980		6,430	—0.61	3.45
7.30 p.m.	—1.60	—1.10	18,000	12,980		14,410	—0.51	3.49
8.00 p.m.	—1.08	—0.85	12,200	18,780		27,390	—0.36	3.56
8.30 p.m.	—0.58	—0.52	6,200	24,780		46,170	—0.18	3.69
9.00 p.m.	—0.06	—0.12	2,000	28,980		70,950	+0.02	3.84
9.30 p.m.	+0.45	+0.20	0	30,980		99,930	+0.33	3.94
10.00 p.m.	+0.94	+0.53	0	30,980		130,910	+0.64	4.00
10.30 p.m.	1.40	+0.86	0	30,980		161,890	+0.95	4.06
11.00 p.m.	1.79	+1.19	0	30,980		192,870	+1.26	4.12
11.30 p.m.	2.10	+1.50	0	30,980		223,850	+1.57	4.21
Midnight	2.33	+1.82	0	30,980		254,830	1.89	4.27
Jan. 25, 1914— 0.30 a.m.	2.49	+2.14	0	30,980		285,810	2.21	4.33
1.00 a.m.	2.51	+2.46	0	30,980		316,790	2.53	4.39
1.30 a.m.	2.40	2.64	12,200	18,780		347,770	2.72	4.46
2.00 a.m.	2.20	2.74	18,600	12,380		366,550	2.82	4.60
2.30 a.m.	1.93	2.78	23,400	7,580		378,930	2.87	4.75
3.00 a.m.	1.71	2.78	26,200	4,780		386,510	2.90	4.89
3.30 a.m.	1.53	2.75	28,000	2,980		391,290	2.91	5.04
4.00 a.m.	1.43	2.73	28,800	2,180		394,270	2.91	5.17
4.30 a.m.	1.41	2.71	28,800	2,180		396,450	2.93	5.25
5.00 a.m.	1.48	2.73	28,200	2,780		398,630	2.95	5.29
5.30 a.m.	1.65	2.78	27,000	3,980		401,410	2.98	5.31
6.00 a.m.	1.89	2.88	25,100	5,880		405,390	3.02	5.31
6.30 a.m.	2.18	3.00	23,000	7,980		411,270	3.08	5.31
7.00 a.m.	2.52	3.13	19,900	11,080		419,250	3.20	5.28
7.30 a.m.	2.90	3.29	15,800	15,180		430,330	3.36	5.28
8.00 a.m.	3.28	3.50	11,800	19,180		445,510	3.57	5.25
8.30 a.m.	3.65	3.74	7,400	23,580		464,690	3.81	5.29

TABLE 5-15—Continued

DISCHARGE THROUGH 30-50′ x 50′ GATES AT POINT SAN PABLO

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Mare Island Light	Elevation at Collinsville
9.00 a.m.						488,270		
	4.00	4.02	3,330	27,650			4.09	5.34
9.30 a.m.						515,920		
	4.30	4.30	0	30,980			4.37	5.54
10.00 a.m.						546,900		
	4.52	4.54	3,340	27,640			4.61	5.76
10.30 a.m.						574,540		
	4.63	4.72	7,080	23,900			4.82	5.99
11.00 a.m.						598,440		
	4.62	4.87	11,800	19,180			4.97	6.22
11.30 a.m.						617,620		
	4.48	4.97	17,600	13,380			5.07	6.40
Noon						631,000		
	4.20	4.98	22,300	8,680			5.15	6.57
12.30 p.m.						639,680		
	3.74	4.95	27,900	3,080			5.18	6.68
1.00 p.m.						642,760		
	3.03	4.88	34,150		3,170		5.16	6.70
1.30 p.m.						639,590		
	2.12	4.75	41,200		10,220		5.08	6.66
2.00 p.m.						629,370		
	1.20	4.55	46,400		15,420		4.96	6.61
2.30 p.m.						613,950		
	0.35	4.30	50,150		19,170		4.81	6.55
3.00 p.m.						594,780		
	−0.40	4.03	53,400		22,420		4.63	6.46
3.30 p.m.						572,360		
	−1.09	3.74	55,700		24,720		4.43	6.35
4.00 p.m.						547,640		
	−1.68	3.44	57,300		26,320		4.22	6.21
4.30 p.m.						521,320		
	−2.14	3.14	58,200		27,220		4.00	6.04
5.00 p.m.						494,100		
	−2.45	2.85	58,300		27,320		3.77	5.91
5.30 p.m.						466,780		
	−2.60	2.59	57,600		26,620		3.53	5.77
6.00 p.m.						440,160		
	−2.53	2.39	56,200		25,220		3.28	5.62
6.30 p.m.						414,940		
	−2.35	2.24	54,200		23,220		3.05	5.43
7.00 p.m.						391,720		
	−2.03	2.10	51,400		20,420		2.85	5.27
7.30 p.m.						371,300		
	−1.65	2.00	48,400		17,420		2.67	5.12
8.00 p.m.						353,880		
	−1.18	1.95	44,900		13,920		2.51	5.00
8.30 p.m.						339,960		
	−0.69	1.93	41,100		10,120		2.39	4.89
9.00 p.m.						329,840		
	−0.15	1.93	36,400		5,420		2.32	4.85
9.30 p.m.						324,420		
	+0.38	1.94	31,500		520		2.32	4.81
10.00 p.m.						323,900		
	+0.87	2 00	26,900	4,080			2.37	4.76
10.30 p.m.						327,980		
	+1.35	2.10	22,000	8,980			2.47	4.71
11.00 p.m.						336,960		
	+1.77	2.24	17,400	13,580			2.61	4.75
11.30 p.m.						350,540		
	2.15	2.42	13,000	17,980			2.77	4.84
Midnight						368,520		
	2.44	2.62	10,500	20,480			2.95	4.96
Jan. 26, 1914— 12.30 a.m.						389,000		
	2.65	2.82	10,200	20,780			3.13	5.08
1.00 a.m.						409,780		
	2.82	3.00	10,600	20,380			3.31	5.23
1.30 a.m.						430,160		

TABLE 5-16

STUDY OF DISCHARGE AT ARMY POINT

Q=750,000 c.f.s

Study of discharge through 30-50′ x 50′ gates at Army Point, with 3 locks also open, 1-80′ x 40′, 1-60′ x 33′ and 1-40′ x 26′, during tidal cycle from 7 p.m. January 24 to 10 p.m. January 25, 1914. Tide gage record at Mare Island assumed applicable to Army Point. Flood of 750,000 c.f.s. assumed.

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Collinsville
Jan. 24, 1914— 7.00 p.m.	−3.00	−1.55	30,980				2.75
7.30 p.m.	−2.88	−1.46	30,740	240		240	2.68
8.00 p.m.	−2.61	−1.26	30,140	840		1,080	2.52
8.30 p.m.	−2.05	−0.84	28,980	2,000		3,080	2.23
9.00 p.m.	−1.45	−0.40	27,300	3,680		6,760	2.03
9.30 p.m.	−0.75	+0.13	25,400	5,580		12,340	1.87
10.00 p.m.	−0.14	+0.60	23,540	7,440		19,780	1.89
10.30 p.m.	+0.50	1.10	21,400	9,580		29,360	2.01
11.00 p.m.	1.03	1.55	19,700	11,280		40,640	2.28
11.30 p.m.	1.64	2.06	18,280	12,700		53,340	2.58
Midnight	2.13	2.52	17,520	13,460		66,800	2.97
Jan. 25, 1914— 12.30 a.m.	2.52	2.92	18,080	12,900		79,700	3.38
1.00 a.m.	2.82	3.25	18,900	12,080		91,780	3.80
1.30 a.m.	3.0	3.50	20,580	10,400		102,180	4.21
2.00 a.m.	3.09	3.67	22,080	8,900		111,080	4.59
2.30 a.m.	3.03	3.73	24,280	6,700		117,780	4.95
3.00 a.m.	2.86	3.68	26,220	4,760		122,540	5.30
3.30 a.m.	2.6	3.53	27,880	3,100		125,640	5.64
4.00 a.m.	2.32	3.35	29,020	1,960		127,600	5.94
4.30 a.m.	2.02	3.15	30,400	580		128,180	6.18
5.00 a.m.	1.80	3.00	30,980	0		128,180	6.33
5.30 a.m.	1.61	2.86	31,440		460	127,720	6.43
6.00 a.m.	1.53	2.79	31,560		580	127,140	6.46
6.30 a.m.	1.60	2.83	31,380		400	126,740	6.40
7.00 a.m.	1.78	2.97	30,940	40		126,780	6.26
7.30 a.m.	2.13	3.23	29,880	1,100		127,880	6.07
8.00 a.m.	2.51	3.51	29,020	1,960		129,840	5.92
8.30 a.m.	3.13	3.97	26,840	4,140		133,980	5.72
9.00 a.m.	3.53	4.29	25,600	5,320		139,300	5.74
9.30 a.m.	3.74	4.49	25,500	5,480		144,780	5.88
10.00 a.m.	4.20	4.85	23,840	7,140		151,920	5.96
10.30 a.m.	4.42	5.06	24,100	6,880		158,800	6.19
11.00 a.m.	4.71	5.33	23,700	7,280			6.38

TABLE 5-16—Continued

STUDY OF DISCHARGE AT ARMY POINT

Q=750,000 c.f.s

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Collinsville
11.30 a.m.						166,080	
	4.98	5.59	23,500	7,480			6.59
Noon						173,560	
	5.10	5.75	24,280	6,780			6.85
12.30 p.m.						180,340	
	5.06	5.79	25,700	5,280			7.14
1.00 p.m.						185,620	
	4.93	5.73	27,000	3,980			7.45
1.30 p.m.						189,600	
	4.60	5.60	29,800	1,180			7.65
2.00 p.m.						190,780	
	4.10	5.38	33,400		2,420		7.72
2.30 p.m.						188,360	
	3.68	5.09	34,800		3,820		7.77
3.00 p.m.						184,540	
	3.10	4.73	37,060		6,080		7.75
3.30 p.m.						178,460	
	2.38	4.33	40,000		9,020		7.59
4.00 p.m.						169,440	
	1.72	3.88	41,600		10,620		7.38
4.30 p.m.						158,820	
	1.07	3.38	42,500		11,520		7.16
5.00 p.m.						147,300	
	0.40	2.87	43,350		12,370		6.90
5.30 p.m.						134,930	
	−0.22	2.35	43,760		12,780		6.62
6.00 p.m.						122,150	
	−0.82	1.82	43,860		12,880		6.35
6.30 p.m.						109,270	
	−1.35	1.36	44,000		13,020		6.00
7.00 p.m.						96,250	
	−1.81	0.96	43,900		12,920		5.59
7.30 p.m.						83,330	
	−1.97	0.63	42,400		11,420		5.21
8.00 p.m.						71,910	
	−1.92	0.40	40,040		9,060		4.88
8.30 p.m.						62,850	
	−1.75	0.32	37,900		6,920		4.53
9.00 p.m.						55,930	
	−1.46	0.36	35,760		4,780		4.19
9.30 p.m.						51,150	
	−0.93	0.50	31,800		820		4.00
10.00 p.m.						50,330	
	−0.36	0.70	27,900	4,080			4.06
10.30 p.m.						54,410	

TABLE 5-17

DISCHARGE THROUGH 30-50′ x 50′ GATES AT ARMY POINT

Tidal cycle from 7.00 p.m., January 24, to 11.00 p.m., January 25, 1914.
Tidal gage record at Mare Island assumed applicable to Army Point.
Assumed river discharge, 500,000 c.f.s.

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Collinsville
Jan. 24, 1914— 7.00 p.m.	−3.00	−2.24	20,660	0		0	−1.23
7.30 p.m.	−2.88	−2.17	20,000	660		660	−1.25
8.00 p.m.	−2.61	−2.00	18,660	2,000		2,660	−1.29
8.30 p.m.	−2.05	−1.65	15,340	5,320		7,980	−1.25
9.00 p.m.	−1.45	−1.23	11,450	9,210		17,190	−1.06
9.30 p.m.	−0.75	−0.69	5,900	14,760		31,950	−0.66
10.00 p.m.	−0.14	−0.12	3,800	16,860		48,810	−0.09
10.30 p.m.	+0.50	+0.51	1,660	19,000		67,810	+0.51
11.00 p.m.	1.03	1.05	4,160	16,500		84,310	1.07
11.30 p.m.	1.64	1.66	1,860	18,800		103,110	1.68
Midnight	2.13	2.17	4,760	15,900		119,010	2.20
Jan. 25, 1914— 0.30 a.m.	2.52	2.60	6,960	13,700		132,710	2.64
1.00 a.m.	2.82	2.94	9,280	11,380		144,090	3.02
1.30 a.m.	3.00	3.19	11,500	9,160		153,250	3.34
2.00 a.m.	3.09	3.35	13,700	6,960		160,210	3.62
2.30 a.m.	3.03	3.42	16,800	3,860		164,070	3.79
3.00 a.m.	2.86	3.36	18,920	1,740		165,810	3.96
3.30 a.m.	2.60	3.23	21,200		540	165,270	4.05
4.00 a.m.	2.32	3.06	22,740		2,080	163,190	4.09
4.30 a.m.	2.02	2.85	24,160		3,500	159,690	4.08
5.00 a.m.	1.30	2.67	24,350		3,600	156,000	4.03
5.30 a.m.	1.61	2.52	24,850		4,190	151,810	3.92
6.00 a.m.	1.53	2.41	24,400		3,740	148,070	3.80
6.30 a.m.	1.60	2.42	23,600		2,940	145,130	3.63
7.00 a.m.	1.78	2.50	22,350		1,690	143,440	3.44
7.30 a.m.	2.13	2.68	19,600	1,060		144,500	3.33
8.00 a.m.	2.51	2.92	17,000	3,660		148,160	3.32
8.30 a.m.	3.13	3.33	11,800	8,860		157,020	3.46
9.00 a.m.	3.53	3.68	10,270	10,390		167,410	3.76
9.30 a.m.	3.74	3.93	11,810	8,850		176,260	4.06
10.00 a.m.	4.20	4.32	9,320	11,340		187,600	4.38
10.30 a.m.	4.42	4.59	11,130	9,530		197,130	4.71
11.00 a.m.	4.71	4.88	11,260	9,400		206,530	5.00
11.30 a.m.	4.98	5.16	11,660	9,000			5.28

TABLE 5-17—Continued

DISCHARGE THROUGH 30-50′ x 50′ GATES AT ARMY POINT

Time	Elevation below barrier	Elevation above barrier	Discharge in acre-feet per 30-minute intervals	Absorbed in storage	Released from storage	Accumulated storage	Elevation at Collinsville
Noon						215,530	
	5.10	5.34	13,670	6,990			5.54
12.30 p.m.						222,520	
	5.06	5.40	16,400	4,260			5.74
1.00 p.m.						226,780	
	4.93	5.38	18,700	1,960			5.88
1.30 p.m.						228,740	
	4.60	5.21	21,500		840		6.00
2.00 p.m.						227,900	
	4.10	4.90	24,340		3,680		6.08
2.30 p.m.						224,220	
	3.68	4.58	25,760		5,100		6.08
3.00 p.m.						219,120	
	3.10	4.20	28,100		7,440		6.00
3.30 p.m.						211,680	
	2.38	3.70	30,360		9,700		5.80
4.00 p.m.						201,980	
	1.72	3.20	30,700		10,040		5.76
4.30 p.m.						191.940	
	1.07	2.70	32,200		11,540		5.54
5.00 p.m.						180,400	
	0.40	2.20	33,800		13,140		5.22
5.30 p.m.						167,260	
	—0.24	1.70	35,200		14,540		4.81
6.00 p.m.						152,720	
	—0.81	1.22	36,000		15,340		4.33
6.30 p.m.						137,380	
	—1.39	0.75	36,900		16,240		3.78
7.00 p.m.						121,140	
	—1.80	0.29	36,460		15,800		3.25
7.30 p.m.						105,340	
	—1.96	—0.14	34,000		13,340		2.84
8.00 p.m.						92,000	
	—1.92	—0.44	30,700		10,040		2.50
8.30 p.m.						81,960	
	—1.76	—0.57	27,500		6,840		2.18
9.00 p.m.						75,120	
	—1.47	—0.60	23,600		2,940		2.03
9.30 p.m.						72,180	
	—0.96	—0.40	19,000	1,660			1.93
10.00 p.m.						73,840	
	—0.35	—0.05	13,800	6,860			1.83
10.30 p.m.						80,700	
	0.33	0.55	11,600	9,060			1.83
11.00 p.m.						89,760	

TABLE 6-1

SAN FRANCISCO HARBOR

Summary of Traffic for the Year 1923

Kind	Tons	Value
Foreign imports	875,057	$166,829,496
Foreign exports	2,174,084	149,490,165
Domestic	13,641,884	1,697,788,993

General ferry—	
Freight, tons	981,009
Passengers	52,448,923
Automobiles	1,660,071
Teams	33,415
Motorcycles	13,709
Stock	1,446
Car ferry—	
Freight, tons	1,632,606

Vessel Classification in 1923

Classes	Total number arrivals	Total net registered tonnage
Steamers and motor ships in foreign trade	780	4,393,754
Steamers and motor ships in domestic trade	11,785	21,331,506
Sailing vessels in foreign trade	7	7,298
Sailing vessels in domestic trade	30	51,791
Barges and lighters	11,285	1,297,390
Gasoline launches	6,902	131,575
Others	2,027	92,914
Totals	32,816	27,306,228

Summary of Trips by Vessels, 1923

Drafts	Steamers or motor ships	Sailing vessels	Barges and lighters	Gasoline launches	Others
	Inbound				
Over 30 feet	260				
28 to 30 feet	265				
26 to 28 feet	147				
24 to 26 feet	274				
22 to 24 feet	258	3	50		
20 to 22 feet	303	1			
18 to 20 feet	1,064	5	46		
16 to 18 feet	1,154	6	2		
14 to 16 feet	1,912	12		1	
12 to 14 feet	740	5			
10 to 12 feet	1,134	5	22		
8 to 10 feet	478		308	701	289
6 to 8 feet	2,674		5,164	2,789	1,087
Less than 6 feet	1,902		5,693	3,411	651
Totals	12,565	37	11,285	6,902	2,027
	Outbound				
Over 30 feet	79				
28 to 30 feet	117				
26 to 28 feet	129				
24 to 26 feet	503				
22 to 24 feet	189	2			
20 to 22 feet	260	1	22		
18 to 20 feet	664	6	96		
16 to 18 feet	1,246	4	2		
14 to 16 feet	2,064	12		1	
12 to 14 feet	507	9	25		
10 to 12 feet	1,142	3	20		
8 to 10 feet	901		273	701	288
6 to 8 feet	2,502		4,559	2,635	1,088
Less than 6 feet	2,129		6,302	3,579	651
Totals	12,432	37	11,299	6,916	2,027

TABLE 6-2

SAN PABLO BAY AND MARE ISLAND STRAIT

Comparative Statement of Traffic

Year	Tons	Value
1919	[1]4,321,904	$164,059,377
1920	[2]1,302,778	36,503,808
1921	[2]1,755,327	83,920,595
1922	[2]2,292,249	98,033,596
1923	[2]2,101,171	85,239,303

[1] Does not include traffic on Mare Island Strait.
[2] Does not include traffic for Carquinez Strait.

Vessel Classification in 1923

Classes	Total number
Steamers and motorships[1]	999
Steamers, bay[2]	3,296
Barges	1,477
Gas launches	970
Others	8
Totals	6,750

[1] No segregation of steamers and motor ships in foreign trade available.
[2] Operated on a regular schedule.
[3] Total net registered tonnage not reported.

Summary of Trips by Vessels, 1923

Drafts	Upbound		
	Steamers and motor ships	Barges	Gasoline launches
Over 30 feet	3		
28 to 30 feet	76		
26 to 28 feet	29		
24 to 26 feet	41	41	
22 to 24 feet	33		
20 to 22 feet	36		
18 to 20 feet	24		
16 to 18 feet	85	46	
14 to 16 feet	1,625		
12 to 14 feet	28		
10 to 12 feet	1,642	1	
8 to 10 feet	52	24	
6 to 8 feet	100	83	19
Less than 6 feet	521	1,282	951
Totals	4,295	1,477	970
	Downbound		
Over 30 feet	3		
28 to 30 feet	76		
26 to 28 feet	47		
24 to 26 feet	29	41	
22 to 24 feet	29		
20 to 22 feet	29		
18 to 20 feet	28		
16 to 18 feet	83	46	
14 to 16 feet	5		
12 to 14 feet	1,648		
10 to 12 feet	1,699	1	
8 to 10 feet	2		
6 to 8 feet	88	83	19
Less than 6 feet	529	1,306	951
Totals	4,295	1,477	970

TABLE 6-3

SUISUN BAY CHANNEL

Comparative Statement of Traffic

Year	Tons	Value	Year	Tons	Value
1919	288,233	$6,849,546	1922	1,272,938	$31,558,538
1920	362,223	13,033,360	1923	2,593,424	43,367,542
1921	519,532	19,271,264			

Vessel Classification in 1923

Classes	Total number		Net registered tonnage
	Foreign	Domestic	
Steamers	1	1,262	1,916,743
Sailing	1	1	4,706
Tow and tug boats		88	1,964
Barges		450	89,618
All other		611	39,947
Totals	2	2,412	2,052,978

Summary of Trips by Vessels, 1923

Draft	Upbound				
	Steamers	Sailing vessels	Tows	Barges	All others
26 to 28 feet	289				
22 to 24 feet	1				
18 to 20 feet	200	2	15	15	2
14 to 16 feet	101				
8 to 10 feet			11	25	
6 to 8 feet	630		5	191	25
Less than 6 feet	42		57	219	584
Totals	1,263	2	88	450	611

Draft	Downbound				
	Steamers	Sailing vessels	Tows	Barges	All others
26 to 28 feet	289				
22 to 24 feet	1				
18 to 20 feet	200	2	15	15	2
14 to 16 feet	101				
8 to 10 feet			11	25	
6 to 8 feet	630		5	191	25
Less than 6 feet	42		57	219	584
Totals	1,263	2	88	450	611

TABLE 6-4
PETALUMA CREEK

Comparative Statement of Traffic

Year	Tons	Value	Year	Tons	Value
1919	235,208	$18,093,925	1922	220,173	$18,866,87[illegible]
1920	281,616	17,061,972	1923	254,289	21,018,[illegible]
1921	173,414	11,490,083			

Vessel Classification in 1923

Classes	Domestic	Net registered tonnage	Passenger
Steamers and motorships	[1]744	162,036	401
Sailing boats	8	282	
Barges	1,004	132,738	
Tow boats	932	8,970	
Launches	625	3,075	
Totals	3,313	307,101	401

[1] Operating on regular schedule between San Francisco and Petaluma, California.

Summary of Trips by Vessels, 1923

Draft	Inbound				
	Steamers	Sailing vessels	Barges	Tow-boats	Launches
6 to 8 feet			23	932	625
4 to 6 feet	744	8	981		
Totals	744	8	1,004	932	625

Draft	Outbound				
	Steamers	Sailing vessels	Barges	Tow-boats	Launches
6 to 8 feet			23	932	625
4 to 6 feet	744	8	981		
Totals	744	8	1,004	932	625

TABLE 6-5

SAN RAFAEL CREEK

Comparative Statement of Traffic

Year	Tons	Value	Year	Tons	Value
1921	33,332	$359,865	1923	61,748	$2,495,286
1922	39,180	3,779,500			

Vessel Classification, 1923

Classes	Domestic, total number	Total net registered tonnage
Steamers or motor ships	522	30,000
Sailing vessels	20	1,800
Barges	196	24,000
Totals[1]	738	55,800

[1] Draft of all vessels less than 6 feet.

Summary of Trips by Vessels, 1923

Both directions	Number
Steamers or motor ships	522
Sailing vessels	20
Barges	196
Total[1]	738

[1] Draft of all vessels less than 6 feet.

TABLE 6-6

NAPA RIVER

Comparative Statement of Traffic

Year	Tons	Value	Year	Tons	Value
1919	76,667	$2,318,922	1922	139,811	[illegible]
1920	111,118	1,054,736	1923	110,814	[illegible]
1921	90,151	766,858			

Vessel Classification, 1923

Classes	Total number of vessels, domestic	Total net registered tonnage
Steamers and motor boats	279	[illegible]
Barges	563	[illegible]
Launches	140	[1]
All other	156	[1]
Totals	1,138	[illegible]

[1] Not reported.

Summary of Trips by Vessels, 1923

Drafts	Upstream				Downstream			
	Steamers	Barges	Launches	All others	Steamers	Barges	Launches	All others
6 to 8 feet	72	402			72	402		
Less than 6 feet	207	161	140	156	207	161	140	[illegible]
Totals	279	563	140	156	279	563	140	[illegible]

TABLE 6-7

SUISUN CHANNEL

Comparative Statement of Traffic

Year	Tons	Value	Year	Tons	Value
1919	16,731	$184,041	1922	55,836	$447,116
1920	71,207	844,086	1923	65,636	396,148
1921	42,016	398,405			

Vessel Classification, 1923

Classes	Domestic, total number	Total net registered tonnage
Steamers	52	3,536
Barges	77	32,725
Totals	129	36,261

Summary of Trips by Vessels, 1923

Drafts	Upbound		Downbound	
	Steamers	Barges	Steamers	Barges
8 to 10 feet		77		
Less than 6 feet	52		52	77
Totals	52	77	52	77

TABLE 6-8

SACRAMENTO RIVER

Comparative Statement of Traffic

Year	Tons	Value	Passengers
1919[1]	1,666,025	$78,601,238	91,54[illegible]
1920[2]	1,377,700	53,946,146	104,9[illegible]
1921[3]	976,596	52,092,263	10[illegible]
1922[4]	1,291,135	60,606,728	9[illegible]
1923[5]	1,264,821	62,470,235	94,22[illegible]

[1] Includes 712,500 tons of water, valued at $27,075.

[2] Includes 599,883 tons of water, valued at $60,468 and 13,682 tons of government materials used in improvement of the river, and valued at $606,191.

[3] Includes 143,000 tons of water, valued at $17,847, and 14,028 tons of government materials used in improvement of the river, and valued at $217,478.

[4] Includes 269,667 tons of water, valued at $20,263, and 12,958 tons of government materials used in improvement of the river, and valued at $199,934.

[5] Includes 105,333 tons of water, valued at $10,000; government materials used in improvement of river are not included.

Vessel Classification, 1923

Classes	Number	Net tonnage reported	Passengers
Registered:			
Steamers	29	11,270	94,1[illegible]
Gas	99	3,897	[illegible]
Unregistered:			
Gas	20	80	[illegible]
Unrigged (tonnage reported)	49	8,444	------
Unrigged (tonnage not reported)	42	------	------
Totals	239	23,691	94,22[illegible]

Summary of Trips by Vessels, 1923

As about 85 per cent of the vessels using this waterway and its interconnecting sloughs in 1923 made only seasonal or occasional trips, it was impracticable to obtain even an approximation of the number of trips made by vessels of various drafts, at reasonable effort and expense. Throughout the year one steamer line maintained a schedule of two trips a day, six days a week, for freight and passengers between bay points and Sacramento, one steamer for through traffic and one for way traffic in each direction, with standard full-load drafts of 5 to 7 feet; another steamer line maintained a schedule of one trip a day, six days a week, for freight and passengers, between San Francisco and Sacramento and way points, in each direction, with standard full-load drafts of 6½ feet; and another steamer line maintained a schedule of two trips a week for freight between bay points and Sacramento, with standard full-load drafts up to 8 feet, and one additional trip per week between bay points and Sacramento and points above as far as Butte City, 112 miles upstream, in each direction, with standard full-load drafts of 3 to 4 feet. More frequent trips were scheduled during seasonal movements of crops and produce, up to the head of navigation; and vessels drawing up to 8 feet were used during high water as far as Colusa. In addition, steam vessels drawing 4½ to 10 feet, and gas launches or schooners 3 to 11 feet, with barges 3 to 8 feet, all standard full-load drafts, made frequent though irregular trips between San Francisco and way points up to Sacramento; and occasional trips above Sacramento, up to the head of navigation were made by gas launches and barges drawing 3 to 6 feet. In the lower 15 miles of river, lumber steamers with standard full-load drafts of 14 feet, made occasional trips.