STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

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

Reports on State Water Plan Prepared Pursuant to Chapter 832, Statutes of 1929

BULLETIN No. 28

ECONOMIC ASPECTS
OF A
SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

1931

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ACKNOWLEDGMENT

In the investigation of the economic aspects of a salt water barrier, valuable assistance and cooperation have been rendered by many individuals and public and private agencies.

Particular appreciation is due the executives and owners of the industries of the upper San Francisco Bay region, who furnished detailed data on their respective plants. Without this assistance it would have been impracticable to carry out the economic studies relative to industrial development.

Many individuals and public officials in the upper San Francisco Bay and Sacramento-San Joaquin delta regions also have furnished information on agricultural developments and operations which has been of great assistance in the economic studies as to the relation and effect of a barrier on the agricultural industry.

Valuable cooperation has been rendered by several departments of the federal government. Many departments of the state have made studies and reports covering important phases of the investigation. Stanford University and the University of California have contributed materially to the investigation.

Special commendation is due the members of the Engineering Advisory Committee whose advice and assistance have been invaluable.

ORGANIZATION

Walter E. Garrison - - - - *Director of Public Works*

Edward Hyatt - - - - - - - *State Engineer*

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ENGINEERING ADVISORY COMMITTEE

This investigation was outlined and the report prepared with the advice of and in consultation with the following consulting engineers:

G. A. Atherton	A. Kempkey
G. A. Elliott	C. T. Leeds
B. A. Etcheverry	C. D. Marx
C. E. Grunsky	T. H. Means

CONCURRING STATEMENT OF ENGINEERING ADVISORY COMMITTEE

The undersigned members of the Engineering Advisory Committee, who have acted in an advisory capacity to the State Engineer throughout the progress of the investigation of the economic aspects of a salt water barrier, are in full accord with the procedure and methods of analysis and concur in the findings and conclusions of the investigation as presented in Bulletin No. 28.

G. A. Atherton
J. H. Elliott
B. A. Etcheverry
A. Kempkey
Chas. T. Leeds.
Chas. D. Marx
Thos. H. Means

Members of Engineering Advisory Committee.

November 21, 1931.

DISSENTING STATEMENT OF C. E. GRUNSKY

Although conversant with the studies made by the State Engineer of the problems connected with a salt water barrier, I can not subscribe to the final conclusion that a salt water barrier "is not necessary or economically justified as a unit of the State Water Plan." The finality of this condemnation of the project does not seem warranted at this time. I am convinced that this project will come up again in the future with further discussion as to its merits and in particular with greater attention to the benefits which it would confer.

In order that my attitude toward a state water policy be made clear I wish to have it understood that I regard the water of the country its greatest natural resource. It is a mistake to place the regulation of stream flow under private control for private benefit. All storage reservoirs for the regulation of the flow and for the conservation of waste water on international and interstate rivers as also some reservoirs on important navigable streams should be permanently under the control of the Federal Government. The comprehensive plan of regulating the flow and conserving the waste water of such streams should originate with the government. Rights to reservoir and dam sites necessary for such regulation should never be permanently alienated from public ownership. Likewise in the case of local waters, i. e., rivers within individual states, the plan of regulation should originate with the state and the control of all important reservoirs even when municipalities or districts or private parties have been permitted to construct the dams, should never be relinquished by the state.

Holding this view I believe that the working out of a state plan for water conservation is timely, and nothing that I here say is to be considered as opposed to a state policy of flow control and stream regulation by storage reservoirs.

Referring now to this Bulletin No. 28, my convictions and opinions in the main can be summarized as follows:

1. The bulletin gives the impression of having been prepared as an argument against any salt water barrier. For example, the facts have not been presented which would permit a comparison of itemized benefits, conferred by such a barrier, with the cost of its construction and operation.

2. The type of barriers which have been brought under discussion in the report are impractical. Therefore the cost estimates based thereon should not be accepted as conclusive. There is in the files of the Department, submitted by me, a preliminary sketch of a barrier of a type which will not require a bed-rock foundation, which has automatic gates for the passage of flood waters, and which will require a minimum of attention and which, while serving as a barrier, could also serve as a support for a highway and a railroad.*

* *See* Final Report Marine Piling Committee (Marine Borers and their Relation to Marine Construction on the Pacific Coast), pp. 43–47.

3. The consideration of barrier locations anywhere except downstream from San Pablo Bay was unnecessary because any barrier elsewhere located will raise the flood plane in the delta region of the Sacramento and San Joaquin Rivers and for this reason alone should be condemned.

4. The quantity of water that would be required to operate a barrier is over-estimated in the report. This is due to the types of barrier and of navigation locks taken into account, and to other causes.

5. The computation of available storage space above the barrier is based on a fluctuation of only one foot in vertical elevation of the water surface. The permissible fluctuation should be taken at two feet or more.

6. The alternative water supply service proposed in the report for a portion of the area which would become riparian or which would be proximate to fresh water above a salt water barrier would involve a new state policy. The state should confine itself to wholesaling water and power developed at the works for stream regulation. The state should not go into retail business.

For further information relating to my views, reference should be had to the comments on these and similar matters which I have submitted to the Department from time to time.

C. E. Grunsky.

Consulting Engineer.

San Francisco, California, September 22, 1931.

STATEMENT IN REPLY TO DISSENTING STATEMENT OF C. E. GRUNSKY

The members of the Engineering Advisory Committee have been conversant with the views held by C. E. Grunsky and have given them careful consideration during the progress of the investigation. The following statement presents the views of the undersigned members of the Engineering Advisory Committee. These views are presented in numerical sequence responsive to the numbered comments in Mr. Grunsky's dissenting statement.

1. In the prosecution of the economic studies of a salt water barrier, there has been no idea of preparing an argument either for or against a barrier. It is believed that this report presents in an unbiased manner all pertinent facts and findings, which speak for themselves.

The primary objectives sought to be attained for the upper bay region and delta have been considered to be of paramount importance. These primary objectives are: The protection of the lands and water supply of the delta from saline invasion; the control of salinity, so that water supplies now or hereafter made available in the lower Sacramento and San Joaquin Rivers would be maintained fresh for utilization in the delta and upper bay region; and the furnishing of fresh-water supplies for domestic, municipal, industrial and agricultural use in the upper bay region. As a means of attaining these objectives, a salt water barrier should stand on its merits as compared to any alternate plan. This investigation has shown that there is an alternate plan for attaining these objectives; that this alternate plan of salinity control and water service is less than half as costly as a barrier; and that this alternate plan would have all of the essential advantages and benefits which a barrier might attain but none of the disadvantages and detriments of a barrier.

The report aims to be constructive, not destructive. It presents a reasonable and effective plan which provides for the water supply needs of the delta and upper bay region and attains all of the essential objectives that a barrier could attain. If a barrier were the only means of attaining the objectives sought, an economic study certainly would require an evaluation, if possible, of all benefits as Mr. Grunsky advocates. However, it is unnecessary to evaluate benefits which are common to alternate plans of development, with or without a barrier. Whatever the value of benefits, it would not justify a barrier when the same benefits and benefit values would be derived from an alternate plan without a barrier costing very substantially less than a barrier.

The final conclusion of the investigation unavoidably follows from the comparison of the merits and costs of alternate plans of development with and without a barrier.

2. When the investigation of the economic aspects of a barrier was started, the matters of design and cost of a barrier were fully discussed at initial meetings of the Engineering Advisory Committee. After careful consideration, it was decided to accept the basic plans and cost estimates presented in Bulletin No. 22, "Report on Salt River Barrier Below Confluence of Sacramento and San Joaquin Rivers," Division of Water Resources, 1929, as being sufficient for the economic studies. However, additional studies were made and cost estimates prepared for a shallower structure than the designs of Bulletin No. 22; and estimates of cost were made for a structure of the type and at the site suggested by Mr. Grunsky. Neither the shallower structure nor the type of structure at the site suggested by Mr. Grunsky indicated any saving in cost, as compared to the plans for the sites used in this investigation. The cost estimates presented in Bulletin No. 22 were reviewed and checked and are believed to be in harmony with cost estimates prepared for units of the State Water Plan. The plans for a salt water barrier in Bulletin No. 22 contemplated the possibility of the structure serving as a highway and railroad crossing, but this possible function is of minor importance and has no governing effect upon the economic feasibility of a barrier.

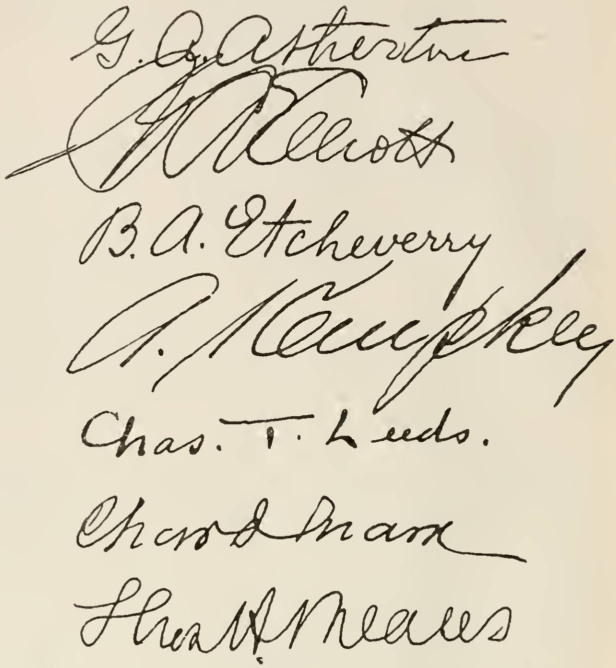
3. The policy of considering three typical sites for a barrier, representative of an upper, intermediate and lower location, was approved by the Engineering Advisory Committee at the beginning of the investigation. It was concluded that it was unnecessary to make a final choice of a site for the economic study. A barrier at any one of the three sites considered could be designed with flood gates which would be capable of passing the maximum flood flows without raising the flood plane in the delta region.

4. The estimates of water required for operation of a barrier to control salinity are based upon detailed and lengthy studies, both by the State Engineer and the United States Army Engineers. It is believed that the estimates presented in Bulletin No. 28, based upon the assumed use and effectiveness of salt-clearing locks, are reasonable and as accurate as could be made with the present knowledge available.

5. The limitation of the usable storage capacity in a barrier lake to one foot of range is based upon a consideration of all of the factors which would govern the permissible fluctuation of barrier-lake level. However, the conclusions would be unchanged even if it were assumed permissible to use two or three feet of storage space instead of one foot.

6. The alternate plan proposed for bringing water to the upper bay region in special conduits extending from controlled fresh-water channels in the delta is believed to represent as reasonable a project for inclusion in a State Water Plan as would a salt water barrier. The objective for the upper bay region of either plan is fundamentally the same; namely, fresh-water supply and service. The studies of this investigation show that a barrier, especially at a lower site below San Pablo Bay as advocated by Mr. Grunsky, would not be a unit which would conserve water. It would serve merely as a diversion structure or, in other words, would make possible the utilization of the upper bay channels above a barrier for assisting in the distribution of fresh-

water supplies now or hereafter made available from the Sacramento and San Joaquin Rivers. Conduits would be required also to distribute the water from a barrier lake.



Members of Engineering Advisory Committee.

November 21, 1931.

FEDERAL AGENCIES COOPERATING IN INVESTIGATION

WAR DEPARTMENT

THOMAS M. ROBINS, *Lieutenant Colonel, Corps of Engineers, Division Engineer, South Pacific Division*

E. H. ROPES, *Major, Corps of Engineers, District Engineer, First District of South Pacific Division*

Under the general direction of Colonel Robins and the immediate supervision of Major Ropes, the War Department has carried out an investigation under H. R. 308, 1927, of the salt water barrier, in cooperation with this office. The work of the Army Engineers has covered important phases of the investigation, including flood control and navigation features, tidal action, and movement of silt and water-borne debris. This has involved extensive field work, with complete new hydrographic and aerial photographic surveys of the entire Suisun and San Pablo Bay regions, measurements of tidal currents and movement of both suspended and bedload silt, installation and operation of automatic tide gages, special evaporation studies, and detailed field counts of water-borne traffic.

DEPARTMENT OF INTERIOR

Geological Survey, Water Resources Branch

H. D. MCGLASHAN, *District Engineer*

During the present investigation, specially concerned with the studies of variation of salinity, valuable cooperation was rendered by Mr. McGlashan in furnishing advance information on stream flow entering the delta, and in improving the installations of certain stream gaging stations maintained for this purpose.

Geological Survey, Topographic Branch

THOMAS D. GERDINE,* *Division Engineer*

Through cooperative agreement, precise level lines were run in the San Francisco Bay Region and delta under the direction of Mr. Gerdine for the purpose of referring the automatic tide gages to a common precise level datum. This work was essential in studies of tidal action.

*Since deceased.

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DEPARTMENT OF AGRICULTURE

Bureau of Public Roads, Division of Agricultural Engineering

W. W. McLaughlin, *Associate Chief*

Under cooperative agreement, the Division of Agricultural Engineering, under the general direction of Mr. McLaughlin and immediate supervision of Major O. V. P. Stout, has made detailed measurements of the consumptive use of water by crops and natural vegetation in the Sacramento-San Joaquin Delta, covering a period of over six years. The results of these measurements have played an important part in the investigation.

Bureau of Chemistry and Soils

L. H. Lapham, *Inspector, District No. 5*

This Bureau, in cooperation with the Division of Soil Technology of the University of California, has furnished advance information on the soil surveys recently completed in Solano County, covering especially the marshlands and uplands adjacent to Suisun Bay.

DEPARTMENT OF COMMERCE

Coast and Geodetic Survey

Thos. J. Maher, *Inspector, San Francisco Field Station*

Commander Maher of the Coast and Geodetic Survey furnished assistance and advice and loaned tide gage equipment in the work of obtaining tidal records in the San Francisco Bay and delta regions.

STATE AGENCIES COOPERATING IN INVESTIGATION

UNIVERSITY OF CALIFORNIA, COLLEGE OF AGRICULTURE

C. B. Hutchison, *Dean*

The College of Agriculture, through Professor Charles F. Shaw of the Division of Soil Technology, cooperated with the Division of Agricultural Engineering of the United States Department of Agriculture in furnishing information on the recently completed soil surveys of the marshlands and uplands adjacent to Suisun Bay.

DIVISION OF HIGHWAYS

C. H. Purcell, *State Highway Engineer*

A report on "Feasibility and Suitability of Combining a Highway Crossing with a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," was prepared by F. J. Grumm, Engineer of Surveys and Plans, and T. A. Bedford, Assistant Engineer of Surveys and Plans, of the Division of Highways. This report is presented as Appendix B.

DEPARTMENT OF PUBLIC HEALTH

W. M. Dickie, *Director*

A report on "Sewage and Industrial Waste Disposal and Water Redemption with Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," was prepared by the Bureau of Sanitary Engineering, under the direction of C. G. Gillespie, Chief. This report is printed as Appendix E.

DEPARTMENT OF NATURAL RESOURCES

F. G. Stevenot, *Director*

A report on the "Fishing Industry with Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," was prepared by Division of Fish and Game, under the direction of N. B. Scofield, in charge of the Bureau of Commercial Fisheries. This report is printed as Appendix F.

INDUSTRIAL ECONOMICS COMMITTEE

A special report entitled "Industrial Survey of Upper San Francisco Bay Area with Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," presented as Appendix A, was prepared by G. W. Dowrie, Professor of Graduate School of Business, Stanford University, assisted by Oscar A. Anderson, Graduate Fellow, Stanford University, under the supervision and direction of the following committee:

WILLARD E. HOTCHKISS, *Chairman*
Dean of Graduate School of Business, Stanford University

HENRY F. GRADY
Dean of College of Commerce, University of California

A. D. SCHINDLER
Consulting Engineer, San Francisco

SPECIAL CONSULTANTS

Consulting engineers and geologists rendered reports on special features of this investigation as follows:

Charles H. Lee, Consulting Engineer, made a special study and submitted a report entitled "Evaporation and Transpiration With Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," which is presented as Appendix C.

C. F. Tolman, Consulting Geologist, made a detailed investigation and prepared a report entitled "Geology of Upper San Francisco Bay Region With Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers," which is presented as Appendix D.

Hyde Forbes, Engineering Geologist, made a special investigation and prepared a report on the underground water resources of Ygnacio and Clayton valleys and Pittsburg-Antioch area.

CHAPTER 832, STATUTES OF 1929

An act making an appropriation for work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development, and utilization of the water resources of California including the Santa Ana river, Mojave river and all water resources of southern California.

[I object to the item of $450,000.00 in section 1 and reduce the amount to $390,000.00. With this reduction I approve the bill. Dated June 17, 1929. C. C. Young, Governor.]

The people of the State of California do enact as follows:

SECTION 1. Out of any money in the state treasury not otherwise appropriated, the sum of four hundred fifty thousand dollars, or so much thereof as may be necessary, is hereby appropriated to be expended by the state department of public works in accordance with law in conducting work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development and utilization of the water resources of California including the Santa Ana river and its tributaries, the Mojave river and its tributaries, and all other water resources of southern California.

SEC. 2. The department of public works, subject to the other provisions of this act, is empowered to expend any portion of the appropriation herein provided for the purposes of this act, in cooperation with the government of the United States of America or in cooperation with political subdivisions of the State of California; and for the purpose of such cooperation is hereby authorized to draw its claim upon said appropriation in favor of the United States of America, or the appropriate agency thereof for the payment of the cost of such portion of said cooperative work as may be determined by the department of public works.

SEC. 3. Upon the sale of any bonds of this state hereafter authorized to be issued to be expended for any one or more of the purposes for which any part of the appropriation herein provided may have been expended, the amount so expended from the appropriation herein provided shall be returned into the general fund of the state treasury out of the proceeds first derived from the sale of said bonds.

FOREWORD

This report is one of a series of bulletins on the State Water Plan issued by the Division of Water Resources pursuant to Chapter 832, Statutes of 1929, directing further investigations of the water resources of California. The series includes Bulletin Nos. 25 to 36, inclusive. Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," is a summary report of the entire investigation.

Prior to the studies carried out under this act, the water resources investigation had been in progress more or less continuously since 1921 under several statutory enactments. The results of the earlier work have been published as Bulletin Nos. 3, 4, 5, 6, 9, 11, 12, 13, 14, 19 and 20 of the former Division of Engineering and Irrigation, Nos. 5, 6 and 7 of the former Division of Water Rights, and Nos. 22 and 24 of the Division of Water Resources.

The full series of water resources reports prepared under Chapter 832, twelve in number, are:

Bulletin No. 25—"Report to Legislature of 1931 on State Water Plan."
Bulletin No. 26—"Sacramento River Basin."
Bulletin No. 27—"Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay."
Bulletin No. 28—"Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."
Bulletin No. 29—"San Joaquin River Basin."
Bulletin No. 30—"Pacific Slope of Southern California."
Bulletin No. 31—"Santa Ana River Basin."
Bulletin No. 32—"South Coastal Basin."
Bulletin No. 33—"Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain."
Bulletin No. 34—"Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley."
Bulletin No. 35—"Permissible Economic Rate of Irrigation Development in California."
Bulletin No. 36—"Cost of Irrigation Water in California."

This bulletin presents the results of a study of the economic aspects of a salt water barrier. It deals with the effect of a barrier on present and future developments and activities of the upper San Francisco Bay and Sacramento-San Joaquin delta regions, the present and future needs of the area, alternate plans with and without a barrier for serving these needs, and finally the necessity and economic justification of a barrier as a unit in the State Water Plan.

CHAPTER I

INTRODUCTION, SUMMARY AND CONCLUSIONS

The salt water barrier, which has been under consideration as a unit in a plan for the conservation and utilization of the state's water resources, has been proposed for the purpose of damming off and preventing the annually recurring upstream movement of salt water from the ocean into the channels of upper San Francisco Bay and the Sacramento-San Joaquin Delta, and thereby creating and maintaining a fresh-water lake from which water supplies now available or hereafter made available from the Sacramento and San Joaquin rivers might be utilized by industries, municipalities and agricultural developments in the upper bay and delta regions. In addition to these primary objectives, previous investigations have indicated that a barrier would be necessary to effect the maximum conservation of water in an ultimate plan of development of the state's water resources and provide a means of diversion for exportation of water from the Sacramento River to San Joaquin Valley. Typical locations for a barrier below the confluence of the Sacramento and San Joaquin rivers, designed to attain these objectives, and the geographical relation of a barrier to the physiographical features of the state and the tributary stream systems of the Sacramento and San Joaquin rivers are shown on Plate I, "Typical Sites for Salt Water Barrier."

Additional functions, which it has been assumed a barrier would have, include the following: assistance in the reclamation of salt marshlands of the upper bay region above a barrier; elimination of the destructive action of marine borers on water front structures above a barrier; elimination of tidal currents and creation of greater average depths of water in navigable channels above a barrier; creation of a fresh-water anchorage affording suitable conditions for removal of marine growth from the bottoms of vessels; prevention of excessive high tides from ocean storms above a barrier; and provision of a convenient crossing of the bay for highway and railroad traffic.

The conception of a physical barrier to prevent the invasion of salt water into tidal channels is not new. As far back as 285 B. C. there is a record of a structure built to control salt water invasion. In that year, the Egyptian King, Ptolemy Philadelphus, constructed locks in a navigation canal extending from the Nile River to the Red Sea, which had as one of its chief purposes the prevention of salt water penetrating the canal and rendering its water unfit for irrigation use.

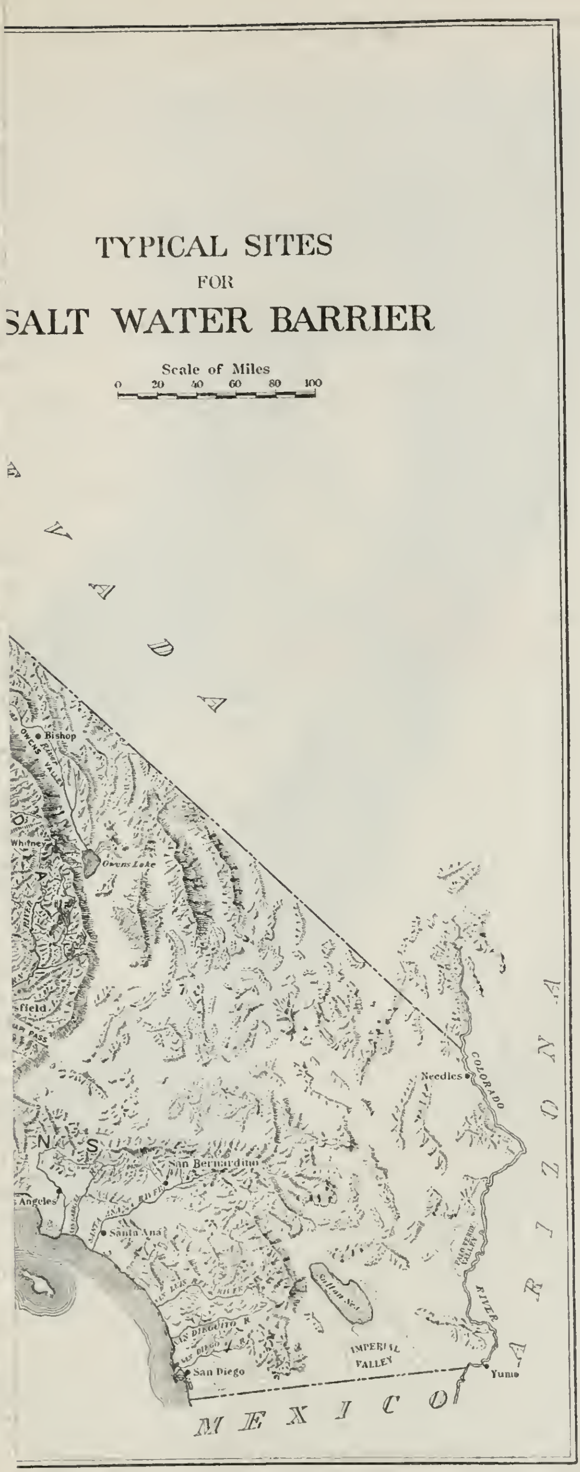
Within the United States there are several examples of a barrier structure of similar nature and purpose to that under consideration below the confluence of the Sacramento and San Joaquin rivers. A similar structure, completed in 1910, is in operation at the mouth of the Charles River Basin at Boston, Massachusetts. Its purpose is to eliminate the unsightly salt water mud flats which existed along the shores of the Charles River Basin and, by the creation of a fresh-water lake at constant level, provide agreeable conditions for residential development and recreational activities along the shores. It is interesting to note that it was found necessary and desirable to intercept all the sewage and industrial waste originally discharged into the Charles River Basin and carry it to an outfall below the barrier. Locks are provided in the structure for the passage of small vessels from the lower river into the lake above. The Lake Washington Ship Canal near Seattle affords another example of a similar structure. This was completed in 1916 for the purpose of increasing the harbor facilities of Seattle and making available a large fresh-water anchorage for vessels. The fresh-water basin comprises Lake Washington and Lake Union, which are cut off from Puget Sound by a barrier structure equipped with locks for the passage of vessels between Puget Sound and the lakes. Other examples are found in bayous and channels of southern Louisiana and Texas. Notable among these is a structure on Schooner Bayou, in southern Louisiana, and one on the Sabine-Neches Ship Canal in southern Texas. These structures are both across navigable channels and necessarily provide locks for the passage of vessels. They were constructed to prevent the invasion of salt water from the Gulf of Mexico into the system of inland waterways and lakes above, so that the water in these latter channels might be fresh enough for use in the irrigation of extensive rice lands.

The results of the operation of the barrier structures in the United States cited above, particularly as regards their effectiveness in preventing the invasion of salt water into the lakes and channels above the barrier, are of special interest in the present study. The experience especially at Lake Washington Ship Canal and studies of its operations furnish valuable information on the effect of lockage operations in saline pollution of the fresh-water lake above the structure, and attempted methods to control such pollution.

Previous Investigations.

The proposal for a barrier at some point below the confluence of the Sacramento and San Joaquin rivers has received consideration at various times since the early sixties, at which time it is reported that such a proposal first was made. In 1880, the State Engineer made a study of a barrier across Carquinez Strait with the object in mind of controlling flood levels in the lower reaches of the Sacramento and San Joaquin rivers. It was hoped that a dam at this point might be so operated as to temporarily store flood waters in the basin above and release them in such a way as to lower the flood plane levels upstream. It was found, however, that the storage capacity above a barrier located in Carquinez Strait would not be sufficient to take care of the large volume of flood flows which would enter the basin between successive low tides, and that such a barrier would not be effective in lowering flood planes above.

In more recent years, the proposal of a barrier once more was brought to attention by the extensive invasion of saline water into the upper bay and delta regions, due to the occurrence of a succession of subnormal dry years, coupled with large increases in irrigation diversions from the Sacramento and San Joaquin river systems. These


TYPICAL SITES
FOR
SALT WATER BARRIER
Scale of Miles
0 20 40 60 80 100
Bishop
Owens Valley
Whitney
Owens Lake
Needles
COLORADO
San Bernardino
Santa Ana
Salton Sea
PALO VERDE VALLEY
RIVER
San Diego
IMPERIAL VALLEY
Yuma
MEXICO
ARIZONA


TYPICAL SITES
FOR
SALT WATER BARRIER
Scale of Miles
0 20 40 60 80 100
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
COAST RANGE
SIERRA NEVADA
SAN JOAQUIN MOUNTAINS
DILLON POINT SITE
POINT SAN PABLO SITE
CHIPPS IS. SITE
Eureka
Redding
Red Bluff
Chico
Mt Shasta
Mt Lassen
Lake Tahoe
Sacramento
Santa Rosa
Napa
Fairfield
San Rafael
Martinez
Oakland
San Francisco
Stockton
Modesto
San Jose
Merced
Fresno
Visalia
Bishop
Owens Lake
Mono
Bakersfield
Santa Barbara
Los Angeles
San Bernardino
Santa Ana
San Diego
Needles
Yuma
IMPERIAL VALLEY
COLORADO
SACRAMENTO
FEATHER
RIVER
MERCED
FRESNO
STANISLAUS
TUOLUMNE

invasions of saline water began to be of unusual extent in 1918, and in 1920 saline water penetrated farther into the delta channels than at any previous time of authentic record. These conditions resulted in considerable apprehension and alarm on the part of the owners of lands in the delta as well as the industrial interests in the upper bay region, and culminated in the filing of the "Antioch" suit. This was filed by the City of Antioch, an appropriator from the San Joaquin River, against the upper irrigation users on the Sacramento River, and sought to enjoin their diversions and to restore natural stream flow conditions in the Sacramento River. During the trial of the suit, the proposal of a salt water barrier as a constructive measure to take care of the salinity problem was broached.

Recognizing the possible merit of a barrier, efforts were made following this latest proposal to carry out studies as to its feasibility. A preliminary study and report* were made by C. S. Jarvis, Captain, Corps of Engineers, U. S. A., in 1921. In 1923, A. Kempkey made a study and report** for the State Department of Public Works, of tentative designs and cost estimates for a barrier located at the upper end of Carquinez Strait. As a part of the investigations from 1920 to 1927 by the San Francisco Bay Marine Piling Committee,*** C. E. Grunsky made preliminary studies and designs of a barrier in the "Narrows" below San Pablo Bay.

As a result of these preliminary studies, a great deal of interest was aroused and concerted efforts were made on the part of those interested to have a thorough study of the proposed structure carried out. The upper irrigation interests, represented by the Sacramento Valley Development Association, and the delta interests, represented by the Delta Land Syndicate, requested the United States Bureau of Reclamation to make an investigation for the purpose of determining the feasibility, probable effectiveness and the approximate cost of a barrier. This investigation was finally carried out under a cooperative contract, drawn January 26, 1924, between the United States Bureau of Reclamation, the State Department of Public Works (Division of Engineering and Irrigation) and the Sacramento Valley Development Association. Funds were provided equally by the United States Bureau of Reclamation and the State of California, supplemented by private subscriptions from agricultural interests in the Sacramento Valley and the delta, and industrial interests of the upper bay region. Actual work was started in April, 1924, and actively prosecuted from that date until March, 1926. A report† covering the investigation was completed in June, 1928, and published in 1929.

The investigation was directed chiefly to the physical aspects of a salt water barrier. Eleven sites were considered, of which three were selected for special investigation and study. These comprised Dillon Point and Army Point sites in Carquinez Strait and Point San Pablo

*"Control of Flood and Tidal Flow in the Sacramento and San Joaquin Rivers, California," Transactions of the American Society of Civil Engineers, Volume 84 (1921).

**"Proposals for Preventing Salt Water Encroachment by Dam Construction," Proceedings of Sacramento River Problems Conference, January, 1924.

***Final Report of San Francisco Bay Marine Piling Committee, "Marine Borers and Their Relation to Marine Construction on the Pacific Coast," 1927.

†Bulletin No. 22, "Report on Salt Water Barrier," by Walker R. Young, Engineer U. S. Bureau of Reclamation, (2 volumes), Division of Water Resources, 1929.

invasions of saline water began to be of unusual extent in 1918, and in 1920 saline water penetrated farther into the delta channels than at any previous time of authentic record. These conditions resulted in considerable apprehension and alarm on the part of the owners of lands in the delta as well as the industrial interests in the upper bay region, and culminated in the filing of the "Antioch" suit. This was filed by the City of Antioch, an appropriator from the San Joaquin River, against the upper irrigation users on the Sacramento River, and sought to enjoin their diversions and to restore natural stream flow conditions in the Sacramento River. During the trial of the suit, the proposal of a salt water barrier as a constructive measure to take care of the salinity problem was broached.

Recognizing the possible merit of a barrier, efforts were made following this latest proposal to carry out studies as to its feasibility. A preliminary study and report* were made by C. S. Jarvis, Captain, Corps of Engineers, U. S. A., in 1921. In 1923, A. Kempkey made a study and report** for the State Department of Public Works, of tentative designs and cost estimates for a barrier located at the upper end of Carquinez Strait. As a part of the investigations from 1920 to 1927 by the San Francisco Bay Marine Piling Committee,*** C. E. Grunsky made preliminary studies and designs of a barrier in the "Narrows" below San Pablo Bay.

As a result of these preliminary studies, a great deal of interest was aroused and concerted efforts were made on the part of those interested to have a thorough study of the proposed structure carried out. The upper irrigation interests, represented by the Sacramento Valley Development Association, and the delta interests, represented by the Delta Land Syndicate, requested the United States Bureau of Reclamation to make an investigation for the purpose of determining the feasibility, probable effectiveness and the approximate cost of a barrier. This investigation was finally carried out under a cooperative contract, drawn January 26, 1924, between the United States Bureau of Reclamation, the State Department of Public Works (Division of Engineering and Irrigation) and the Sacramento Valley Development Association. Funds were provided equally by the United States Bureau of Reclamation and the State of California, supplemented by private subscriptions from agricultural interests in the Sacramento Valley and the delta, and industrial interests of the upper bay region. Actual work was started in April, 1924, and actively prosecuted from that date until March, 1926. A report† covering the investigation was completed in June, 1928, and published in 1929.

The investigation was directed chiefly to the physical aspects of a salt water barrier. Eleven sites were considered, of which three were selected for special investigation and study. These comprised Dillon Point and Army Point sites in Carquinez Strait and Point San Pablo

*"Control of Flood and Tidal Flow in the Sacramento and San Joaquin Rivers, California," Transactions of the American Society of Civil Engineers, Volume 84 (1921).

**"Proposals for Preventing Salt Water Encroachment by Dam Construction," Proceedings of Sacramento River Problems Conference, January, 1924.

***Final Report of San Francisco Bay Marine Piling Committee, "Marine Borers and Their Relation to Marine Construction on the Pacific Coast," 1927.

†Bulletin No. 22, "Report on Salt Water Barrier," by Walker R. Young, Engineer U. S. Bureau of Reclamation, (2 volumes), Division of Water Resources, 1929.

site at the upper end of the "Narrows" below San Pablo Bay. Field work consisted of detailed surveys of sites together with rather extensive diamond-drill borings to determine the character of the foundations at three typical sites. In addition to the surveys and drilling explorations, preliminary geological studies were made at each of the sites. Studies were made of tides, floods, navigation, storage, salinity, silt, and water requirements for operation of a barrier. The report presents nineteen alternate plans and cost estimates, covering various modifications of design for the three sites and for a fourth site at Benicia not explored in detail. The estimates of cost range from $38,900,000 to $97,100,000, not including interest during construction. The important conclusion of the investigation was that a salt water barrier would be physically feasible of construction at any of the sites investigated.

No studies were made of the economic aspects of a barrier other than to point out some of the indicated advantages and disadvantages. However, the recommendation was made that an economic study would be necessary to determine whether the benefits to be derived from construction of a barrier would be commensurate with its cost.

Scope of Present Investigation.

The present investigation of a salt water barrier has been directed chiefly to a study of its economic aspects. This has involved a survey and study of the upper bay and delta regions, with particular reference to manufacturing industries, industrial water front structures, irrigation, reclamation, flood control, navigation, fishing, municipalities, sewage and industrial waste disposal, and the effect of a barrier thereon. Estimates have been made of immediate future and ultimate water requirements for all purposes. An essential feature of the investigation has been a study of alternate plans, with and without a barrier, to provide the basic requirements of salinity control and dependable fresh-water supplies for the upper bay and delta regions. The purpose of this study has been to determine, if possible, the most practicable and economical means of supplying present and ultimate water demands and facilitating the development of industries, municipalities and agriculture in the area. Finally, consideration has been given to the necessity and economic justification of a barrier, not only as a means for serving the needs of the upper bay and delta regions but also as a unit for attaining the maximum conservation and utilization of the state's water resources.

Additional studies have been made of the physical aspects of a barrier to ascertain more completely some of the more important physical elements affecting its cost and operation. The preliminary plans and cost estimates for a barrier, as presented in Bulletin No. 22, have been reviewed. A similar preliminary plan and cost estimate for a barrier at an upper site at Chipps Island have been prepared in order to carry out economic studies for a barrier at a typical upstream location for comparison with lower sites. A complete geological investigation has been made of the entire area in which the barrier sites are situated. Additional studies of tidal action, movement of silt and water-borne debris, floods and navigation have been carried out. Detailed studies and estimates have been made of the loss of water by evaporation and transpiration from a barrier lake and the water requirements for operating a barrier, leading to estimates of its conservation efficiency.

Work was started in the summer of 1929 with the initiation of an intensive study of the variation and control of salinity in the upper bay and delta. The results of the salinity investigation, based upon an exhaustive analysis of the records of salinity obtained during the period of the last ten years, are presented in a separate report.* Estimates have been made of the amount of stream flow required for controlling invasion of salinity at various points in the upper bay and delta region and for various degrees of salinity control, and the amounts of supplementary water supply required in addition to present stream flow to effect the desired degree of control.

For the purpose of obtaining the basic data required for carrying out the economic studies, a series of seven questionnaires were prepared and used, covering the following: Industries, industrial water front structures, public water supplies, irrigation and reclamation development in the delta, irrigation and reclamation development in the Suisun and San Pablo Bay region, sewage and industrial waste disposal and fishing industry.

The industrial survey embraced the area from Antioch and Isleton on the east to Richmond on the south on both sides of the bay, involving a total of 114 separate industries. The questionnaire consisted of 26 pages and covered information for each industry on products, date of location, reasons for and advantages and disadvantages of location, sources of raw materials, markets, power and fuel used, period of continuous operation, transportation facilities, labor, water supply (consumption and cost), sewage and industrial waste disposal, reclamation works, statistical information on capital investment, assessed valuation, cost of raw material, gross value of sales, number of employees, payroll, and questions covering the economic advantages and disadvantages of a barrier. Representatives of each industry were personally interviewed. The survey extended over a period of about six months. The results of the compilation and analysis of these data supplied an essential part of the basic information for the study of industrial development made by the special industrial economics committee, whose report is presented as Appendix A.

Industrial water front structures on both sides of the bay from the lower end of the delta to Point Richmond were examined. Data were obtained as to type of structure, character of construction, type of piling, and capital and annual costs. Information also was obtained on the effect of marine borers, including the additional capital and annual costs necessitated by reason of their attacks. The survey included the examination and gathering of detailed information on 256 structures.

Public water supply systems serving towns and industries in the area from Antioch to Richmond were surveyed, including a total of 22 separate systems. Data were obtained on sources and consumption of water, character and costs of plant and equipment, cost of water, and statistical data covering the growth of each system.

* Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

A comprehensive study was made of irrigation and reclamation developments in the delta and the marshland and upland areas adjacent to Suisun and San Pablo bays. This study embraced an area of about 850,000 acres, of which about 500,000 acres lie in the delta and the balance in marshlands and uplands adjacent to Suisun and San Pablo bays. Field surveys were made and questionnaires used to obtain data on crops, soil, irrigation and reclamation works, extent of irrigation, water requirements, irrigation and drainage costs and data relating to the effect of a barrier on irrigation and reclamation works and operations.

An important feature of the investigation has been a study of the consumption of water by evaporation and transpiration from a barrier lake and the amount of water required for barrier operation. Estimates of transpiration from vegetation are based partly upon measurements carried out cooperatively with the United States Department of Agriculture during the last six years, and partly upon special studies presented in Appendix C. Estimates of evaporation are based upon a special study, presented in Appendix C, of all available evaporation and meteorological records including special measurements taken during the investigation. The water requirements for barrier operation are based in part upon estimates submitted by the United States Army Engineers.

Cooperative Investigations.

The report of the State Division of Highways (Appendix B) presents the results of a study of present and future traffic requirements, present and proposed bridge facilities and the relation thereof to traffic requirements, and the necessity, desirability and feasibility of the use of a barrier at any of the proposed sites as a highway crossing for both present and future needs.

The special investigation and study made by the Bureau of Sanitary Engineering of the State Department of Public Health, presented in Appendix E, has included detailed field surveys of sources and character of pollution, effect of present pollution on quality of water and an analysis of the effect of present and future estimated pollution on the quality and redeemability of water in a lake created by a barrier, together with a consideration of treatment and disposal works necessary to take care of sewage and industrial waste in order to protect the quality of the water and make it redeemable for all purposes.

The report of the State Fish and Game Commission in Appendix F presents data and statistics on the commercial fishing industry in the upper bay and river channels, information on the habits of the more important commercial fish and studies of the possible effect of a barrier upon fish life and the fishing industry.

The investigation by the United States Army Engineers of a salt water barrier has included studies of the barrier plans, with particular regard to navigation and flood control features, and studies relating to the effect of a barrier upon navigation, silt and water-borne debris, flood control and tidal action. This has involved extensive field work, with complete new hydrographic and aerial photographic surveys of Suisun and San Pablo bays, measurements of tidal currents, tidal flows, movement of both suspended and bed-load silt, installation and operation of automatic tide gages, special evaporation and meteorological measurements, detailed counts of water-borne traffic, and determination of volume, source and destination of water-borne commerce. Special studies also have been made to obtain data for estimating the amount of water required to operate a barrier, especially in connection with lockage of vessels through locks of the usual or standard type. This has involved a program of laboratory experiments with models. From these experiments, data have been obtained on the action and effect of salt water entering a barrier lake through standard locks and the amount of fresh water required to flush out the accumulations of salt water in order to prevent the lake from becoming harmfully polluted thereby. Data from these studies have been made available and used in this report.

Results of Investigation.

The results of the investigation are briefly summarized in the following portion of Chapter I. The detailed presentation and studies are contained in the following chapters and appendixes.

*Salinity Conditions.**—The waters of San Francisco Bay are a combination of the salt water of the ocean, which enters the bay through the Golden Gate, and the fresh waters of the Sacramento and San Joaquin rivers and local streams of the San Francisco Bay region, which discharge into the bay. The salinity of the water resulting from this combination is extremely variable both geographically and during different periods of the year and depends upon the amount of fresh water discharged into the bay by the streams. In general, the more saline waters are found in the lower bay nearest the ocean, the fresher waters in the upper bays and tidal estuaries and channels through which the fresh water enters the bay, while in between are found gradations of salt to fresh water.

The flow of the Sacramento and San Joaquin rivers, which discharge their waters through the network of channels in the delta, converging into a common mouth at the upper end of Suisun Bay (See Plate I), has the most profound effect on salinity of the water in Suisun and San Pablo bays and the delta channels. These two great river systems carry the run-off from 32,000 [1] square miles of mountain and foothill land or 39 per cent of the entire mountain and foothill catchment area of the state. The combined discharge of these streams into the delta for the period 1871 to 1929 has ranged from about 6,000,000 acre-feet to about 80,000,000 acre-feet, with an average of about 31,000,000 acre-feet per season. Eighty per cent or more of the total flow in any season is usually discharged during the six months of January to June, inclusive. The period of the remaining six months is usually one of low stream flow, with the minimum rate of flow during the season usually occurring in midsummer.

The channels of the Sacramento-San Joaquin Delta form a part of the tidal basin of San Francisco Bay. The regimen of these channels is affected by tidal action, the extent and magnitude of which is dependent at any particular time upon the amount of stream flow

* The detailed records and studies of salinity conditions are presented in Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

[1] Does not include Kings River.

discharging through the channels into the bay. During summer periods of low stream flow the effect of tidal action in these channels is a maximum and is characterized by the rise and fall and flood and ebb of the channel waters. As stream flow increases with the winter season and floods occur, these tidal effects are diminished and often eliminated from all or a large portion of the delta channels; and during extreme floods the effect of tidal action is diminished over a large portion of the upper bay.

The pulsating action of the ocean tides, which accompanies the tidal flow into and out of the tidal basin of San Francisco Bay, exerts a positive force, tending to push upstream the more saline waters from the lower bay and mix them with the fresher waters of the upper bay, with a resulting upstream advance of salinity. Opposed to this action, stream flow resists this upstream advance of salinity and tends to push the fresher waters downstream. The relative magnitude of the opposing forces exerted by tidal action and stream flow controls the advance and retreat of salinity in the upper portions of the tidal basin through which the streams discharge. The force exerted by tidal action toward advancing salinity upstream is measured by the total amount of tidal flow into and out of the basin. Since the amount of tidal flow passing any section in a basin decreases the farther the section lies upstream and the smaller the tidal volume becomes in the basin above the section, the force exerted by tidal action in advancing salinity decreases progressively for farther upstream sections.

The salinity at any point in the tidal basin is constantly changing with the rise and fall of the tide. Wide variations occur during a tidal cycle, amounting to as much as 200 per cent above and 80 per cent below a mean value for the tidal cycle. The maximum salinity during a tidal cycle occurs at the time of slack water following high high tide and the minimum at the time of slack water following low low tide. The salinity at any time during a tidal cycle is directly related to the height of the tide above lower low water, increasing in direct proportion to the height of the tide above its lower low stage.

Salinity increases only slightly with depth. The maximum variation of mean salinity during a tidal cycle from surface to bottom for water with an average salinity about half that of ocean water was found to be 0.3 per cent increase per foot of depth. The amount of increase is gradually less as the water becomes either more fresh or more salty.

There is little lateral variation in the salinity of water as found in the channels of the delta. The waters in an entire channel section are quite uniform in saline content at any particular time, except for a tendency toward some increase in salinity at greater depths. There is no evidence of high concentrations of salt water creeping along either the bottom or sides of any channel.

The salinity conditions in the upper bay and delta regions during any season are characterized by marked cyclic variations which result directly from the variations in stream flow entering the basin. As the stream flow gradually decreases with the approach of summer, the salinity gradually advances upstream until the maximum extent of advance and degree of salinity at any point is reached in late summer, some time after the minimum stream flow for the season occurs. The salinity starts to retreat as soon as the stream flow has increased sufficiently above its minimum summer flow and continues as the stream flow gradually increases with the coming of winter until it reaches a point of maximum retreat at the time of maximum flood flows during the winter season.

The invasion of saline water from the lower bay into the upper bay as far as the lower end of the delta is a natural phenomenon which has occurred each year at least as far back as historical records reveal. Under conditions of natural stream flow before upstream irrigation and storage developments occurred, the extent of saline invasion and the degree of salinity reached in the lower delta and upper Suisun Bay usually was smaller than during the last ten to fifteen years. However, the evidence of all information available, including the records of barge travel of the California-Hawaiian Sugar Company back to 1908, the testimony of the early inhabitants of the upper Suisun Bay and lower delta section and other historical information, miscellaneous records of salinity observations made prior to 1920, and the analyses of the present investigation of estimated salinity for conditions of natural stream flow, all point to the conclusion that saline water from the bay has advanced as far upstream as the vicinity of Collinsville and Antioch causing a noticeable degree of salinity of ten parts or more of chlorine per 100,000 parts of water at some time every year during the period of low stream flow.

The extent of saline invasion and the degree of salinity reached at any point vary widely from year to year as a direct result of the wide variations in the total amount and distribution of seasonal stream flow entering the delta and upper bay. The extent of advance and retreat of salinity are related approximately to the total seasonal stream flow into the delta, the records indicating that the drier the season and the smaller the total amount of stream flow entering the delta, the greater will be the advance and the smaller the retreat of salinity. The advance of salinity is related more closely to the total amount of summer stream flow into the delta. Records show that the smaller the total amount of stream flow into the delta during the summer period of June 15 to September 1, the farther upstream will be the advance of salinity and the greater will be the degree of salinity reached at any point in the upper bay and delta channels.

The actual occurrence of advance or retreat of salinity at any point or channel section in the upper bay or delta regions is dependent upon the rate of stream flow passing the section and the degree of salinity present in the water at the particular point at any time. For any particular degree of salinity at any particular point or channel section there is a rate of stream flow which will equalize the action of the tides and prevent the advance of salinity. If the rate of flow at any time is less than that required to prevent the advance of the particular degree of salinity, the salinity will tend to advance to points farther upstream and to increase to greater degrees at the particular point or channel section. If, on the other hand, the rate of flow is greater than that preventing advance, the salinity will tend to retreat to points downstream and to decrease to smaller degrees at the particular point or channel section. At any particular section, the rate of stream flow required to prevent the advance of salinity increases as the degree of salinity at the particular point or channel section decreases. For any particular degree of salinity the rate of flow required to prevent the advance of salinity becomes smaller the farther upstream the point or channel section.

During certain years since 1917, the invasion of saline water into the channels of the upper bay and delta has occurred in greater degree and extent than ever before as far as known. The extent of invasion was particularly notable in 1920, 1924 and 1926, and resulted for the most part from subnormal precipitation and stream flow in the seasons immediately preceding the summer of these years, augmented to some extent by increased upstream diversions. At the time of maximum invasion of salinity during the 1924 season, the water in the channels of about one-half of the delta had a salinity of 100 parts or more of chlorine per 100,000 parts of water or a greater salinity than has been assumed generally to be the limit of suitability for irrigation of most crops. In 1920 and 1926, about one-fifth of the delta was similarly affected. The invasions of salinity into the delta that have occurred up to 1930 have had no apparent adverse effect on the quality of land in the delta. It is possible that the invasion, especially in 1924, resulted in some decrease in crop yields on account of the necessity of discontinuing irrigation, but no definite information is available as to any losses in crops or yields. However, a longer period and greater extent of saline invasion than has occurred up to 1930 might result in loss of crops and damage to lands. The menace of saline invasion into the delta has tended to lower the market value of the delta lands. The greater degree and period of saline invasion during recent years has also substantially reduced the amount of fresh-water supplies which the industries, especially in the Antioch-Pittsburg area, could obtain from the lower river and upper Suisun Bay channels. The limitation in this source of supply for these industries has made it necessary for them to seek other sources for their fresh-water needs, entailing additional capital expenditures and more expensive supplies than those obtained in the lower river and upper bay channels.

The prevention of the invasion of salinity into the upper bay and delta channels, in order to insure a dependable source of fresh-water supply from the Sacramento and San Joaquin Rivers for the delta and for the use of industries, municipalities and agricultural lands in the upper bay region may be accomplished by either of two methods: namely, by means of a physical barrier at some feasible point below the confluence of the Sacramento and San Joaquin rivers, supplemented by release of necessary water supplies from mountain storage reservoirs; or, without the use of a physical barrier, by means of release of fresh-water supplies from mountain storage reservoirs sufficient in amount to supplement the stream flow available, thus preventing the invasion of saline water into the delta. The comparative merits and costs of the two alternate methods of controlling salinity and of alternate plans of development, with and without a barrier, to serve the needs of the delta and upper bay region are an essential part of the economic studies presented in this report.

Location and Cost of Barrier.—For the purposes of this economic study, three typical sites have been considered representative of an upper, intermediate and lower location. These comprise the Chipps Island, Dillon Point and Point San Pablo sites, respectively, as shown on

Plate I. The capital and annual costs for a barrier at each of these sites are estimated as follows:

Cost of Salt Water Barrier

	Capital cost	Annual cost
Chipps Island Site	$40,000,000	$3,300,000
Dillon Point Site	50,000,000	3,900,000
Point San Pablo Site	75,000,000	5,600,000

These estimates are based upon the provision of the usual or standard type of navigation locks, the operation of which would allow salt water to enter and pollute a barrier lake. If a barrier were constructed, the locks should be designed to prevent such pollution. Salt-clearing locks could be provided at estimated additional capital and annual costs as follows:

Additional Cost of Salt-Clearing Locks

	Capital cost	Annual cost
Chipps Island Site	$3,500,000	$300,000
Dillon Point Site	4,000,000	360,000
Point San Pablo Site	7,000,000	660,000

Effect of a Barrier on Regimen of Bay and Rivers.—The studies of the present investigation on the effect of a barrier on the regimen of the bay and rivers, including floods, movement of silt and water-borne debris and tidal action, have been made by the United States Army Engineers. The final results of their field investigations and office studies are not as yet available for presentation in this report. Preliminary considerations indicate that flood gates could be provided in a barrier which would have sufficient capacity to pass the largest floods without appreciably raising the flood plane levels in the lower river channels of the delta above those which may be expected to occur without a barrier. The flood gates provided in the plans upon which the cost estimates are based are deemed to be sufficient for this purpose.

Preliminary studies submitted by the United States Army Engineers indicate that a barrier at Point San Pablo site would so greatly reduce the tidal flow through the Golden Gate into and out of San Francisco Bay that it would seriously affect the maintenance of the navigation channels across the bar outside the Golden Gate. This barrier would also have some detrimental effect on the maintenance of channels in San Francisco Bay below Point San Pablo site. A barrier located at either Dillon Point site or Chipps Island site would have a much smaller effect upon the tidal flow into and out of San Francisco Bay, and would probably not materially increase the problems and difficulties of navigation channel maintenance on the Golden Gate bar. However, it appears probable that a barrier at either of these two latter sites would have a detrimental effect on the channels in San Pablo and Suisun bays below either site, and increase the cost of channel maintenance. The elimination of tidal action would have some adverse effect upon navigation channels in San Pablo and Suisun bays and the Sacramento and San Joaquin rivers above a barrier, especially with the lower site, but the effect probably would not be serious.

Industrial Development.—The present industrial development in the upper San Francisco Bay region from Antioch to Richmond is an important part of the industrial structure of the San Francisco Bay territory and California. In 1929, the capital investment was about $115,000,000, the annual pay roll about $27,000,000 and the gross annual value of products about $300,000,000. In the Suisun Bay area above Dillon Point, in 1929, the capital investment was about $43,000,000, annual pay roll about $13,000,000 and the gross annual value of products about $112,000,000. The region is an attractive one for industries, as evidenced by the rate of growth during the five years preceding 1929 when the value of products increased at a rate about one-third greater than the average for California and about five times as great as the average for the United States as a whole.

All factors are favorable for industrial development with the one exception of fresh-water supplies. At present, industrial fresh-water supplies are obtained partly from private wells, partly from public water supply systems and partly from the bay and river. In 1929, the amount of fresh water used for boiler and process purposes totaled about sixteen million gallons a day for the industries in the entire area and about thirteen million gallons a day for those above Dillon Point. The average cost of water per thousand gallons was about twelve cents for the entire area and about seven cents for the industries above Dillon Point. The supplies furnished by public water supply systems are relatively expensive, and the cheaper supplies obtained by private wells and diversions from the bay and river are limited and not dependable. Additional dependable fresh-water supplies are required both for the immediate needs and for future growth of industries, and a smaller cost than the present would be desirable

A much larger quantity of water is used by the industries for cooling and condensing purposes, amounting in 1929 to about 65 million gallons per day in the entire area and 38 million gallons per day above Dillon Point. Most of the supply for this purpose is obtained from the river and bay at an average cost of about 2.1 cents per thousand gallons. The use of salt or brackish water is satisfactory for cooling and condensing purposes, and hence saline invasion does not limit the use of water from bay and river for this purpose.

Industrial Water Front Structures.—The industrial water front structures in the upper bay region have been seriously affected during the past ten to fifteen years or more by an infestation of marine borers, chiefly the teredo, which attack and destroy timber piles in saline water. For the existing structures, the bulk of the damage has already occurred and capital investments have already been made for replacement by more resistant types of piling. However, a change to fresh-water conditions above a barrier probably would effect savings in annual cost of piling in place and in capital expenditures for new piling. Untreated timber piles could be used for future structures and for replacement of piling in existing timber pile structures instead of the more expensive treated timber piles now generally required and used. If the piling in present timber pile structures were replaced by untreated timber piling, it is estimated that the present annual cost would be reduced by $247,000, $96,000 and $14,000 for the structures above the Point San Pablo, Dillon Point and Chipps Island sites, respectively. These indicated savings might be increased to double these amounts at some future time, possibly in 25 years.

Fishing Industry.—The studies made by the Fish and Game Commission indicate that the construction and operation of a barrier might prove to be a serious detriment to the fishing industry. The major varieties of commercial fish, including salmon, striped bass and shad, are migratory in their habits and it is apparent that a barrier would offer an obstruction to their free migration into and out of the bay and rivers. Fishways could, of course, be provided in a barrier structure for the passage of fish, but there is considerable uncertainty as to their effectiveness, especially for striped bass and shad. Moreover, a barrier might eliminate the shallow brackish water areas which are now present in the upper bays and which are necessary as a source of food supply for the young fish fry, which gradually float downstream after the spawning season, and also for the adult striped bass and shad.

Navigation.—Navigation operations in the Upper San Francisco Bay region would be considerably affected by the construction of a barrier. Vessels would have to pass through locks, resulting in some delays. Based upon studies made by United States Army Engineers, the water-borne traffic past the three typical barrier sites at present (1929) and that predicted for a future time about 25 years hence are shown in the following tabulation:

Present and Predicted Future Water-borne Traffic Past Barrier Sites

	Average number of vessels per day	
Barrier site	*Present (1929)*	*Estimated for 25 years hence*
Chipps Island	61	97
Dillon Point	67	112
Point San Pablo	148	255

It is estimated by the United States Army Engineers that the increased cost to navigation interests due to the delays occasioned by passage of vessels through the locks would amount to $4.50 per vessel lockage for present traffic and $7.50 per vessel lockage for future traffic.

Maintenance of navigation channels above and below a barrier would be increased in cost, especially for a barrier at Point San Pablo, which would affect the maintenance of the channels across the Golden Gate bar. As against these detriments, it is believed that navigation operations above a barrier would be improved and assisted by the removal of tidal currents and fluctuations which under natural conditions result in some difficulties and delays to navigation operations. Some advantage would accrue also if a higher constant water level and greater average depth of navigation were maintained above a barrier. Moreover, a barrier lake would provide a fresh water anchorage for vessels which might be an advantage to navigation interests for the removal of marine growths from the bottoms of vessels.

Municipal Development.—Along the shores of upper San Francisco Bay are numerous urban and suburban districts, more or less intimately related to the industrial and agricultural activities of the region. Most of the larger cities have experienced a substantial growth during the last three decades, chiefly as a reflection of growth of industry. Water supplies for these cities and towns are obtained locally from wells and streams. Antioch obtains its supply from the San Joaquin River near its mouth. A public utility serving several cities and towns in Contra Costa County obtains a considerable portion of its supply from the lower river channel about two miles west of Pittsburg. In the entire area from Antioch to the northerly limits of Richmond on both sides of the bay, 4.6 million gallons per day were used for municipal and domestic purposes in 1929, with an average cost to the public water supply systems of 34 cents per thousand gallons and with a somewhat higher water rate to the consumer.

The present available supplies would appear to be sufficient for present requirements but the additional supply that is capable of economic development is limited and it will be necessary to import supplies from some suitable outside source to take care of the ultimate requirements which may be expected.

Sewage and Industrial Waste.—A large amount of sewage and industrial waste is now discharged into the upper bay channels and Sacramento and San Joaquin rivers. The surveys and studies of present pollution in the channels of the Sacramento and San Joaquin rivers and the delta from Sacramento and Stockton to the lower end of the delta show that, from an organic and bacterial standpoint, the waters in the lower channels of the delta are satisfactory and redeemable for all purposes under present conditions of pollution and would be satisfactory and redeemable for a long time in the future. Under present conditions of pollution in the upper bay channels, tidal action assists in the removal of sewage and industrial waste with little, if any, nuisance resulting therefrom. This method of disposal under conditions similar to the present, would be satisfactory probably for an indefinite period in the future.

If a barrier were constructed, the beneficial action of the tides in removing the sewage and industrial waste discharged along the shores of the bay would be eliminated. The studies indicate that if sewage and industrial waste, in the increasing amounts to be expected with the future growth of industries and urban districts along the shores of the bay, were discharged into a barrier lake, it would pollute the water of the lake so as to make it unfit and unredeemable for domestic and industrial process uses during a portion of the year. Disposal and treatment works involving substantial expenditures would be required to prevent such pollution.

Sacramento-San Joaquin Delta.—The Sacramento-San Joaquin Delta has a gross area of nearly a half million acres of some of the richest agricultural land in the state, of which about 350,000 acres are now under cultivation. All lands in the delta feasible of reclamation have been reclaimed at large expense with levees and interior drainage ditches and pumping plants. The lands in the delta are composed of peat and sediment soils and for the most part lie at an elevation below mean sea level. The market value of the lands in the delta is estimated at $85,000,000, with an estimated assessed valuation of $45,000,000. The value of crops in 1929 is estimated to have been $30,000,000.

The network of channels which separate the lands of the delta into islands and through which the Sacramento and San Joaquin rivers discharge into Suisun Bay is not only the source of water supply for the irrigation of crops in the delta, but also provides efficient and economical water transportation for the products of the soil and materials, equipment and supplies. The consumptive use of water for irrigation of crops in the delta and for transpiration from natural vegetation and for evaporation from open water is estimated to vary from a minimum of 400 second-feet (in mid-winter) to a maximum of 3700 second-feet (in mid-August) with an average consumption during July and August of 3500 second-feet. The total annual consumption is about 1,250,000 acre-feet or over 2.5 acre-feet per acre on the gross area.

The stream flow into the delta during the ten-year period, 1920 to 1929, has been insufficient during the summer months of certain of these years to supply the consumptive demands in the delta. Moreover, the invasion of saline water from the bay into the delta channels during recent years, especially in 1920, 1924 and 1926, has made the water in a portion of the channels unfit for irrigation so that diversions could not be made for crops over considerable areas of the delta in the latter part of the irrigation season. The irrigation supply in the delta is, therefore, not dependable under present conditions. The menace of saline invasion has tended also to depreciate land values in the delta.

Marshlands and Uplands Adjacent to Suisun and San Pablo Bays—Adjacent to Suisun and San Pablo bays, there is a gross area of about 130,000 acres of marshlands about equally divided between the two bays. In the Suisun Bay area, about 46,000 acres are leveed, of which only 5000 acres are farmed. In San Pablo Bay area, there are also about 46,000 acres leveed of which 24,000 acres are farmed. Farming operations have not been very successful on account of the saline conditions. Most of the marshlands are heavily impregnated with salt, which is estimated to average 2 per cent of the dry weight of the soil. This would have to be removed before most crops could be grown successfully. At present, much of the marshland, especially in the Suisun area, is devoted to duck preserves and apparently is more valuable for this purpose than any other. These lands if furnished with a fresh water supply might be completely reclaimed and brought into agricultural production. This would involve the building of levees and drainage works and removal of salt from the soil, all of which would be difficult and expensive. The cost of completely reclaiming these lands is estimated to be considerable greater than the average market value of fully developed and producing lands in the delta and of large areas in the San Joaquin and Sacramento valleys served with a water supply and ready to be farmed. Under present conditions, large expenditures for development of these marshlands to agriculture would not be economically justified.

Adjacent to upper San Francisco Bay, there are upland areas below the assumed limit of present economic pumping lift of 150 feet, totaling 246,000 acres, about 118,000 acres bordering on Suisun Bay and about 128,000 acres on San Pablo Bay. About 190,000 acres are suitable for irrigation development and some 12,000 acres may be classified as urban and industrial areas. About half the area is now under cultivation, of which about 40 per cent is devoted to a valuable development of orchards and vineyards, about the same amount to grain and hay and the balance in miscellaneous field and truck crops. Only a small area is now irrigated. Some of the areas, now under irrigation, are deficient in water supply. Others, such as Napa Valley, appear to have sufficient local water, if properly conserved and applied, to meet their ultimate irrigation requirements. Some of these areas, particularly the Ygnacio and Clayton valleys and the area between Antioch and Knightsen lying south of the San Joaquin River, are in immediate need of a supplemental supply.

Salinity Control and Water Supply and Service for the Upper Bay and Delta Region.—A study of the ultimate water requirements and sources of supply for the San Francisco Bay Basin indicates that, in addition to the water supply obtainable from a complete feasible development of all local water resources and the imported supplies from the Tuolumne and Mokelumne rivers, there would be required about 600,000 acre-feet of water annually, principally for the upper bay region. Additional supplies will also be required for both present and ultimate water requirements of the delta. The stream flow into the delta during the summer months has been insufficient in five years of the period 1920 to 1929 to meet the consumptive demands of the delta. The shortage in supply reached a maximum of 277,000 acre-feet in 1924, and amounted to 225,000 and 140,000 acre-feet in 1920 and 1926, respectively. There were also small shortages in 1928 and 1929.

The water requirements of the delta and all, or the greater portion, of the additional water supply required to be imported into the upper San Francisco Bay region could be furnished under the operation of the proposed mountain storage reservoirs of the State Water Plan. The water supply for the upper bay region could be made available in the lower channels of the Sacramento and San Joaquin rivers, thus providing a nearby source of supply for the area to be served. In order to make this source of supply dependable at all times, provision must be made to control the invasion of saline water into the delta. This objective could be attained either by a salt water barrier or by means of stream flow without a barrier. In both methods of salinity control, supplemental water supplies would have to be furnished from mountain storage reservoirs.

There has been a somewhat prevalent idea that a physical barrier below the confluence of the Sacramento and San Joaquin rivers would, in itself, positively prevent invasion of saline water above the structure. This would be true if a barrier could be built and operated as a continuous tight dam. However, a barrier must be provided with navigation locks for the passage of vessels and a large number of flood gates to pass the floods discharged by the Sacramento and San Joaquin rivers. This would permit the entrance of salt water into a barrier lake by leakage around the flood and lock gates and by the operation of the usual or standard type of navigation locks. Substantial quantities of fresh water would be required to flush out this salt water and in addition take care of the direct losses of water during lockage and by leakage around the flood gates and lock gates and for operation of fish ladders. Moreover, a barrier lake with a large area of water surface and extensive marginal vegetation would result in large evaporation and transpiration losses which could not be prevented and which would have to be supplied as part of the water requirements for salinity control with a barrier.

Contrary to what has been popularly supposed, a barrier would not create a storage reservoir in which large amounts of water could be impounded for utilization as necessity demanded. The level at which water could be held in a barrier lake would be limited both as to its maximum and minimum elevation. On account of several limiting factors, the range of fluctuation of water level in a barrier lake and the usable storage capacity therein would be limited to about one foot below a maximum elevation of three feet above mean sea level. The usable storage capacities above each barrier site are shown in the following tabulation:

Usable Storage Capacity in Barrier Lake

Barrier site	*Usable capacity in acre-feet*
Chipps Island	45,000
Dillon Point	75,000
Point San Pablo	155,000

The quantity of water which would be made available by the utilization of this limited amount of storage would be so small as to be of relatively small importance. The usable storage would be far from sufficient to take care of the water demands for salinity control with a barrier. Even if a greater range of fluctuation were allowable, the storage would conserve only a small per cent of the tributary run-off.

The rate of flow required for controlling salinity with a barrier under both present and future conditions, with the utilization of navigation locks of the usual or standard type, is shown for each typical barrier site in the following tabulation. The basis of these estimates is presented in Chapter IV.

Rate of Flow During Summer Months for Control of Salinity With a Barrier With Standard Locks

Barrier site	*Rate of flow in second-feet*	
	Present conditions	*Future conditions*
Chipps Island	1300	2800
Dillon Point	2300	2650
Point San Pablo	5550	7500

Inasmuch as a salt water barrier properly should be considered in the light of future development and requirements of the upper bay and delta region and of the State Water Plan, the water requirements for salinity control under future conditions are of especial importance and significance.

If a barrier, entailing a large expenditure, were constructed for the primary purpose of preventing the invasion of salt water, it is obvious that the structure, especially the locks, should be so designed as to prevent, if possible, the entrance of salt water into a barrier lake. Studies indicate that salt-clearing locks could be provided which would be practical in operation, feasible in cost of construction and effective in preventing entrance of salt water into a barrier lake and substantially reducing water requirements for lockage operations. The estimated water requirements for control of salinity with a barrier with salt-clearing locks are shown in the following tabulation:

Rate of Flow during Summer Months for Control of Salinity With a Barrier With Salt-Clearing Locks

	Rate of flow in second-feet	
Barrier site	*Present conditions*	*Future conditions*
Chipps Island	900	1200
Dillon Point	1900	1500
Point San Pablo	3600	3300

The portion of the water requirements for gate leakage and fish ladders and evaporation and transpiration are identical with the previous tabulation, the only change being in the requirements for lockage operations.

The more significant and important figures are those for future conditions and it may be assumed that the estimates of water required with salt-clearing locks represent the minimum amounts which would be required for control of salinity with a barrier under future conditions with any design of locks practical in operation and feasible in cost of construction. These required rates of flow based upon the use of salt-clearing locks have been adopted as the basis for the estimates of supplemental water supply required for control of salinity with a barrier.

The alternate method for control of saline invasion by means of stream flow without a barrier is based upon an intensive study of the variation and control of salinity in the upper bay and delta. It is concluded from this study that the invasion of saline water into the delta can be positively prevented and salinity controlled by provision of a fresh-water supply sufficient to maintain a flow in the two rivers of not less than 3300 second-feet past Antioch into Suisun Bay. With such a control at the mouth of the rivers, a source of diversion of a fresh-water supply of equal dependability and quality to that provided in a barrier lake would be available in the channels of the delta and not far distant from the upper bay area.

The flow of the Sacramento and San Joaquin rivers into Suisun Bay during most of the last ten years has been insufficient during the months of low stream flow to supply the water required for salinity control either with or without a barrier. Therefore, in order to provide for salinity control with either alternate plan, supplemental supplies would have to be furnished from mountain storage reservoirs. For future conditions, a larger amount of supplemental supply would be required for salinity control without a barrier than with a barrier with salt-clearing locks. With stream flow as it occurred during the period 1920–1929, the average, maximum, and minimum annual savings in supplemental water supply which the estimates indicate would be obtained by controlling salinity with a barrier, are shown in the following tabulation. In making these estimates, the water required under future conditions for control with a barrier with salt-clearing locks has been used and the usable storage capacity in a barrier lake at each barrier site has been credited as an additional water supply deducted from the supplemental supply required for control with a barrier.

Amount of Supplemental Water Supply Saved by Controlling Salinity with a Barrier with Salt-clearing Locks Under Future Conditions

	Annual supplemental water supply saved in acre-feet		
Barrier Site	*Minimum 1920 to 1929*	*Average 1920 to 1929*	*Maximum 1920 to 1929*
Chipps Island	112,000	279,200	561,000
Dillon Point	112,000	274,400	523,000
Point San Pablo	112,000	148,400	160,000

If the usual or standard type of locks were used in a barrier structure, the indicated maximum saving in supplemental water supply with a barrier would be reduced under future conditions to annual amounts of 172,000 acre-feet and 240,000 acre-feet for the Chipps Island and Dillon Point sites, respectively, while, for the Point San Pablo site, a much greater supplemental supply than that required without a barrier, amounting to 1,262,000 acre-feet a year, would be required.

Under both the initial and ultimate developments of the State Water Plan,* the studies of water supply, yield and demand show that, in addition to supplying the full water requirements for either the initial or ultimate development of the Sacramento and San Joaquin valleys, the Sacramento-San Joaquin Delta and the upper bay region, ample water supplies would be available for providing positive control of salinity at the lower end of the delta without a barrier. If supplies were needed in addition to those provided under the ultimate State Water Plan, additional reservoir capacity is available on tributaries of the Sacramento River for development of substantial increases in supply and additional supplies could be economically developed and brought in from the Eel River. Therefore, the amount of supplemental water supply which the estimates indicate might be saved with a barrier would not be needed to furnish the full initial and ultimate requirements of the Great Central Valley and the upper bay region. From the standpoint alone of supplemental water supplies saved by a barrier, the cost of the maximum indicated amounts of water saved would be about three times as much for the Chipps Island site, four times as much for the Dillon Point site and twenty times as much for the Point San Pablo site, as the cost of developing equal amounts in mountain storage reservoirs.

As a means of providing a fresh-water supply from the lower Sacramento and San Joaquin Rivers for the present and ultimate needs of the upper bay and delta region, the two alternate methods of salinity control are fundamentally equivalent. Water supplies now or hereafter made available in the delta channels would be protected from saline invasion by either method of control and would be suitable in quality for all uses both in the delta and in the upper bay region. With either method, conduits would be required to transport water to the areas to be served in the upper bay region. The only salient difference between the physical features of the plans for water service

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

under the two methods of salinity control would be in the length and size of conduits. Either plan would render equally favorable service. The determination of the better plan must, therefore, rest upon the question of cost. Preliminary plans and cost estimates on a strictly comparable basis have been made of the major conduit units for water service and other required works, for alternate plans of development providing equivalent service and accomplishments with and without a barrier. The alternate plans provide for main canals only, extending from the source of supply whether from the delta or a barrier lake, both north and south of the bay, and designed to economically serve the areas. In the alternate plan with a barrier, sewage and industrial waste disposal works to prevent a harmful pollution of a barrier lake are included. In the alternate plan without a barrier, the physical works include additional levees and facilities assumed as required for reclaiming the marshlands of Suisun and San Pablo bays, and also a connecting channel between Sacramento River and San Joaquin River Delta to provide for transfer of surplus Sacramento River water across the delta for exportation to the San Joaquin Valley.

Based upon these studies of alternate plans, it is estimated that a plan of ultimate development with conduits extending from controlled fresh-water channels of the lower delta, together with additional works for the reclamation of the marshlands of Suisun and San Pablo bays and channel enlargements in the delta, could be consummated for a capital expenditure of about $18,000,000, as compared to costs ranging between about $52,000,000 and $86,000,000 for an equivalent development with a barrier. The estimated annual cost (including interest, amortization, operation, maintenance and depreciation) of the required physical works alone would be about $2,100,000 for the plan without a barrier, as compared to annual costs ranging from about $4,800,000 to $7,100,000 for the alternate plan with a barrier. These costs do not include the additional cost of salt-clearing locks.

It is unquestionable that there would be substantial benefits accruing to many interests by the consummation of either plan of development, with or without a barrier. These would include reduced costs of water supplies for industries, municipalities and agricultural lands in the upper bay region, increased values of industrial, urban and agricultural lands in the upper bay and delta, and elimination of costs of litigation between the lower and upper river interests. In addition there would be many more or less intangible benefits, emanating from the stimulation of growth and the greater prosperity of industrial, agricultural and municipal developments in the upper bay and delta region, which would be enjoyed by the northern bay and delta counties, the metropolitan areas of the East Bay and San Francisco and the state and nation. Estimates might be made of the value of these various benefits but all would be common to both of the alternate plans of development with or without a barrier, and hence it is entirely unnecessary in the present investigation of the economic aspects of a barrier to evaluate these common benefits.

There are, however, certain tangible benefits and detriments directly attached to a barrier which have been estimated and included in final comparisons of annual cost of the alternate plans. The direct tangible benefits of a barrier include reduced annual costs on timber piling of industrial water front structures and savings in supplemental water supply required for control of salinity. The tangible detriments chargeable directly to a barrier include delays to navigation and increased drainage and levee maintenance costs in the delta and bay marshlands. An evaluation has been made of these direct tangible benefits and detriments in the final economic considerations of comparative annual cost of the alternate plans of development. Other detriments which might accrue from a barrier include possible losses to the fishing industry and the possible increase in cost of maintenance of navigation channels, but these have been considered too uncertain to include in the estimates. Taking into account these benefits and detriments directly attached to the alternate plan of development with a barrier, the estimated net total annual cost with a barrier would range from $4,500,000 to $8,000,000, as compared to $2,100,000 without a barrier.

Based upon this study of the comparative merits and costs of alternate plans of development, with and without a barrier, it is evident that the plan without a barrier would fully satisfy the basic needs of the upper bay and delta region at a cost of less than one-half of that for a plan with a barrier. Therefore, the salt water barrier has not been included as a unit in the State Water Plan, but provision is made in the plans for controlling salinity at the lower end of the delta by stream flow with necessary supplies furnished from mountain storage reservoirs to supplement the stream flow available for this purpose. The proposed plans for the initial development of the State Water Plan provide for an initial conduit unit to serve the immediate pressing needs of the present developed industries and agricultural lands in upper Contra Costa County. The estimated capital cost is $2,500,000 with an estimated annual cost of $300,000, or $6.90 per acre-foot (2.1 cents per 1000 gallons) for water delivered at points along the conduit.

Conclusions.

1. It would be physically feasible to construct a salt water barrier at sites in Carquinez Strait and at Point San Pablo. Foundation conditions at the Chipps Island site are not as favorable for constructing a barrier at this location. The capital cost of a barrier would vary with the location and type of structure from $40,000,000 to $75,000,000 and annual cost corresponding to the same would vary from $3,300,000 to $5,600,000.
2. The amount which might be contributed from highway funds towards the building of a barrier, by reason of present facilities and savings effected, is small in comparison with the total cost of a barrier and can not be considered a controlling factor in selecting the site, methods of financing or time of construction; and the combination of a highway crossing with a salt water barrier is not economically warranted.
3. The furnishing of an adequate and dependable cheap fresh-water supply for industries, municipalities and agricultural lands in the upper San Francisco Bay region would benefit these developments and stimulate their growth. It would no doubt prove an especial attraction to industries requiring large amounts of fresh water. If this were accomplished by the assistance of a barrier with a fresh-water lake maintained by

adequate water supplies furnished from mountain storage reservoirs, the benefits to all these interests and the attraction to industries might be still further enhanced. However, other competing industrial areas naturally would offer counter attractions, such as comparable water rates, and hence it can not be expected that there would be any rapid influx of industries to locate on a barrier lake. Moreover, the large expenditure required for a barrier might result in these benefits being entirely offset by the burden of additional taxes which the local industrial, municipal and agricultural interests might have to assume as their share of a barrier cost. Therefore, in so far as fresh-water demands of the upper bay region are concerned, the essential requirement would be the furnishing of adequate fresh-water supplies by the consummation of the most practicable and economical plan which can be devised.

4. A salt water barrier could be operated to prevent saline invasion into the upper bay and delta channels and maintain a fresh-water lake from which water supplies now or hereafter made available from the Sacramento and San Joaquin rivers could be utilized for industrial, domestic and agricultural purposes in the upper bay and delta region. Its function as regards water supply and service would be primarily that of a diversion structure. In order to control salinity with a barrier, substantial quantities of fresh water would have to be furnished from upstream storage developments, to provide for barrier operation (lockage, flushing and leakage losses) and unavoidable losses (evaporation and transpiration) from a barrier lake. A barrier in itself would not create the water supplies required either for present or future needs of the area. The usable storage capacity would be insufficient to supply even the water required for barrier operation and unavoidable losses from a barrier lake. Only a small percentage of the tributary run-off could be conserved in a barrier lake. Therefore, the necessity and desirability of a barrier as a means of controlling salinity and serving the fresh-water demands of the upper bay and delta region must be determined on the basis of the comparative cost of a plan of salinity control and water service with a barrier and an alternate plan without a barrier providing equivalent service and accomplishments.

5. The control of saline invasion, so that water supplies now or hereafter made available in the delta from the Sacramento and San Joaquin rivers could be maintained fresh and utilized for all purposes in the upper bay and delta region, could be provided with equal certainty without a barrier by means of fresh water released from mountain storage reservoirs to supplement the available stream flow. With salinity controlled by this means at the lower end of the delta, not only would the delta be fully protected and its water requirements satisfied, but also a fresh-water supply equivalent in dependability and quality to that in a barrier lake could be made available in the delta channels for use in the upper bay area and not far distant therefrom.

6. A barrier is not necessary for the exportation of water from the Sacramento River to the San Joaquin Valley above the delta. With salinity controlled at the lower end of the delta by stream flow and with additional channel capacity connecting the Sacramento River to the San Joaquin River delta, there would be no physical impediment to the transfer and diversion of water up the San Joaquin River.
7. A barrier would not be essential to the feasibility of reclaiming the marshlands adjacent to Suisun and San Pablo bays.
8. A barrier would probably effect substantial savings in the capital and annual costs of water front structures in the barrier lake above, but such savings would be more than offset by the losses suffered in delays to navigation, additional costs of drainage and levee maintenance in the delta and bay marshlands, possible increased cost of navigation channel maintenance, and possible damage to the fishing industry. Moreover, construction of a barrier would precipitate a sewage and industrial waste disposal problem which would require substantial expenditures for construction of disposal and treatment works for its solution.
9. The proposed alternate plan, with salinity controlled by means of stream flow without a barrier, providing conduits from the delta to serve the fresh-water demands of the upper bay area, additional works of channel enlargment between the Sacramento River and San Joaquin River Delta and works for the reclamation of the upper bay marshlands, could be consummated for a capital and annual cost of less than half that required for a plan of equivalent scope and service with a barrier. It would have the additional advantage of requiring immediate expenditures of but a small fraction of the cost of a barrier for initial conduit units that would amply serve the needs of the immediate future. Moreover, it would lend itself to a program of progressive development with expenditures made only as required to keep pace with the growing demands, thus keeping both capital and annual costs to a minimum for the progressive and ultimate stages of development.
10. All present and ultimate fresh-water requirements and the complete development of the ultimate potentialities of industries, municipalities and agricultural lands in the upper San Francisco Bay region would be provided for under the proposed alternate plan of development and service, with salinity controlled to the lower end of the delta by stream flow supplemented with fresh-water releases from mountain storage. The plan would include main conduits extending westerly from the delta along the north and south sides of the bay, located and designed to serve the fresh-water demands in the upper bay area. The upper bay channels would continue to serve as outlets for sewage and industrial waste and as a source of supply for cooling and condensing water for industries, with advantages resulting for both purposes. Preliminary designs and studies of the proposed plan demonstrate its physical feasibility and economical advantage and give assurance of satisfactory service.

The proposed alternate plan would not disturb the present and future developments and operations in the upper San Francisco Bay and delta region and, to a large extent, would restore fresh-water conditions in upper San Francisco Bay equivalent to those existing under natural conditions before the expansion of irrigation and reclamation in the Great Central Valley and mountain storage developments.

11. Water in the amounts that might be saved in controlling salinity with a barrier would be available and could be furnished at considerably less cost from mountain storage reservoirs. The conservation efficiency and value of a barrier would be small in comparison with the cost.
12. The final conclusion of this investigation of a salt water barrier located at any of the three typical sites is that this structure is not necessary or economically justified as a unit of the State Water Plan.

CHAPTER II

LOCATION AND COST OF SALT WATER BARRIER

The location and cost of a salt water barrier are important basic elements of the economic study of this structure. The advantages and disadvantages which might accrue from construction and operation of a barrier and the capital and annual costs of a structure would differ considerably for different barrier sites. The value of benefits and detriments and the comparative capital and annual costs of a barrier at different locations therefore must be given consideration in order that a decision may be reached not only as to the most advantageous location, but also as to the economic justification for a barrier at any location.

In all of the studies of a salt water barrier, including the present investigation, all locations considered have been below the confluence of the Sacramento and San Joaquin rivers. This naturally follows from a consideration of the maximum benefits desired to be attained by the construction and operation of a barrier in its primary functions of preventing saline invasion and providing a means for diversion of fresh-water supplies for the upper bay area. From the standpoint of these primary functions of a barrier, it is evident that the maximum benefit to industrial, municipal and agricultural developments of the upper bay area would be obtained with a barrier located as far downstream as practicable. On the other hand, considerations of interference with navigation and other interests, and of conservation efficiency, point to a location as far upstream as practicable. Finally, consideration must be given to the physical elements controlling the choice of a site, especially the geology and the foundation material, as these elements directly affect the physical feasibility and cost of construction.

Location of Barrier.

In the investigation by the Bureau of Reclamation,* eleven suggested sites for a barrier, located at various points from the confluence of the Sacramento and San Joaquin rivers to the Golden Gate, were considered.

Upper Sites.—The upper sites comprised one at the westerly end of Sherman Island and another at Chipps Island, near the O. and A. ferry (Sacramento Northern Railroad ferry). These sites were eliminated from consideration early in the investigation because a barrier at either location would not provide the amount of storage deemed necessary and desirable in the operation of a barrier.

Intermediate Sites.—The intermediate sites are located in Carquinez Strait and comprised Army Point, Benicia, Dillon Point and Vallejo

* Bulletin No. 22, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers," Division of Water Resources, 1929.

Junction. Of these four sites in Carquinez Strait, the Army Point and Dillon Point sites appeared to be the more feasible and, hence, the more intensive studies, surveys and explorations were made at these two sites. The proposed location at Benicia was not so seriously considered because the structure, as planned, crossed an active fault line. The Vallejo Junction site was not studied in any great detail because it appeared to offer no advantages not found in the Dillon Point site. The Dillon Point site offers the narrowest location and has the greatest depth of water of any of the available sites.

Lower Sites.—The lower sites comprised Point San Pablo (Point San Pablo to Point San Pedro), Molate Point to Point San Quentin, Castro Point to California Point, Point Richmond to Bluff Point, and Golden Gate. With the exception of the site suggested at the Golden Gate, all of these sites lie in what is known as the "Narrows" of San Francisco Bay. The width of channel at all of these sites is considerably greater than at any of the intermediate sites. For example, at the Point Richmond to Bluff Point site, the channel is 3.3 miles wide. The depth of water at this site is comparatively great, especially on the west end. A barrier at the Golden Gate could not be seriously considered, because a structure at this site would obstruct the full use and development of San Francisco Bay as a harbor and naval base. While there are other important disadvantages for a barrier at this site, the one stated above is sufficient to eliminate it from consideration. The same objection holds true for a site extending from San Francisco through Alcatraz and Angel islands to the Tiburon Peninsula, which has more recently been suggested. The Point San Pablo site was selected for detailed study, exploration and design because it appeared to offer greater advantages with smaller cost than any of the other sites in the "Narrows."

Choice of Site.—The final selection of an exact location for a salt water barrier is not within the scope of the present study and report because it is not necessary to a consideration of its economic aspects. It has been deemed sufficient in the present study to consider three sites representative of an upper, intermediate and lower location. The typical sites selected (see Plate I) for the economic study are:

Upper site—Chipps Island.
Intermediate site—Dillon Point.
Lower site—Point San Pablo.

As far as physical considerations are concerned, a barrier could be constructed at any of the three typical sites, although foundation conditions at Chipps Island site are rather unfavorable. All of the sites proposed in Carquinez Strait are satisfactory from the standpoint of foundation rock. However, there are two active faults, designated the Sunol-Southampton Bay fault, which crosses the strait in the vicinity of Benicia, and the Franklin Canyon-Mare Island fault, which crosses the lower end of the strait near Selby, that must be considered in a final design and location of a barrier in Carquinez Strait. The Dillon Point site, which has been selected as typical of an intermediate location, appears especially satisfactory from the standpoint of foundations and geologic conditions. Geological studies in the vicinity of the Point

San Pablo site indicate that foundation rock conditions are less satisfactory than in Carquinez Strait, but that a barrier could be built at this site if properly designed.

The geology of the region in the vicinity of the Chipps Island site and the foundations revealed by borings made at the railroad company's ferry crossing show that the foundation conditions are relatively unfavorable for the construction of a barrier. The formation underlying and adjacent to the river channel consists of deposits of recent alluvium, with alternating beds of sand and clay. Considerable deposits of peat and muck overlie these alluvial deposits on the islands north of the channel. Underlying these more recent alluvial deposits, which are estimated to have a thickness of 100 to 150 feet, are rather incoherent, clayey, fine sandstone or clay-cemented sand and silt deposits which may be considered to be the bedrock underlying the upper end of Suisun Bay in so far as a barrier structure is concerned. The entire body of the recent alluvial material would be greatly disturbed by earthquake waves.

While there are no fault lines exposed in the vicinity of this site, the records indicate that Antioch has suffered from numerous and heavy earthquake shocks in past years, possibly due to the existence of faults hidden by the great depth of alluvial and Pleistocene deposits. There are records of earthquakes at Antioch in 1866, 1872, 1889 and in 1901, 1902 and 1903, that of 1872 apparently having been the worst experienced. It was concluded from the geological investigations that while it might be possible to design a satisfactory structure supported on piles of ample length, no final approval of the site could be made until detailed exploration borings were completed. The preliminary plans prepared for a structure at this site have, therefore, been carefully and conservatively designed in order to provide safety and stability as nearly comparable as possible with that provided by the designs for an intermediate or lower site. The preliminary plans are believed to offer a conservative basis for estimating the cost of a structure at such an upper location and to be sufficient for carrying out the economic studies.

Without making a final choice of a barrier site, the economic studies have been made to evaluate, as far as possible, the benefits and detriments which might accrue from a barrier at each typical site, as compared to the capital and annual costs thereof. Finally, the cost of a development, with a barrier at each of the sites, for serving the ultimate water demands of the upper bay area has been compared with an alternate plan of development, without a barrier, providing the equivalent in control of salinity and service of fresh-water demands.

Design Features of Barrier.

The detailed plans for a salt water barrier for the intermediate and lower sites are fully presented in Bulletin No. 22 and hence will be but briefly described herein. The two basic features of the plans for the structure include, first, navigation locks suitable in size and number to expeditiously handle the passage of vessels through the structure and, second, a series of large-capacity floodgates designed to pass the maximum estimated flood flows without appreciably raising the flood plane above a barrier. The navigation locks, and the piers and sills of the floodgates are designed of massive concrete founded on solid bedrock. The plans generally provide for the location of locks and floodgates on one side of the channel with the balance of the structure designed as a rock-fill dam made tight by filling the voids therein with mud. The floodgates provided in the plans are of massive steel construction of the "stony-roller" type, while the gates in the navigation locks are of the usual standard type of design used in modern locks. The height of a barrier is governed by the maximum level reached by the tide and the plans provide for an elevation for the top of the structure at ten to fifteen feet above mean sea-level. In one of the alternate plans prepared for the Dillon Point site, the entire structure was designed for construction in the present channel and would consist of floodgates covering the entire width of the channel, with the navigation locks located on one side and with no part of the structure built as a rock-fill section. This appeared to be the least expensive of the several alternate plans for this site. At the time the plans were prepared, it was thought possible that arrangements might be made for combining both highway and railroad crossing facilities with a barrier structure at both the Carquinez Strait and Point San Pablo sites. Accordingly, several of the alternate designs made provision for combinations with overhead bridges to accommodate highway and railroad traffic.

Plans for Chipps Island Site.—In order to carry out the economic studies for a barrier located at an upper site, it was deemed desirable to prepare preliminary designs and cost estimates for a structure located immediately below the confluence of the Sacramento and San Joaquin rivers. The site chosen, designated the Chipps Island site, is located near the present railroad ferry crossing of the Sacramento Northern Railroad (more frequently called the O. and A. Ferry). No rock foundations exist at this site. The preliminary design prepared was adapted from the plans presented in Bulletin No. 22, the superstructure and details of the locks and gates being practically identical. The preliminary plan provides for locks on one side of the channel, with the remainder of the structure consisting of a series of 45 floodgates 50 by 55 feet in size across the entire width of the present channel. The main structure is designed of massive concrete, with the gate sills and floors of the locks of heavier construction than in the structures designed for rock foundations and with the addition of a liberal provision of steel reinforcement to take care of the effect of earthquake shocks for a structure on an unstable foundation. A line of steel sheet piling extends for the entire length of the main structure under the upstream edge of the floodgate sills. Extending downstream from the gate sills, a heavy concrete apron is provided, terminating on a line of sheet piling. The entire structure is supported on timber piles 60 feet in length, extending into the heavy clay formation. The remainder of the barrier structure consists of an earth levee extending from the main structure across Chipps and Van Sickle islands to the mainland on the north and across the lowlands to higher ground on the south. While the plans prepared are preliminary and subject to considerable revision for a final design, they are nevertheless deemed sufficient as a basis for obtaining a reasonable estimate of cost for use in this study.

Modification of Designs and Plans.—As previously stated, the barrier plans presented in Bulletin No. 22 are considered adequate as a basis for estimating the cost of a barrier at the various sites considered. It is possible that a final design study of a barrier would result in some alteration in the type of structure which might be finally selected. A suggestion has been made by C. E. Grunsky for a considerably different type of structure than that proposed in Bulletin No. 22, which would be adapted to a long shallow site such as one in the "Narrows" below Point San Pablo. The suggested design would provide for a weir-type structure to be built of concrete in sections constructed on shore and floated out in the form of caissons and sunk on a prepared foundation. Provision would be made for a long floodgate section consisting of shallow gates in pairs, one of which would be designed to operate automatically to prevent the entrance of tidal waters and at the same time carry off excess waters from the barrier lake above. A preliminary estimate of cost was made for a structure of this type, located at a suggested site between Molate Point and San Quentin Point in the "Narrows," below San Pablo Bay. This indicates that the cost of such a structure probably would be as much or more than the cost of a structure at the nearby Point San Pablo site as planned in Bulletin No. 22. As far as design features of a barrier are concerned, the present studies have been directed to a consideration of those features which might be changed on the basis of more complete information and studies of requirements, and which might affect the cost estimates. The features particularly considered have included those for navigation and passage of flood waters.

Inasmuch as the final plans for a barrier would necessarily be approved by the United States Army Engineers, particularly in regard to navigation and flood control features, studies of the present investigation on these matters have been carried out by the Army Engineers. New and more complete information was obtained as to the character and magnitude of water-borne traffic at each of the sites. Based upon this additional information, the Army Engineers have proposed modifications in number and size of the navigation locks to take care of present and future navigation requirements. Their proposals as to number and size of locks for each of the three typical sites are shown in Table I. For comparative purposes the data on locks provided for in the plans of Bulletin No. 22 also are shown in parallel columns.

It will be noted that the number and size of locks proposed by the United States Army Engineers are larger than those provided for in the plans of Bulletin No. 22 and hence would tend to increase the cost estimates to some extent. It also has been proposed by the Army Engineers that "guard gates" included in the plans for locks presented in Bulletin No. 22 be omitted; and, also, that one of the "emergency dams" provided for in the plans for each lock might be omitted where two locks of the same width are used; and costs reduced accordingly. These proposed modifications of the Army Engineers have been used as a basis for the revised estimates of cost presented herein.

TABLE 1

NUMBER AND SIZE OF NAVIGATION LOCKS

Site	Proposed by U. S. Army engineers				Plans of Bulletin No. 22			
	Number of locks	Length, in feet	Width, in feet	Depth on sill, in feet	Number of locks	Length, in feet	Width, in feet	Depth on sill, in feet
Chipps Island	1	150	45	14	[1]1	200	40	26
	1	300	60	20	[1]1	500	60	33
	1	500+300	90	20+16	[1]1	825	80	40
	1	800	90	40				
Dillon Point	1	150	45	14	1	200	40	26
	1	300	60	20	2	500	60	33
	1	500+300	90	20+16	1	825	80	40
	1	800	90	40				
Point San Pablo	2	150	45	14	1	200	40	26
	2	300	60	20	1	500	60	33
	1	500+700	120	37	2	825	80	40
	1	1,200	120	41	1	1,000	110	44

[1] In Bulletin No. 22 no plans were presented for the Chipps Island site. For comparative purposes, data are given on the farthest upstream location at Army Point.

The studies made by railroad interests and the State Division of Highways as to the feasibility and suitability of combining railway and highway crossings with a barrier eliminate from consideration all previous proposals of such combinations. The Division of Highways concluded that the combination of a highway crossing with a salt water barrier is not feasible nor economically warranted. One of the important considerations leading to this conclusion was that a modern main highway crossing must be so constructed that there will be no undue delays to traffic. A high level crossing which would clear navigation traffic is therefore necessary and hence no great economy in the construction of a bridge would result from its combination with a low level barrier structure. This consideration is of equal importance in connection with a railroad crossing which must also be designed at a sufficient height above water level so that no undue delays will be caused by passage of vessels. Hence, both highway and railroad crossings would have to be elevated a considerable distance above a barrier structure and the bridge foundations that would have to be provided would be the same as if no combination were made with a barrier. The Southern Pacific Railroad Company has already constructed a bridge across Carquinez Strait. For these reasons, the features of the designs in Bulletin No. 22, providing for combinations of highway and railroad crossing facilities with a barrier, were eliminated from the plans upon which estimates of costs were prepared.

Cost of Barrier.

The estimates of capital cost for a barrier at the Dillon Point and Point San Pablo sites are based upon the plans of Bulletin No. 22, modified as previously described as to number and size of locks and by the omission of features for highway and railway crossing combinations. The quantities for all major items and the unit prices used are the same as presented in Bulletin No. 22. Unit prices are representative of contract prices for recent years on similar construction work and are believed to be conservative and strictly comparable to those used for other units of the State Water Plan presented in other reports. These same unit prices also have been applied to the preliminary plans prepared for a barrier at Chipps Island site. One important additional unit price not included in Bulletin No. 22 is that for untreated timber piling, estimated at 50 cents per lineal foot in place.

The estimated capital costs for a barrier at the three typical sites are summarized in Table 2. These include interest during construction at 4½ per cent, compounded semiannually for an assumed construction period of six years, and 25 per cent to cover contingencies, administration, engineering and other miscellaneous expenditures.

The cost estimates presented in Bulletin No. 22 included 25 per cent for overhead, but did not include interest during construction. For the Dillon Point site, those estimates range from $38,900,000 to $97,100,000, covering different alternate plans. The plan, which is perhaps the most comparable to that upon which the cost estimate presented in Table 2 is based, was estimated to cost from $50,000,000 to $53,000,000, including a bridge and approaches. At Point San Pablo site, the estimates of cost in Bulletin No. 22 range from $66,000,000 to $82,100,000. The plan with the minimum estimated cost is perhaps most comparable to that used as a basis for the cost estimate presented in Table 2.

TABLE 2

CAPITAL COST OF BARRIER

Item	Barrier site		
	Chipps Island	Dillon Point	Point San Pablo
Unwatering	$4,750,000	$1,940,000	$6,820,000
Flood channel	1,250,000	900,000	2,960,000
Control works [1]	8,050,000	12,900,000	4,340,000
Navigation locks [2]	12,350,000	17,850,000	23.100,000
Rock and earth fill	610,000	310,000	13,250,000
Miscellaneous	600,000	610,000	1,300,000
Contingencies, administration and engineering	6,900,000	8.630,000	12,940,000
Interest during construction	5,490,000	6,860,000	10,290,000
Total	$40,000,000	$50,000,000	$75,000,000

[1] The control works provide flood gates as follows:
Chipps Island site—45 gates, 50 feet wide by 55 feet high
Dillon Point site—21 gates, 70 feet wide by 80 feet high
Point San Pablo site—15 gates, 70 feet wide by 82 feet high
[2] See Table 1 for number and size of locks provided.

A preliminary design and cost estimate also is presented in Bulletin No. 22 for a barrier at Benicia site. The estimated cost of this structure, without a bridge, is given as $40,200,000. The site used in the plans crosses a major active earthquake fault and is not considered a desirable site for a barrier. It is possible that a barrier might be located at some site in the vicinity of Benicia, upstream from this major fault line, which might prove to have some advantages over Dillon Point site. The possibilities of such a location are presented in Appendix D. It appears probable that the cost of a barrier at a site near Benicia, or at any other site in Carquinez Strait, would be approximately the same as that estimated for the Dillon Point site. In any event, it is believed that the difference in cost would be relatively small and would not affect conclusions as to comparative costs and benefits in the present economic studies.

No estimates of annual cost of a barrier were presented in Bulletin No. 22. Inasmuch as this plays an important part in the economic analysis undertaken in the present investigation, estimates have been made and are presented in Table 3 for each of the three typical sites. The estimates of annual cost are based upon the following percentages applied to the capital cost:

Interest—4½ per cent.
Amortization—1.05 per cent (4 per cent sinking fund basis for 40-year bonds).
Depreciation—On 4 per cent sinking fund basis.

Gates and operating equipment	8.0 per cent
Structural steel	2.0 per cent
Concrete	0.3 per cent
Rock and earth	0.3 per cent
Flood channel (excavation) and unwatering	0.0 per cent

The estimated costs for operation and maintenance include operating organization and cost of electric power, materials, supplies, and miscellaneous maintenance and repair work.

TABLE 3

ANNUAL COST OF BARRIER

Item	Barrier site		
	Chipps Island	Dillon Point	Point San Pablo
Interest	$1,800,000	$2,250,000	$3,375,000
Amortization	420,000	525,000	787,000
Depreciation:			
Unwatering	----	----	----
Flood channel	----	----	----
Control works	338,000	411,000	271,000
Navigation locks	408,000	387,000	727,000
Rock and earth fill	3,000	1,000	58,000
Miscellaneous	11,000	11,000	12,000
Operation and maintenance	320,000	315,000	370,000
Totals	$3,300,000	$3,900,000	$5,600,000

The estimates of annual cost of a barrier, as shown in Table 3, range from $3,300,000 to $5,600,000 and are believed to closely approximate the probable range of annual cost which might reasonably be expected for the operation and maintenance of a barrier at available sites which might be utilized. It will be noted that the item of interest alone ranges from 55 to 60 per cent of the total estimated annual cost, while interest and amortization together make up 68 to 75 per cent of the total.

Salt-clearing Locks.

If a barrier were constructed for the purpose of preventing saline invasion, it appears obvious that navigation locks in the structure should be designed, if possible, to prevent the entrance of salt water into a barrier lake. With the usual or standard type of navigation lock, salt water would be discharged into the lake during lockage operations and, if allowed to accumulate, would pollute the fresh-water lake and possibly limit its utilization to such an extent as to defeat the primary purpose of a barrier.

Considerable study has been made of possible modifications of design for navigation locks to prevent entrance of salt water into a barrier lake during operation of the usual type of lock. In Bulletin No. 22, a plan for a salt-clearing lock as proposed by W. M. Meacham of Seattle, Washington, is presented. In general, the suggested plan provides for displacement of salt water present in the lock with fresh water, introduced from the lake above, before the upper lock gate is opened for the vessel to enter the lake on upstream lockage. No provision was suggested for saving the fresh water which normally would be lost on downstream lockages. This plan appears to have considerable merit and preliminary designs and cost estimates for each site have been made for a salt-clearing lock designed from the standpoint of practical operation.

The lock would be designed with ports in the floor of the lock leading to conduits downstream and ports on the sides of the lock, opening out above the maximum water level therein, leading to a fresh-water conduit extending to the barrier lake. The method of operation would be briefly as follows:

With a vessel locking upstream and with salt water in the lock chamber, the downstream lock gate would be closed after the vessel entered and fresh water introduced through the fresh-water conduit and ports on the sides of the lock at the surface of the water in the lock chamber. At the same time the salt water in the lock chamber would be drawn off through the ports in the bottom of the lock and discharged through the conduit leading below the barrier. In this manner the salt water in the lock would be gradually displaced by the fresh water let in on the surface. In order to get all of the salt water out some fresh water of course would have to be wasted. With a vessel locking downstream, and the lock full of fresh water, the upstream gate would be closed and salt water introduced through the ports at the bottom of the lock chamber, gradually displacing the fresh water, which would be carried off through the open ports on the sides of the lock and conducted through the conduits back into the lake. Here again it would not be possible to save all of the fresh water in the lock. If the scheme should prove practical, however, a large portion of the fresh water which would be lost directly with the ordinary type of lock would be saved and, likewise, the scheme would prevent the entrance of salt water into the lake, with a fresh-water loss of only a small fraction of that required to flush out the salt water after it had entered the lake in the operation of the ordinary type of lock.

In order to carry out these operations and avoid undue delay to lockage of vessels, large size conduits with capacities of as much as 6000 second-feet for the larger locks would be required. In addition, large-size pumping equipment would be necessary under the variable head conditions to pump the water in and out of the locks. Pump operating costs of course would be larger.

It is estimated that the delay to vessels in locking through the largest lock would be about seven and one-half minutes more than with the ordinary type of lock proposed. For the smaller lock, an additional delay of about five minutes would be entailed. However, during the greater portion of a normal year, when the stream flow is sufficient to supply ample water for continuously flushing out the salt water, the salt-clearing devices would not have to be operated and the lockage time of vessels would be reduced by reason of the larger capacity conduits. Hence, the average annual loss of time to vessels by reason of locking through a barrier probably would not be any greater than with the ordinary design of lock.

The important feature about the salt-clearing lock is the possible saving in fresh water which would be required for operation of the usual or standard type of lock. Once salt water entered the lake it would have to be flushed out in order to preserve the fresh quality of the lake waters. Although there is some doubt as to the amount of fresh water required for flushing out salt water in the quantity which would enter a barrier lake by the operation of standard locks, it is evident from the experimental data and studies of the United States Army Engineers and the experience of operations at the Lake Washington Ship Canal that the amount would be large, especially with the volume of future water-borne traffic which might be expected. Hence, if some method could be found to prevent salt water entering the lake during lockage of vessels it would increase the conservation value of a barrier. It is estimated that, under future navigation traffic, the amount of water which might be saved by salt-clearing locks would have a value greater than the additional annual cost of salt-clearing locks. The amount of saving in water which might be realized by such a modification of plans will be more fully discussed in Chapter IV.

Cost of Salt-clearing Locks.—Estimates of the additional capital and annual costs of constructing this type of salt-clearing locks in place of standard locks have been prepared for each of the three typical sites and are summarized in Table 4.

TABLE 4

ADDITIONAL CAPITAL AND ANNUAL COST FOR SALT-CLEARING LOCKS

Barrier site	Capital cost	Annual cost
Chipps Island	$3,500,000	$300,000
Dillon Point	4,000,000	360,000
Point San Pablo	7,000,000	660,000

The estimates of annual cost for salt-clearing locks include interest, amortization, depreciation, maintenance and operation for future traffic with stream flow into Suisun Bay as during the period 1920–1929. The cost of operation alone would vary from year to year in proportion to the volume of water-borne traffic, and even more with stream flow, which would affect the period of operation. It is estimated that annual operation costs would range from $25,000 to $75,000 at the Chipps Island site, $30,000 to $90,000 at the Dillon Point site and $55,000 to $175,000 at the Point San Pablo site, corresponding to present and estimated future traffic about 25 years hence.

The question as to whether the additional cost of salt-clearing locks would be justified depends upon their effectiveness in saving fresh water, which would have to be furnished to prevent pollution from salt water entering a barrier lake with the operation of standard locks; and the amount and value of such water saved. The effectiveness and practicability of such salt-clearing devices are subject to some uncertainty because of lack of precedent. These could be finally determined only by carefully conducted laboratory experiments with models and possibly only after actual experience with full size locks operating under similar conditions to a barrier. However, it is reasonable to assume that some practical design and plan of operation could be devised, which would be effective in substantially reducing the fresh water required for operation of locks. Estimates are presented in Chapter IV of the water required for lockage operations using salt-clearing locks, based upon a consideration of the results which might be reasonably expected to be effected by their operation.

CHAPTER III

DEVELOPMENTS AND ACTIVITIES IN UPPER SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA REGION AFFECTED BY SALT WATER BARRIER

The primary objectives and the resulting effects of a salt water barrier are chiefly related to present and future developments, operations and activities in the upper San Francisco Bay and Sacramento-San Joaquin Delta region. An important part of the present economic investigation therefore has involved a study of the character and needs of both present and predicted future developments, operations and activities in this region, with particular regard to the necessity, desirability and economic justification of a salt water barrier for furnishing present and future water demands and facilitating the consummation of a complete development of the ultimate potentialities of the region. The industrial and agricultural developments, with the cities and towns connected therewith, and the location of operations and activities in the upper bay and delta region, are shown on Plate II, "Industrial and Agricultural Developments in Upper San Francisco Bay and Sacramento-San Joaquin Delta Regions Related to a Salt Water Barrier."

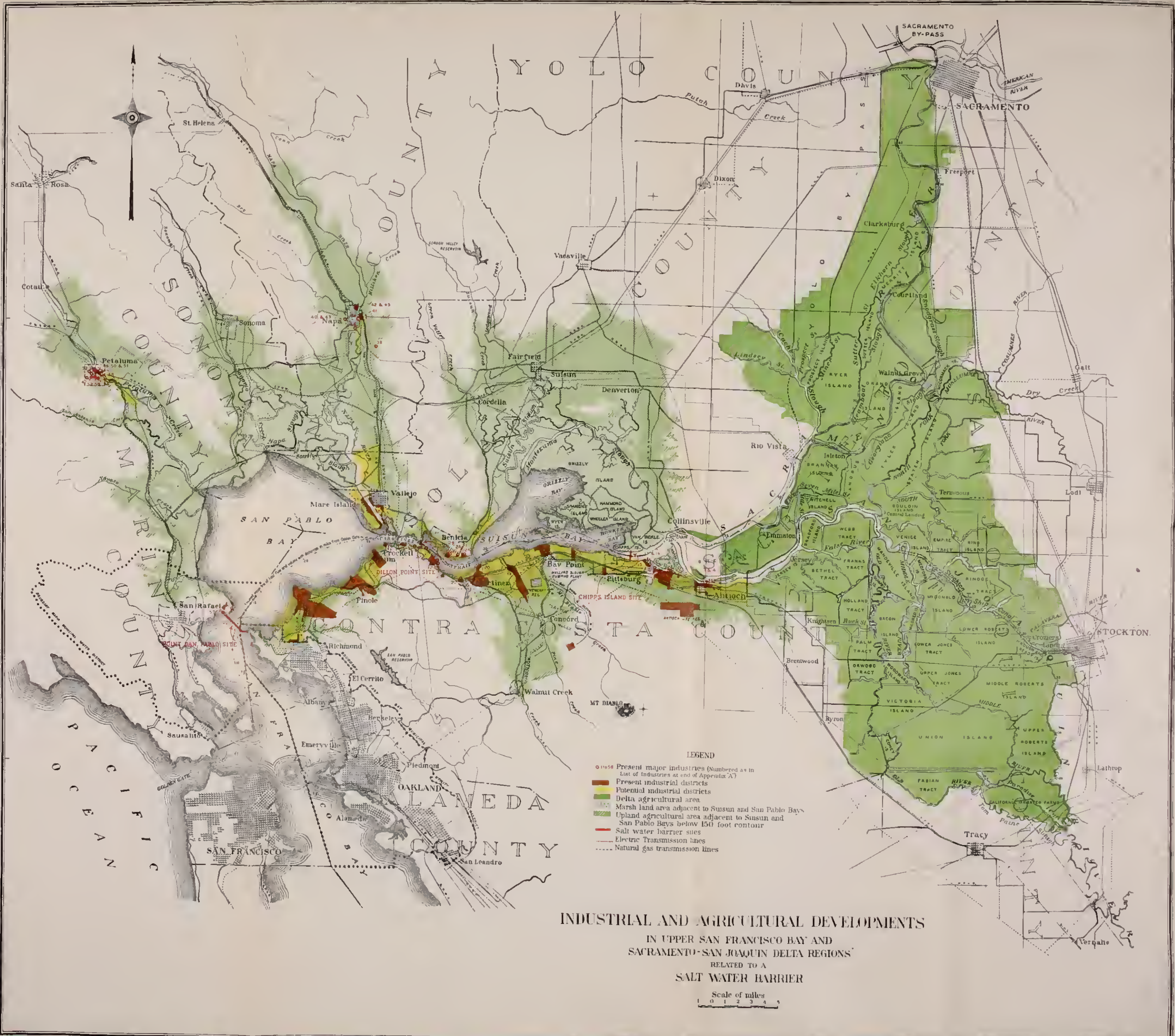
MANUFACTURING INDUSTRIES

The present investigation has included a survey of the manufacturing industries of the upper bay region, including the entire industrial district on both sides of the bay from the lower part of the delta on the east to the northerly boundary of Richmond on the west.

Magnitude of Present Industrial Development.

The industries in the upper San Francisco Bay region comprise a substantial part of the industrial structure of the San Francisco Bay region and California. Plate II shows the location of the major industries in this area and present and potential industrial districts. The magnitude of present industrial development may be judged from the fact that it represents a capital investment of about $115,000,000, with an estimated value in annual production of $300,000,000. About 17,000 workers are employed, with an aggregate annual pay roll of about $27,000,000. Table 5 summarizes the more important elements of industrial development, subdivided as to the portion above each of the three typical barrier sites. The figures compiled from data obtained directly from the industries are shown under the column headings "Partial for 1929." These comprise about 80 per cent of the entire industrial development. Based upon this information and other available data, an estimate was made of the total industrial development, which is shown under the column headings "Estimated total for 1929." The

PLATE II



INDUSTRIAL AND AGRICULTURAL DEVELOPMENTS
IN UPPER SAN FRANCISCO BAY AND
SACRAMENTO-SAN JOAQUIN DELTA REGIONS
RELATED TO A
SALT WATER BARRIER

TABLE 5

MAGNITUDE OF INDUSTRIAL DEVELOPMENT IN UPPER SAN FRANCISCO BAY REGION

Item	Above Chipps Island site			Above Dillon Point site			Above Point San Pablo site					
							Excluding industries in Napa-Petaluma area			Including industries in Napa-Petaluma area		
	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940
Average number of employees	4,030	5,040	10,260	6,670	8,660	18,850	14,080	16,070	29,330	15,060	17,150	31,300
Annual payroll	$6,300,000	$7,400,000	$21,500,000	$11,000,000	$13,100,000	$34,000,000	$23,700,000	$25,700,000	$54,600,000	$24,900,000	$27,200,000	$57,200,000
Capital investment	$13,000,000	$18,500,000	$50,800,000	$20,200,000	$42,500,000	$107,900,000	$82,300,000	$111,100,000	$190,600,000	$85,400,000	$114,900,000	$198,300,000
Annual value of products	$18,500,000	$28,300,000	$57,400,000	$96,700,000	$112,100,000	$179,900,000	$172,100,000	$283,500,000	$455,000,000	$186,200,000	$299,000,000	$466,800,000
Assessed valuation	$3,500,000	$3,600,000	$9,900,000	$14,900,000	$15,200,000	$38,700,000	$24,400,000	$25,100,000	$43,000,000	$24,700,000	$26,500,000	$45,700,000

[1] Compiled from data obtained directly from industries, and comprising about 80 per cent of total industrial development.

TABLE 5

MAGNITUDE OF INDUSTRIAL DEVELOPMENT IN UPPER SAN FRANCISCO BAY REGION

Item	Above Chipps Island site			Above Dillon Point site			Above Point San Pablo site					
							Excluding industries in Napa-Petaluma area			Including industries in Napa-Petaluma area		
	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940	Partial for 1929[1]	Estimated total for 1929	Estimated total for 1940
Average number of employees	4,030	5,040	10,260	6,670	8,660	18,850	14,080	16,070	29,330	15,060	17,150	31,300
Annual payroll	$6,300,000	$7,400,000	$21,500,000	$11,000,000	$13,100,000	$34,000,000	$23,700,000	$25,700,000	$54,600,000	$24,900,000	$27,200,000	$57,200,000
Capital investment	$13,000,000	$18,500,000	$50,800,000	$20,200,000	$42,500,000	$107,900,000	$82,300,000	$111,100,000	$190,600,000	$85,400,000	$114,900,000	$198,300,000
Annual value of products	$18,500,000	$28,300,000	$57,400,000	$96,700,000	$112,100,000	$179,900,000	$172,100,000	$283,500,000	$455,000,000	$186,200,000	$299,000,000	$466,800,000
Assessed valuation	$3,500,000	$3,600,000	$9,900,000	$14,900,000	$15,200,000	$38,700,000	$24,400,000	$25,100,000	$43,000,000	$24,700,000	$26,500,000	$45,700,000

[1] Compiled from data obtained directly from industries, and comprising about 80 per cent of total industrial development.

table also shows estimated totals for 1940, based upon the rate of growth exhibited by the industries during the last five years. It is interesting to note the distribution of industrial development with respect to the three typical barrier sites. For the area above the Chipps Island site, which comprises the industrial district from Pittsburg to Antioch, the average number of employees and annual pay roll amount to 29 and 27 per cent, respectively, capital investment 16 per cent, annual value of products 9½ per cent, and assessed valuation 13½ per cent of the total for the entire area above Point San Pablo site. For the industries above the Dillon Point site, the average number of employees are 50 per cent, annual payroll 48 per cent, capital investment 37 per cent, value of products 37 per cent and assessed valuation 57 per cent of the total for the entire area above Point San Pablo site.

Growth of Industries.

There has been a substantial growth in the manufacturing industries up to the present time. The evidence of the rate of growth is available only for the period of the five years preceding 1930, for which sufficiently complete statistical data were obtained from the industries reporting. The rates of growth in average number of employees, annual pay roll, capital investment and annual value of products are shown in Table 6.

TABLE 6

RATE OF GROWTH OF INDUSTRIAL DEVELOPMENT IN UPPER SAN FRANCISCO BAY REGION, 1924-1929

Item	Average annual rate of growth in per cent			
	Above Chipps Island site	Above Dillon Point site	Above Point San Pablo site: Excluding industries in Napa-Petaluma area	Above Point San Pablo site: Including industries in Napa-Petaluma area
Average number of employees	9.4	10.7	7.5	7.5
Annual pay roll	17.4	14.5	10.2	10.0
Capital investment	15.9	14.0	6.5	6.6
Average value of products	9.3	5 5	5.5	5 1

As compared to these rates of growth, the average annual increase in value of industrial products during the period 1923 to 1927 was less than 1 per cent for the United States as a whole and a little over 4 per cent for California. In average number of employees and annual pay roll during the same period, there was a decrease for the United States as a whole and an increase of less than 2 per cent for California. The comparison clearly indicates the healthy growth experienced by the industries in the upper bay region. Thus, in value of products, the rate of growth during the last five years in the upper bay region has been about one-third greater than the average for California and about five times as great as the average for the United States as a whole.

Table 6 shows that the industries in the Pittsburg-Antioch area above Chipps Island site have experienced a much greater percentage of growth than the other parts of the upper bay region. Thus, in capital investment, the percentage of increase has been about two and one-half times the percentage of increase for the entire area, while in value of products the percentage increase has been almost twice that for the entire area.

The history of growth of the manufacturing industries in the upper bay region shows that there has been at least one important industry located and put into operation in each decade since 1870. Starting with the location of the arsenal at Benicia and the navy yard at Mare Island by the federal government in the early fifties, the number of major industries which have located in the area during the several decades are as follows:

Before 1881	6	1901–1910	12
1881–1890	4	1911–1920	6
1891–1900	2	1921–1930	13

The above figures indicate the rate of growth only in a general way, inasmuch as the type and size of industry is of greater importance. Further details as to the type and character of these industries are presented in Appendix A, which also presents a complete tabulated list of the present major industries in the upper bay region. However, the above figures give a general indication that there has been not only a continuous growth, especially during the last 30 years, but also that growth during the past decade perhaps has been fully as substantial and important as in any of the previous decades. It has been distinguished by three outstanding developments: (1) the Johns Manville Company, manufacturing asbestos products, established in 1925; (2) the United States Steel Products Company's tin plate mill, added to the steel mill in 1929; and (3) the Shell Products Company's chemical plant, established in 1930. A new plant of the Stockton Brick Company also has been established during 1930. It thus appears that no serious obstacles have arisen in the area to materially hamper the industrial growth to the extent that might be reasonably expected. If the industrial growth of the entire area were to continue during the next ten years at the same rate of increase as during the last five years, the number of employees would increase 75 per cent, pay roll 100 per cent, capital investment about 65 per cent and value of products 50 per cent above their present magnitude. The estimates for 1940, based upon the application of the average rates of growth during the last five years, are shown in Table 5. There is, of course, considerable uncertainty as to the accuracy of such estimates of future growth and the figures can be deemed to be indicative only of the possibilities if the rates of growth experienced during the past five years continue during the next ten. The actual rate of growth will depend upon a number of factors which can not be foretold. It is evident, however, that most of the factors which influence the location of industries are favorable in the upper bay region.

Plate II shows many of these favorable physical elements for industrial growth in the upper bay region, such as suitable industrial sites, deep water transportation, ample rail facilities, electric power and natural gas lines and fuel oil supplies. These favorable elements, together with the westward trend of industry as discussed in detail in Appendix A, form the basis for the reasonable expectation that the upper bay region will experience a continuation of substantial growth in industrial development.

Industrial Water Supply.

The one element among the factors influencing the location of industries which appears at present to be unfavorable is that of fresh-water supplies for boilers, processes and similar uses by industries. At present the industries in the upper bay region obtain part of their supply from private wells, part from public water supply systems operating in the area and part from the upper bay and lower river. During the summer and fall months when the combined flow of the Sacramento and San Joaquin rivers into the delta and upper bay is small, saline water from the lower bay gradually invades the upper bay and lower river channels. During this five or six months' period of low stream flow, the water of the upper bay and lower river channels becomes so brackish that it is suitable only for cooling and condensing purposes. The period during which the water is brackish and unfit for industrial process use varies considerably geographically. Thus, in the Antioch-Pittsburg area the water may be fresh enough for all purposes for a period of six or seven months, depending upon the normality of the seasonal run-off and upon its distribution during the season. Below Pittsburg, the periods during which fresh water is available for all uses becomes progressively shorter the farther downstream. The records show that fresh water is available for a brief period in many years as far down as Carquinez Strait. However, there is seldom any time when the waters in San Pablo Bay are fresh enough for industrial process use, and then only at infrequent intervals during abnormally large floods from the Sacramento and San Joaquin rivers. As a direct result of these conditions, it is found that only in the Antioch-Pittsburg district is any large use made of the river as a source of industrial fresh-water supplies. In the remainder of the upper bay region, fresh-water supplies are obtained almost entirely from private wells and public water supply systems.

In former years it was possible for the industries along the shores of Suisun Bay to obtain more of their fresh-water supplies from the bay than has been possible during recent years. Because of the greater degree and duration of saline invasion into the upper bay and lower river channels since about 1917, the use of this source of fresh-water supply by the industries, especially in the Antioch-Pittsburg district, has been curtailed considerably. This has made it necessary for the industries to find other sources of fresh-water supply. Local ground water supplies in the Antioch-Pittsburg area have been developed at considerable expense to supplement the supply of fresh water obtainable from the lower river channels. Some of these well supplies have turned saline, giving rise to considerable apprehension as to the dependability of underground supplies in this district. The cause of the well supplies turning saline has been investigated by one of the large industries in this area and found to be due to the fact that more water is being pumped from the underground basin than the amount of natural replenishment from the tributary drainage area, thus resulting in a lowering of the ground water level below the river level and allowing saline water when present in the river channel to enter the aquifer and pollute the well supplies.

The industries in the lower Suisun Bay area also have been required to obtain a greater portion of their fresh water than in former years from private wells and by purchase from public water supply systems, generally entailing an increase of cost of supply. The California-Hawaiian Sugar Company at Crockett, which prior to 1920 obtained all of its fresh-water supply from the upper bay and river channels by means of water barges which were filled at points upstream where fresh water was found, has, since 1920, obtained a part of its supply from Marin County because of the greatly increased distance which the barges had to be towed to get fresh water from the river under the conditions of saline invasion during recent years. Due to the greater expense and difficulty of obtaining fresh-water supplies by barge in this manner, the company is now (1930) developing an entirely new supply from wells in the lower end of the Napa Valley, and conveying the water by pipe line to Crockett.

Inasmuch as the industries in the Pittsburg-Antioch district are relatively heavy users of fresh water for industrial process purposes, the lack of dependability in the present available sources of fresh-water supply, both from the river and from underground, is a matter of concern. As a consequence, the industries in this area in particular have naturally focused their interest on the consummation of some plan which would make possible the diversion of fresh-water supplies throughout the year from the river, which evidently offers the cheapest and most logical source of industrial fresh-water supply. In order to make this supply available throughout the year some plan would be necessary to prevent the invasion of salinity into the upper bay and lower river channels. A salt water barrier located at some point below has been proposed as one means of accomplishing this purpose.

In the area from Pittsburg to Martinez, almost half of the industrial fresh-water supply is obtained from public water supply systems although a considerable portion is obtained from private wells. Only about 20 per cent of the total fresh-water supply consumed is obtained from the river or bay. In the San Pablo Bay area from Carquinez Strait to Richmond, about 70 per cent of the total fresh-water supply used is obtained from public water supply systems, while most of the remainder is obtained from the river. However, the water obtained from the river for use in this area is not a direct local diversion, but is made up almost entirely of the fresh-water supplies used by the California-Hawaiian Sugar Company at Crockett, which have been obtained by barges filled at points upstream where fresh water was available.

One public utility serves the fresh-water demands of several industries in Contra Costa County. This company, which originally obtained most of its supply from wells in the vicinity of Concord at the lower end of Ygnacio Valley, recently has completed a new development with a pumping plant at Mallard Slough, about two miles below the city of Pittsburg, and a pipe line from this point to a new reservoir near the town of Clyde, south of Bay Point. Water is pumped during a period usually of three to five months each year, when fresh water is available at the point of diversion, and stored in the reservoir for use throughout the year. With this new development, which is capable of considerable enlargement, the water company expects to have ample supplies to take care of all municipal and industrial demands in the portion of Contra Costa County it serves. The facilities probably could be made entirely ample to serve all industrial needs in this area. The unfavorable feature in connection with this supply is its relatively high price, which ranges in cents per thousand gallons from 23.3 for large users to 46.7 for small users. The industries using this supply have expressed a desire to obtain cheaper water. It is probable that a much cheaper water supply could be obtained from this or a similar type of development if all the industrial fresh-water demands in the area were combined under one system and the expense of water treatment eliminated.

North of the bay in Solano, Napa and Sonoma counties, the industrial fresh-water supplies are served almost entirely by public utility and municipal water-supply systems, including those in Vallejo, Napa, Petaluma, Benicia and Suisun. The price of water is relatively high. Supplies are sufficient for the present needs in most of these districts, but there has been some difficulty in meeting present demands during recent dry years, especially at Benicia.

Present Use and Cost of Industrial Water Supply.—The present use of fresh water by the industries in the entire upper bay region is about sixteen million gallons per day, of which about thirteen million gallons per day is used in the area above Dillon Point and ten million gallons per day in the area above Chipps Island. The present cost of fresh water per thousand gallons, based upon the data submitted by the industries, ranges from a minimum of 1.2 cents for water obtained from the river to a maximum of 93 cents for water obtained from public water supply systems, with an average cost from all sources (river, private wells and public water-supply systems) ranging from 2.3 cents for the industries above Chipps Island site to 11.9 cents for the industries in the entire area above Point San Pablo site. The lowest costs of industrial fresh water are found in the Pittsburg-Antioch area, where supplies are obtained cheaply from both river and underground sources. In the area below Pittsburg, about half of the fresh-water supplies are obtained from public water-supply systems at an average cost of about 37 cents per thousand gallons. The above costs of water include operation, maintenance, depreciation and interest on the fresh-water supply systems of each industry. For supplies obtained from public water supply systems the cost includes also the price paid for water. Additional details as to cost of industrial fresh-water supplies as related to source of supply and industrial district are presented in Appendix A.

The fresh-water demands of the industries make up but a small part of their total water demands. By far the greater part of the demand is for cooling and condensing purposes, amounting at present in the entire area to 65 million gallons per day or about four times the fresh-water demand. The present demands for this purpose above the Dillon Point and Chipps Island sites are 38 and 10 million gallons per day respectively. The availabilty of the water supplies present in the bay and lower river channels for this purpose is not limited by saline invasion. It is true that the use of saline water for cooling and condensing causes a greater degree of corrosion and increased rate of depreciation in the cooling and condensing equipment, especially if the equipment is not designed for saline water conditions. However, most of the industries along lower Suisun Bay and San Pablo Bay have installed equipment designed for saline water. In general, all industries have installed equipment which will result in the least cost of maintenance and depreciation for the particular conditions and quality of water at their plants. The average cost of cooling and condensing water to the industries based on the data obtained from them ranges from 2 to 2.1 cents per thousand gallons. This includes the cost of maintenance, operation, depreciation, and interest on the investment for the cooling water systems. Thus, the cost of cooling and condensing water to the industries is low and it is evident that the utilization of the bay waters for this purpose is satisfactory.

The data on use and cost of industrial water in the upper San Francisco Bay region are summarized in Table 7. These data are compiled from the information obtained from the industries by the State Engineer's questionnaire, except for a small part of the amount shown for the water used for boiler and process purposes which was estimated from other information for a few industries not reporting. The corresponding figures tabulated in Appendix A show only the water used by industries reporting. The table also shows an estimate of the industrial water requirements predicted by the present industries themselves for their needs in 1940.

TABLE 7

USE AND COST OF INDUSTRIAL WATER IN UPPER SAN FRANCISCO BAY REGION

(Compiled from data furnished by the industries)

Area	Amount used in 1929, in million gallons per day	Predicted use in 1940, in million gallons per day	Cost in 1929, in cents per thousand gallons		
			Maximum	Minimum	Average
Water for boiler, process and miscellaneous purposes					
Present industries above Chipps Island site	9.8	16.3	38.2	1.2	2.3
Present industries above Dillon Point site	13.0	20.6	93.0	1.2	6.9
Present industries above Point San Pablo site:					
(a) Excluding Napa-Petaluma area	16.1	24.6	93.0	1.2	11.9
(b) Including Napa-Petaluma area	16.4	25.1	93 0	1.2	11.9
Water for cooling and condensing purposes					
Present industries above Chipps Island site	10.5	20.8	39.0	1.1	2.0
Present industries above Dillon Point site	38.3	58 7	39.0	0.8	2.0
Present industries above Point San Pablo site:					
(a) Excluding Napa-Petaluma area	64.6	98.0	39.0	0.4	2 1
(b) Including Napa-Petaluma area	64.6	98 0	39.0	0.4	2.1

Future Industrial Water Supply and Service.—There is room for considerable improvement in the present situation both as to source and cost of industrial fresh-water supplies in the upper bay region. As previously stated, this is the one unfavorable factor in the present situation which might limit the future industrial growth in this region. It would be desirable to effect some means of obtaining fresh-water supplies both for the present and future needs of industries which not only would be dependable as to quantity and quality, but also cheap as possible and comparable to water rates in competing industrial areas. The furnishing of an adequate and dependable cheap fresh-water supply would no doubt prove to be an attraction to heavy users of industrial water and would probably stimulate industrial growth in the upper bay region. This objective might be attained by providing some means of controlling the invasion of salinity into the upper bay and delta channels so that water supplies now or hereafter made available in the lower channels of the Sacramento and San Joaquin rivers could be utilized at all times for industrial fresh-water demands. The consideration of alternate plans with and without a barrier for controlling saline invasion and serving the industries as well as the municipal and agricultural developments of the upper bay region with required fresh-water supplies from this source is of primary importance in the present investigation and is presented in Chapter IV.

INDUSTRIAL WATER FRONT STRUCTURES

In connection with the industrial development and commercial activities of the upper bay region, there are a large number of docks and wharves along the shores of the bay for handling incoming and outgoing water-borne commerce. Most of the major industries are situated directly on the shores of the bay in order to take advantage of the cheap water transportation afforded by the upper bay channels communicating not only with ocean trade routes, but also with the inland waterways of the interior valley. Ocean-going vessels discharge and take on cargoes directly at the docks of many of the upper bay industries. In addition to the docks and wharves directly connected with major industries, there are dockage and warehouse facilities, especially in the Carquinez Strait area, in which cargoes of grain from valley shipping points, brought down by barge and other shallow river craft, are temporarily warehoused and later loaded aboard ocean-going vessels.

In the present investigation, all of the industrial water front structures in the upper bay region from Antioch to Richmond, on both sides of the bay, were surveyed and examined and information obtained as to the character and type of structure and the capital and annual costs. As far as possible, the owners of the structures were personally interviewed and desired information obtained with the aid of questionnaires. In cases where no data or only partial data could be obtained from the owners, an examination was made of the structures and estimates prepared of capital and annual costs, based upon data obtained on structures of similar type and character. In all, 256 water front structures were examined and information obtained thereon. Many of the structures examined were small, both as to size and value, and were eliminated from consideration in the final studies and analyses. The studies presented hereafter have been confined to 150 water front structures which, it is considered, might be affected by a change to fresh-water conditions above a barrier. No trestles or similar pile structures on railroads in the area were included. The ferry slips and piers of the Southern Pacific Company at Benicia and Port Costa were omitted from the studies because of the imminence of their abandonment. Similarly, those of the Sacramento Northern Railroad Company ferry at Chipps Island (O. and A. Ferry) also were excluded because of the possibility of their abandonment in the not distant future upon construction of a proposed railroad bridge at this location.

Infestation of Marine Borers.

The industrial water front structures in the upper bay region have been seriously affected during the last ten to fifteen years by an infestation of marine borers, chiefly the teredo, which attack and destroy timber piling in saline water. Prior to the occurrence of this infestation, most of the industrial water front structures in the upper bay region, even on the shores of San Pablo Bay, were supported on untreated timber piles. Many of these structures stood for a considerable period of years without molestation by marine borers, although it is evident that the degree of salinity present in the waters of San Pablo and Suisun bays in most years would have made it possible for the teredo to live and attack the timber piling. The first discovery of the teredo in the upper bay channels was made in 1914, when a borer, later identified as *Teredo navalis*, was reported in a structure at Mare Island. There was also some evidence that it had been there in 1913. Its activities in this area of the bay were temporarily curtailed between 1914 and 1917 because of the occurrence of heavy precipitation and run-off with large floods discharged from the Sacramento and San Joaquin rivers freshening up the upper bays and either killing the borers or temporarily curtailing their activities. During this period, however, the teredo infestation spread to all parts of the lower bay, where waters of higher salinity prevailed, thus adding this borer *Teredo navalis* to the marine borers which already existed in the lower bay, including *the bankia* and *limnoria*. Beginning with the subnormal period of precipitation and run-off in the year 1917, the teredo infestation in the upper bay region soon developed renewed activity and by 1919 most of the untreated timber piling supporting the water front structures had been destroyed. Many wharves collapsed in 1919 with additional failures occurring during 1920. According to the report based upon the exhaustive investigation of the San Francisco Bay Marine Piling Committee,* the destruction by the teredo affected 50 structures with a damage estimated at $15,000,000 up to 1920. By 1921 all of the untreated piling in the upper bay region had been destroyed and the same authority estimates the total damage amounted to at least $25,000,000. In the upper bay region every untreated pile structure as far upstream as Antioch was attacked in varying degree.

* "Marine Borers and Their Relation to Marine Construction on the Pacific Coast." Final report of the San Francisco Bay Marine Piling Committee, 1927.

Following this destruction of the untreated piles, reconstruction was immediately started using treated timber and concrete piles. Thus, at present, capital investments have already been made to replace most of the original untreated timber piles with more resistant types. However, untreated timber piling is still in use to some extent. The most permanent of the resistant types of piling is that of reinforced concrete which, if properly constructed, may be considered as permanent in so far as freedom from attack of marine borers. The other resistant types of piling, including creosoted timber and timber piles with concrete jackets, are still subject to some attack because of the imperfections in the protection afforded.

Life of Piling.

Excluding the more permanent concrete piling, the timber piling in the present industrial water front structures comprises in general six distinct types of round piles and three of sheet piling. Based upon information obtained from the owners of these structures and other sources, the average life of each of these types of piling has been estimated for each of the areas for present average conditions of salinity in the bay and is shown in Table 8.

TABLE 8

LIFE OF TIMBER PILING IN UPPER SAN FRANCISCO BAY REGION UNDER PRESENT AVERAGE SALINITY CONDITIONS

Type of piling	Estimated life in years			
	Above Chipps Island site	Between Chipps Island and Dillon Point sites	Between Dillon Point and Point San Pablo sites	Napa-Petaluma area
Round piles				
Fir—concrete jacketed	(1)	15	15	(1)
Fir—creosoted, best construction	30	30	30	30
Fir—creosoted, inferior construction	20	15	15	(1)
Fir—creosoted, redriven	(1)	10	(1)	(1)
Redwood, gum and cedar, untreated	15	(1)	5	25
Fir—untreated	6	5	3	20
Sheet piling				
Fir—creosoted, best construction	(1)	(1)	40	40
Redwood—untreated	25	(1)	(1)	(1)
Fir—untreated	20	(1)	15	30

[1] No piles of the particular type are now present in the particular area.

Capital Cost of Present Timber Pile Structures.

The capital cost of timber pile structures segregated as to type of piling and for the areas above and between barrier sites are shown in Table 9. These costs are compiled from data obtained from the owners of the structures and include the original cost of piles, bracing, caps, stringers, decks and superstructure. As shown by this table, the total cost of all industrial water front structures with timber piling in the upper bay region between Point San Pablo site and Antioch aggregates $5,900,000, of which about 7 per cent is above Chipps Island site, 28 per cent between Chipps Island and the Dillon Point sites and about 62 per cent between Point San Pablo and Dillon Point sites and but 3

TABLE 9

CAPITAL COST OF PRESENT INDUSTRIAL WATER FRONT STRUCTURES ON TIMBER PILES IN UPPER SAN FRANCISCO BAY REGION

(Compiled from data furnished by owners of industrial water front structures)

Type of piling	Capital cost				
	Above Chipps Island site	Between Chipps Island and Dillon Point sites	Between Dillon Point and Point San Pablo sites	Napa-Petaluma area	Entire upper bay region
Round piles					
Fir—concrete-jacketed		$103,000	$337,000		$440,000
Fir—creosoted, best construction	$26,000	923,000	1,381,000	$1,000	2,331,000
Fir—creosoted, inferior construction	196,000	335,000	586,000		1,117,000
Fir—creosoted, redriven		19,000			19,000
Redwood, gum and cedar, untreated	78,000		56,000	66,000	200,000
Fir—untreated	121,000	274,000	331,000	100,000	826,000
Sheet piling					
Fir—creosoted, best construction			96,000	6,000	102,000
Redwood—untreated	3,000				3,000
Fir—untreated	8,000		843,000	11,000	862,000
Totals	$432,000	$1,654,000	$3,630,000	$184,000	$5,900,000

per cent in the Napa-Petaluma area. The structures in the Napa-Petaluma area are of small importance and value relative to the major industrial water front structure development of the upper bay region, and may be eliminated from further consideration.

The estimated capital cost of timber piling in place in the upper bay region is shown in Table 10. The figures show the estimated cost per lineal foot for round piles and per cubic foot for sheet piling. These are based upon data obtained from the owners and are representative of average costs during recent years in the entire upper bay region. The cost of the better type of creosoted timber pile is about two and one-half times that of an untreated pile in place, while the concrete-jacketed timber piles are estimated to cost over three times the untreated timber pile.

TABLE 10

CAPITAL COST OF PRESENT TIMBER PILING IN UPPER SAN FRANCISCO BAY REGION

Type of piling	Estimated unit cost in place[1]		
	Materials	Labor	Total
Round piles			
Fir—concrete-jacketed	$0.80	$0.20	$1.00
Fir—creosoted, best construction	.75	.25	1.00
Fir—creosoted, inferior construction	.70	.20	.90
Fir—creosoted, redriven	.40	.20	.60
Redwood, gum and cedar—untreated	.42	.18	.60
Fir—untreated	.22	.18	.40
Sheet piling			
Creosoted—best construction	1.50	.50	2.00
Redwood—untreated	.80	.40	1.20
Fir—untreated	.65	.35	1.00

[1] The cost estimates for round piles are on the lineal foot basis, while those for sheet piling are on a cubic foot basis.

Annual Cost of Timber Piling.

Based upon the estimated capital cost and life of the various types of timber piling for the several geographical subdivisions of the upper bay region segregated by barrier sites, the annual costs of present piling under the present average conditions of salinity have been estimated and are presented in Table 11. These estimates include interest, maintenance, repairs, insurance, miscellaneous expense, and depreciation, and are shown per lineal foot for round piles, per cubic foot for sheet piling and in total for both types. Interest is assumed at 6 per cent

TABLE 11

ANNUAL COST OF PRESENT TIMBER PILING IN UPPER SAN FRANCISCO BAY REGION UNDER PRESENT SALINITY CONDITIONS

Area	Type of piling	Estimated annual unit costs[1]			Total quantity of piling (round piles in lineal feet, sheet piling in cubic feet)	Estimated total annual cost
		Interest, repairs, insurance and miscellaneous expenses	Depreciation	Total		
Above Chipps Island site	**Round piles**					
	Fir—creosoted, best construction	$0.11	$0.01	$0.12	15,000	$1,800
	Fir—creosoted, inferior construction	0.10	0.02	0.12	85,000	10,200
	Redwood, gum and cedar, untreated	0.06	0.03	0.09	76,000	6,800
	Fir—untreated	0.04	0.06	0.10	70,000	7,000
	Sheet piling					
	Redwood—untreated	0.10	0.02	0.12	2,000	200
	Fir—untreated	0.09	0.03	0.12	8,000	1,000
	Subtotal					$27,000
Between Chipps Island and Dillon Point sites	**Round piles**					
	Fir—concrete-jacketed	$0.11	$0.04	$0.15	58,000	$8,700
	Fir—creosoted, best construction	0.11	0.01	0.12	418,000	50,200
	Fir—creosoted, inferior construction	0.10	0.04	0.14	300,000	42,000
	Fir—creosoted, redriven	0.06	0.05	0.11	29,000	3,200
	Fir—untreated	0.04	0.07	0.11	308,000	33,900
	Subtotal					$138,000
Between Dillon Point and Point San Pablo sites	**Round piles**					
	Fir—concrete-jacketed	$0.11	$0.04	$0.15	188,000	$28,200
	Fir—creosoted, best construction	0.11	0.01	0.12	613,000	73,600
	Fir—creosoted, inferior construction	0.10	0.04	0.14	309,000	43,300
	Redwood, gum and cedar—untreated	0.06	0.11	0.17	20,000	3,400
	Fir—untreated	0.04	0.13	0.17	324,000	55,100
	Sheet piling					
	Fir—creosoted, best construction	0.17	0.01	0.18	44,000	7,900
	Fir—untreated	0.09	0.04	0.13	550,000	71,500
	Subtotal					$283,000
Total for upper San Francisco Bay region						$448,000

[1] The estimated annual cost is on the lineal foot basis for round piles and on the cubic foot basis for sheet piling.

and maintenance, insurance and miscellaneous expense at 5 per cent for round piles and 2½ per cent for sheet piling, of the capital cost. Depreciation is estimated on a 6 per cent sinking fund basis over the estimated life of the pile.

Effect of a Salt Water Barrier on Industrial Water Front Structures.

If continuous fresh-water conditions in place of the present variable saline water conditions in the upper bay channels were brought about by some means, the marine borers would die and their destructive activities would be eliminated. This would have the effect of materially prolonging the life of all types of timber piling and thus reducing annual depreciation costs. Annual maintenance costs also would be materially reduced by decreasing the number of replacements and by the possible replacement with untreated piling and timber braces. Capital costs for future structures might also be reduced because of the possibility of using the cheaper untreated timber piling. This is one of the beneficial results which it may be assumed would be effected by a salt water barrier for timber piling in structures above a barrier. Studies have been made to estimate the decrease in annual cost of timber piling in present structures under an assumed change to fresh-water conditions.

Life of Timber Piling Under Fresh-Water Conditions.—Considerable study has been given to the matter of estimating the probable life of untreated timber piling under fresh-water conditions. Although one of the large railroad companies estimates the average life of untreated timber piling in fresh water at fifteen years, data obtained from owners of industrial water front structures in the upper bay show that many of the untreated timber pile structures had been in service thirty years or more without material depreciation until the advent of the teredo infestation. There are also many examples of timber pile structures along the Sacramento and San Joaquin rivers 20 to 30 years old without appreciable depreciation. For the purpose of this study the life of untreated timber piles under fresh-water conditions has been assumed at 30 years.

It appears possible that a longer life might be obtained with creosoted timber piles, but one of the large railroad companies is authority for estimating the life of creosoted timber piling at 30 years for fresh-water conditions. For the want of more accurate information, the life of both creosoted and concrete-jacketed timber piling has been assumed at 30 years under fresh-water conditions.

Estimated Annual Cost of Timber Piling Under Fresh-Water Conditions.—Under an assumed change to fresh-water conditions, computations of annual cost of timber piling including interest, maintenance and depreciation have been made on two assumptions: First, for the present piling in place and present capital cost but with an assumed life of 30 years for fresh-water conditions; and, second, with the timber piling in present structures assumed as replaced by untreated timber piling with a correspondingly smaller capital cost and with an assumed life of 30 years under fresh-water conditions. The estimated annual costs under the first assumption for piling of the various types segregated as to the same geographical areas by barrier sites are shown in Table 12. They have been compiled on the same basis as Table 11.

It will be noted that Table 12 shows the estimated annual unit cost for untreated timber piles under fresh-water conditions at five cents per lineal foot for round piles and ten cents per cubic foot for sheet piling. These figures are directly applicable to the estimates of total annual cost under the second assumption, and hence no detail tabulation is necessary.

TABLE 12

ANNUAL COST OF PRESENT TIMBER PILING IN UPPER SAN FRANCISCO BAY REGION UNDER FRESH-WATER CONDITIONS

Area	Type of piling	Estimated annual unit costs[1]			Total quantity of piling (round piles in lineal feet, sheet piling in cubic feet)	Estimated total annual cost
		Interest, repairs, insurance and miscellaneous expenses	Depreciation	Total		
Above Chipps Island site	**Round piles**					
	Fir—creosoted, best construction	$0.09	$0.01	$0.10	15,000	$1,500
	Fir—creosoted, inferior construction	0.08	0.01	0.09	85,000	7,700
	Redwood, gum and cedar—untreated	0.06	0.01	0.07	76,000	5,300
	Fir—untreated	0.04	0.01	0.05	70,000	3,500
	Sheet piling					
	Redwood—untreated	0.10	0.01	0.11	2,000	200
	Fir—untreated	0.09	0.01	0.10	8,000	800
	Subtotal					$19,000
Between Chipps Island and Dillon Point sites	**Round piles**					
	Fir—concrete-jacketed	$0.09	$0.01	$0.10	58,000	$5,800
	Fir—creosoted, best construction	0.09	0.01	0.10	418,000	41,800
	Fir—creosoted, inferior construction	0.08	0.01	0.09	300,000	27,000
	Fir—creosoted, redriven	0.06	0.01	0.07	29,000	2,000
	Fir—untreated	0.04	0.01	0.05	308,000	15,400
	Subtotal					$92,000
Between Dillon Point and Point San Pablo sites	**Round piles**					
	Fir—concrete-jacketed	$0.09	$0.01	$0.10	188,000	$18,800
	Fir—creosoted, best construction	0.09	0.01	0.10	613,000	61,300
	Fir—creosoted, inferior construction	0.08	0.01	0.09	309,000	27,800
	Redwood, gum and cedar—untreated	0.06	0.01	0.07	20,000	1,400
	Fir—untreated	0.04	0.01	0.05	324,000	16,200
	Sheet piling					
	Fir—creosoted, best construction	0.16	0.01	0.17	44,000	7,500
	Fir—untreated	0.09	0.01	0.10	550,000	55,000
	Subtotal					$188,000
Total for upper San Francisco Bay region						$299,000

[1] The estimated annual unit costs are on the lineal foot basis for round piles and cubic foot basis for sheet piling.

Indicated Saving in Cost of Timber Piling Under Fresh-Water Conditions.—Table 13 summarizes the total estimated capital and annual costs of timber piling segregated as to areas above the three typical barrier sites, for: first, present timber piling under present salinity conditions; second, present timber piling under fresh-water conditions; and, third, untreated timber piling in place of present timber piling with fresh-water conditions. Finally, the difference in annual cost or the indicated savings under the two assumed changed conditions are shown. The estimates include all of the industrial water front structures with timber piling in the upper bay region as previously described, omitting only those of minor importance and value at Napa and Petaluma. For the present structures and types of piling, it is estimated that an annual saving of $149,000 might be realized by a substitution of fresh-water conditions with a barrier at Point San Pablo. If a barrier were constructed at Dillon Point, the corresponding indicated annual saving under the same conditions would be $54,000, while above the Chipps Island site the saving is estimated at $8,000.

TABLE 13

COMPARISON OF CAPITAL AND ANNUAL COST OF TIMBER PILING IN PRESENT WATER FRONT STRUCTURES OF UPPER SAN FRANCISCO BAY REGION WITH PRESENT SALINITY CONDITIONS AND WITH FRESH-WATER CONDITIONS

Area	Governing conditions	Estimated total costs		Difference in annual cost
		Capital	Annual	
Above Chipps Island site	Present piling with present salinity conditions	$175,000	$27,000	
	Present piling with fresh-water conditions	175,000	19,000	$8,000
	Untreated piling in place of present piling with fresh-water conditions	108,000	13,000	14,000
Above Dillon Point site	Present piling with present salinity conditions	$1,062,000	$165,000	
	Present piling with fresh-water conditions	1,062,000	111,000	$54,000
	Untreated piling in place of present piling with fresh-water conditions	554,000	69,000	96,000
Above Point San Pablo site	Present piling with present salinity conditions	$2,921,000	$448,000	
	Present piling with fresh-water conditions	2,921,000	299,000	$149,000
	Untreated piling in place of present piling with fresh-water conditions	1,729,000	201,000	247,000

Under the second assumption, when at some future time all of the piling in present structures might be replaced by untreated timber piles if fresh-water conditions were maintained, it is estimated that the annual saving for present structures with a barrier at the Point San Pablo site would be $247,000, at the Dillon Point site $96,000, and at the Chipps Island site $14,000.

The estimates apply only to the present structures and the present types of timber piling in the upper bay region. If the present types of piling were materially changed by replacement with other types, the annual costs and indicated savings would be different than the amounts shown in this analysis. Larger savings might be realized as more industrial water front structures were constructed, depending, however, on the type of construction. Thus, if the capital value of industrial water front structures increased at a rate of 4 per cent per year, capital expenditures for piling in new structures might be reduced under fresh-water conditions by reason of the possibility of using untreated timber piles, and the savings in annual cost of maintenance and depreciation would amount to a materially greater figure than for the present structures in direct proportion to the increase in water front structure development. Thus, in 25 years, the savings might be double the amounts estimated for present structures, if of the same average pile construction. Inasmuch as it is impossible to foretell with any degree of certainty what the future will bring in the way of increased number and character of industrial water front structures, it is impracticable to present estimates of future savings. Morover, it is reasonable to expect that, even under fresh-water conditions, some owners will choose to put in more expensive and more permanent types of piling, including treated timber and concrete piles. For example, it is the standard practice of one of the large railroad companies to use creosoted timber piling for all structures requiring timber piles, whether for fresh- or salt-water conditions. A change to fresh-water conditions might result in some benefit also to concrete piling by decreased depreciation resulting from the elimination of the deteriorating effect of saline water on concrete. No attempt has been made in this study to evaluate this possible benefit.

The indicated savings shown in Table 13 for a barrier at Dillon Point site are about 1.4 and 2.5 per cent of the annual cost of a barrier, under the first and second assumed changed conditions, respectively; while for Point San Pablo site, the corresponding percentages are about 2.7 and 4.4; and for Chipps Island site, less than one-half of one per cent. Therefore, the possible benefit to water front structures could not be considered as a controlling factor in arriving at a conclusion as to the necessity and desirability of a salt water barrier. Although the benefit value indicated would substantially increase with the future growth of water front structures above a barrier, it still would assume a position of minor importance as compared to the main objective sought to be attained by barrier, namely, that of serving the fresh-water demands and facilitating the development of the upper bay region. However, as a contributing beneficial factor which might be realized, its evaluation is a necessary part of the economic studies undertaken.

FISHING INDUSTRY

One of the important activities of the upper bay and Sacramento and San Joaquin rivers which would be affected by a salt water barrier is the fishing industry. This involves not only commercial, but also extensive pleasure fishing. Information is available only for commercial fishing, no records being kept of the amount of fish caught by sportsmen. The State Fish and Game Commission has prepared a report, presented in Appendix F, on the fishing industry and the possible effect thereon of a salt water barrier

Magnitude of Fishing Industry.

The economic importance of the commercial fishing industry in the upper bay and rivers may be measured from the fact that the total catch of commercial fish in 1929 amounted to over 3,000,000 pounds, having an estimated sale value of about $350,000. Over 500 men are engaged in commercial fishing operations at the present time and the estimated capital investment in commercial fishing equipment and plants amounts to nearly $800,000.

The chief varieties of fish caught commercially are salmon, shad and striped bass. In former years, salmon fishing was by far the most important as to both amount and value of catch. Of late years, due to a number of factors, the commercial catch of salmon has declined materially. At the same time, shad fishing has assumed a position of greater importance than in former years. The amount of striped bass caught commercially has continued fairly uniform for the past ten years or more. It is believed that the catch of striped bass for pleasure has increased during the past decade and now equals or perhaps exceeds the amount caught commercially. Other fish caught commercially comprise catfish and carp. The magnitude of commercial fishing operations from statistics compiled in the State Fish and Game Commission reports is shown in Table 14, covering the period 1918 to 1929. Data are shown for the major varieties of fish only which represent over 95 per cent of the total commercial catch in this area.

TABLE 14

COMMERCIAL CATCH OF FISH IN UPPER SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA REGIONS

Period 1918 to 1929

Year	Catch in pounds					
	Salmon	Shad	Striped bass	Catfish	Carp	Total
1918	5,829,126	1,317,820	1,218,508	109,466	170,455	8,645,375
1919	4,308,739	1,564,462	651,469	125,523	237,218	6,887,411
1920	3,721,046	1,376,784	527,178	83,124	126,442	5,834,574
1921	2,336,395	779,258	495,436	62,839	96,115	3,770,043
1922	1,700,273	1,077,812	515,688	2,475	53,216	3,349,464
1923	2,174,981	1,256,832	801,242	78,402	126,761	4,438,218
1924	2,640,110	1,527,494	589,926	289,864	70,717	5,118,111
1925	2,778,846	2,389,083	752,337	203,040	62,377	6,185,683
1926	1,261,776	885,564	643,438	153,518	42,420	2,986,716
1927	920,786	3,981,645	612,014	292,151	55,040	5,861,636
1928	553,777	2,006,008	468,596	384,475	81,533	3,494,389
1929	517,110	1,479,276	504,693	460,919	70,565	3,032,563
Average	2,395,247	1,636,836	648,377	187,150	99,405	4,967,015

Habits of Fish.

The three important species of commercial fish, salmon, shad and striped bass, are all migratory in their habits, entering the bay and ascending the rivers each year to spawn and, except the salmon which die after spawning, returning later to the ocean. The young fish fry hatched in the upper river channels gradually drift downstream to the bay where they remain for a considerable time in the shallow brackish-water areas and feed on marine life present under the brackish-water conditions. The adult striped bass and shad also feed in these brackish-water areas.

Effect of a Salt Water Barrier on Fishing Industry.

The studies of the State Fish and Game Commission indicate that the construction and operation of a salt water barrier might have a serious detrimental effect on the fishing industry. It is evident that a barrier would offer an obstruction to the free migration of fish into and out of the bay and rivers and would substantially reduce and possibly largely eliminate the shallow brackish-water areas which are essential as a feeding ground not only for the young fish fry but also for adult striped bass and shad. It is possible that fishways could be provided in a barrier to successfully take care of the passage of salmon, but it is a difficult matter to obtain complete success in fish ladders even for salmon. Moreover, the migrating adult salmon can not pass suddenly from salt to fresh water. In the case of the striped bass and shad, however, it is believed by the Fish and Game Commission to be extremely doubtful if they could be induced to pass a barrier by any of the fishways now known.

Although perhaps not of determining importance, the probable detrimental effect that a barrier would have on commercial and recreational fishing must be given due consideration. The whole matter would have to be very carefully studied before final conclusions could be made as to the resulting detriment, if any. If the construction and operation of a barrier should result, as the preliminary studies indicate, in abandonment of present commercial fishing operations, it would entail a loss in annual value of commercial fishing catch of about $350,000. Also, the commercial fishermen and the federal and state governments might have to be reimbursed for their capital investment in equipment and fish hatcheries.

Both the state and federal governments are deeply interested in the maintenance of this natural resource. Large expenditures have been and are at present being made in the interest of promoting and increasing the opportunities for fishing. It is probable that serious objections would be raised to any structure which might have the effect of seriously disturbing or eliminating commercial and recreational fishing in the upper bay and rivers.

NAVIGATION

Navigation on the upper bay and Sacramento and San Joaquin rivers is one of the major commercial activities of the region. An important factor favoring industrial and commercial development in this area is the existence of the natural waterways of both bay and river channels which afford a means of cheap transportation for the products of the factory and the soil.

Magnitude of Water-borne Commerce.

The magnitude of water-borne commerce is indicated by the statistics shown in Table 15, which are compiled from the annual reports of the Chief of Engineers, United States War Department. The data

TABLE 15

WATER-BORNE COMMERCE IN UPPER SAN FRANCISCO BAY AND SACRAMENTO AND SAN JOAQUIN RIVERS

Period 1919 to 1929

Year	San Joaquin River		Sacramento River		Suisun Bay		Carquinez Strait		San Pablo Bay		Totals	
	Tonnage	Value	Tonnage	Value	Tonnage	Value	Tonnage	Value	Tonnage	Value	Tonnage	Value
1919	647,000	$54,100,000	1,666,000	$78,601,000	305,000	$7,034,000	(Included Pablo	in San Bay)	4,634,000	$184,472,000	7,252,000	$324,207,000
1920	692,000	42,203,000	1,378,000	53,946,000	433,000	13,877,000	2,079,000	$97,991,000	1,696,000	54,621,000	6,278,000	262,638,000
1921	647,000	37,263,000	977,000	52,092,000	562,000	19,670,000	No	data	2,039,000	96,178,000	4,225,000	[1]205,203,000
1922	679,000	34,292,000	1,291,000	60,607,000	1,329,000	32,006,000	No	data	2,652,000	118,234,000	[1]5,951,000	[1]245,139,000
1923	698,000	38,028,000	1,265,000	62,470,000	2,659,000	43,764,000	No	data	2,466,000	109,022,000	[1]7,088,000	[1]253,284,000
1924	727,000	38,185,000	1,796,000	58,663,000	2,341,000	51,066,000	No	data	4,200,000	156,999,000	[1]9,064,000	[1]304,913,000
1925	850,000	47,192,000	1,427,000	80,500,000	4,204,000	88,670,000	7,673,000	183,001,000	4,754,000	234,409,000	18,908,000	633,772,000
1926	935,000	56,456,000	1,223,000	85,315,000	4,205,000	90,687,000	7,844,000	135,522,000	4,677,000	260,934,000	18,884,000	628,914,000
1927	1,153,000	51,605,000	1,210,000	78,617,000	4,382,000	62,672,000	6,572,000	144,642,000	4,264,000	233,589,000	17,581,000	571,125,000
1928	984,000	43,378,000	1,066,000	77,748,000	4,241,000	62,690,000	7,935,000	159,899,000	4,551,000	173,393,000	18,703,000	517,108,000
1929	941,000	42,760,000	1,129,000	74,088,000	4,906,000	64,395,000	9,707,000	228,532,000	5,287,000	120,341,000	21,970,000	530,119,000
Average	814,000	$44,133,000	1,305,000	$69,332,000	2,688,000	$48,776,000	6,968,000	$158,264,000	3,747,000	$158,381,000	----------	----------

[1] Partial totals exclusive of Carquinez Strait.

compiled in this table cover the period 1919 to 1929, inclusive, and show the magnitude of water-borne commerce, both as to tonnage and value of cargo transported to and from the several major geographic subdivisions of the region. For 1929, the total cargo carried for the entire area from San Pablo Bay to Sacramento and Stockton was 22,000,000 tons, having a total value of about $530,000,000.

Interest of Federal Government in Navigation.

The interests of navigation and the maintenance of navigation channels are a primary function of the federal government through the War Department. An average annual expenditure of $350,000 has been made during the last five years for normal maintenance work in the upper bay and Sacramento and San Joaquin rivers. In addition to the normal annual maintenance, special projects for improvement of navigation are being undertaken from time to time. The special project at present under way which is of most interest in connection with a consideration of a salt water barrier is the Stockton Ship Canal. This project, involving an estimated capital expenditure of $3,715,000, exclusive of right of way, will, when completed, provide a navigable channel with a minimum depth of 26 feet from the bay to Stockton, suitable for ocean-going vessels. The project involves channel deepening and widening at sections in Suisun Bay and through New York Slough from Pittsburg to Antioch and along the San Joaquin River to Stockton Harbor.

A structure which would affect navigation in any way is the particular interest of the War Department, and hence a salt water barrier would finally have to receive its approval. For this reason, the detailed studies in regard to navigation and the possible effect of a barrier thereon have been carried out by the United States Army Engineers as a part of their special cooperative studies of the present investigation.

Water-borne Traffic.

The magnitude and character of present water-borne traffic passing each of the three typical barrier sites are based upon a detailed investigation and survey by United States Army Engineers, covering traffic during 1929. Statistics were obtained from shippers in the upper bay and delta regions on size, character and point of departure and destination of all vessels. These statistical data were supplemented by an actual field count of vessels passing strategic points, including Point San Pablo, Selby and Army Point, during a period of two or three months from April to June, 1930. A record was obtained of the time of arrival, length, draft and character of all craft passing these points during this period. Based upon these combined sources of information, the total annual water-borne traffic for 1929 past each typical barrier site was compiled. The detailed tabulations showing size, length and character of vessels for each site are too voluminous to include in this report. The data have been briefly summarized by grouping the vessels with respect to increments of length and draft corresponding to the dimensions of barrier locks, and are shown in Table 16.

TABLE 16

PRESENT WATER-BORNE TRAFFIC PASSING BARRIER SITES

(From survey by U. S. Army engineers for 1929)

Length of vessel, in feet	Total annual number of vessels								
	Chipps Island site			Dillon Point site			Point San Pablo site		
	Draft less than 10 feet	Draft from 10 to 16 feet	Draft more than 16 feet	Draft less than 10 feet	Draft from 10 to 16 feet	Draft more than 16 feet	Draft less than 10 feet	Draft from 10 to 16 feet	Draft more than 16 feet
0 to 150	13,680	362	0	11,592	630	4	26,223	2,608	2
150 to 300	6,436	259	76	7,203	1,656	711	12,432	7,342	1,070
300 to 500	300	108	5	497	309	1,107	1,300	1,348	1,853
500 to 800	51	168	0	56	364	4	4	0	8
Over 800[1]	316	0	0	172	0	0	0	0	0
Subtotals	20,783	897	81	19,520	2,959	1,826	39,959	11,298	2,935
Totals		21,761			24,305			54,192	

[1] Barges towed in tandem.

Predictions of the magnitude and character of future water-borne traffic are somewhat uncertain. However, it is reasonable to expect that there will be a continuation in growth of industrial and agricultural developments and commercial activities in the region with a corresponding growth in water-borne commerce and traffic. It is estimated by the United States Army Engineers that the cargo tonnage of water-borne commerce will about double in 25 years. After taking into account the additional factor of probable change in size and character of vessels likely to occur in the future, estimates have been made of future water-borne traffic 25 years hence, expressed in terms of number of lockages through different sized locks, by the application of these factors to the lockages deduced for present traffic. The number of vessels and the estimated lockages for both present and future traffic are shown in Table 25 in Chapter IV.

Effect of Salt Water Barrier on Navigation.

A salt water barrier would be an obstruction to navigation. Opinions differ as to how serious the effect of such an obstruction would be. It is evident, however, that suitable locks could be provided in a barrier structure and that the only direct inconvenience to navigation operations would be the delay resulting from the necessity of passing through the locks. This interference and delay to navigation would be greater the farther downstream a barrier were located because of the greater volume of traffic. The maximum interference would result from a barrier at Point San Pablo where, in addition to the commercial traffic, the movements of naval vessels to and from Mare Island Navy Yard at the upper end of San Pablo Bay would be affected. Whether such interference with the movement of naval vessels would result in the federal government's disapproval of such a lower site has not been ascertained. However, for the purposes of the economic studies of the present investigation, it is not necessary to arrive at a decision relative to this matter.

It is estimated by the Army Engineers that the average delay to vessels due to lockage through a barrier would be one-half hour under both present and future traffic conditions; and that the average monetary loss per vessel lockage would be $4.50 under present conditions and $7.50 under future conditions. Based upon the present and estimated future traffic at the three typical sites, the estimated annual loss to navigation interests due to lockage delays is shown in Table 17.

TABLE 17

ANNUAL LOSS TO NAVIGATION INTERESTS DUE TO LOCKAGE DELAYS WITH A BARRIER

Barrier site	Estimated annual loss	
	Present traffic	Future traffic
Point San Pablo	$243,000	$698,000
Dillon Point	110,000	307,000
Chipps Island	100,000	266,000

Under conditions of future volume of traffic which might be expected at a more remote time than 25 years hence, the indicated loss to navigation interests might be considerably greater. It is not believed that this detriment should be considered as a determining factor in the consideration of the necessity and desirability of a barrier. It may be expected that vessels would continue to operate to points past a barrier to take care of the full demands of water transportation. However, it is proper to evaluate this element of detriment in a consideration of the economic aspects of a barrier.

MUNICIPAL DEVELOPMENT

There are numerous towns and cities in the upper bay region generally connected with the industrial, commercial and agricultural activities and developments. The chief urban and suburban districts lie along the shores of the bay, with the greater number along the south shore in Contra Costa County, where Antioch, Pittsburg, Martinez, Crockett and several small towns are located. The largest city within the region is Vallejo, located on the north shore of Mare Island Strait north of San Pablo Bay. Here the activities of the Mare Island Navy Yard have given rise to a substantial urban development. The only other urban district on the north shore of the bay proper is Benicia at the easterly end of Carquinez Strait, where the federal government's arsenal is located. Farther inland and situated on tributary tidal estuaries some distance from the bay proper are Napa and Petaluma, north of San Pablo Bay, and Suisun and Fairfield, north of Suisun Bay. Concord and Walnut Creek are situated south of Suisun Bay. There are several small communities along the south and easterly shores of Suisun and San Pablo bays, usually centering about one or more of the important manufacturing industries.

Population.

The available population statistics from the United States Census Bureau for the larger cities or towns in the upper bay region from

1900 to 1930, inclusive, are shown in Table 18. The data in the table indicate that most of the larger cities have experienced a relatively substantial growth during the past three decades, while some of the smaller towns have had little, if any, growth. As a matter of fact, the population statistics directly reflect, for the most part, the magnitude of industrial activity. This is borne out particularly for Vallejo,

TABLE 18

POPULATION OF MUNICIPALITIES IN UPPER SAN FRANCISCO BAY REGION

(Compiled from statistics of United States Bureau of Census)

City or town	Population			
	1900	1910	1920	1930
Antioch	674	1,124	1,936	3,563
Benicia	2,751	2,360	2,693	2,913
Concord		703	912	1,125
Fairfield	716	834	1,008	1,131
Hercules		279	373	392
Martinez	1,380	2,115	3,858	6,569
Napa	4,036	5,791	6,757	6,437
Petaluma	3,871	5,880	6,226	8,245
Pinole	411	798	967	781
Pittsburg		2,372	4,715	9,610
Sonoma	652	957	801	980
Suisun	625	641	769	905
Vallejo	7,086	10,064	16,845	14,476
Walnut Creek			538	1,014

Pittsburg, Martinez, Antioch, and to some extent by Petaluma and Napa. The greater population shown in 1920 for Vallejo is directly attributable to the war time operations at the navy yard. The direct effect of increased development of the manufacturing industries is typified by the growth in Antioch, Pittsburg and Martinez, about which much industrial activity is centered. The growth of such towns as Petaluma, Napa, Suisun, Fairfield, Concord and Walnut Creek probably is more directly dependent on the growth and prosperity of tributary agricultural developments and activities. The urban and suburban districts of the upper bay region will continue to experience a substantial growth if the industrial and agricultural activities of the region are further extended.

Municipal Water Supply.

The water supplies used for domestic and municipal purposes in the upper bay region generally have been obtained from local surface streams, springs and underground sources by means of wells. However, in the Suisun Bay area, some of the domestic and municipal supplies have been obtained from the lower river and bay channels. Some towns and cities own and operate their own water systems, while others are served by public utilities. Antioch has obtained all or a portion of its supply from the San Joaquin River since the sixties. In the early days the water system was very primitive and the raw river water was used with little, if any, treatment to remove turbidity and purify the supply. Improvements were made in the water system from time to time, especially in the provision of treatment works. For the last fifteen years or more the water has been filtered and chlorinated.

As early as the seventies it is reported that the water occasionally became too brackish for domestic use and sometimes even for garden irrigation. The period of brackishness was in the late summer and early fall months during the period of low stream flow. At such times it was necessary to pump water from the river only at low tide in order to get as fresh a supply as possible. It is stated that many of the early residents in Antioch built cisterns which were filled when the river supply was fresh and fairly clear, immediately following the June freshets, so that they would have fresh water for their use in the late summer and early fall months. With the greater magnitude of saline invasion in recent years following 1917, the water in the river at Antioch was too brackish for domestic use for such long periods of time each year that it became necessary to provide reservoir storage in order to furnish the city with fresh water during the annual periods of saline invasion. A reservoir for this purpose was built by the city and has been in operation since about 1925. After undergoing necessary treatment, a satisfactory supply is said to be obtained which is one of the cheapest in the upper bay region.

In former years, Pittsburg also obtained most of its supply from the river (New York Slough). The first water system is reported to have been built in 1880, consisting of a small windmill and tank from which nearby residents carried supplies of water. From this early beginning the water system was gradually enlarged and extended under private ownership, as the city (originally called Black Diamond) continued to grow. Treatment and purification works were necessary to make this river supply suitable for domestic use. During the late summer and early fall months of each year, when the river flow was low, the supply was affected by saline invasion from the bay, resulting in a somewhat greater degree and duration of brackishness than at Antioch. During such periods water was pumped only at low tide in order to obtain as fresh water as possible. With the greater magnitude of saline invasion after 1917 the river water at Pittsburg was much too brackish in the summer and fall months for domestic and municipal use. However, the use of the river as the principal source of municipal water supply was continued until 1920, in which year the privately owned system was purchased by the city. Because of the unsatisfactory character of the supply available in the river the use of river water by the city was discontinued in December, 1920, and since that time the city has obtained its water supply from deep wells in the vicinity. The present supply from wells is said to be satisfactory in quantity, but somewhat deficient in quality because of hardness and a tendency to become saline. There is, therefore, some question as to the dependability of this underground supply.

Benicia is reported to have obtained part of its supply in former years from the bay channels offshore. However, fresh water was available offshore only during limited periods of time each year during winter and spring floods. It is stated that it was the practice in former years to fill barges with fresh water when it was available near by and pump water out of these barges in the remainder of the year. This method of obtaining a supply was not very satisfactory and the city's needs for the most part have been taken care of by development of local surface and underground water supplies. This local supply is limited and in dry years the city has experienced difficulty in obtaining a sufficient quantity of water for its needs.

The remaining cities and towns along and not far distant from the south shore of the bay in Contra Costa County are served by a public utility. This company originally obtained its supply from wells near Concord. In 1930, this source of supply was greatly augmented by a new development. Water is diverted by pumps from the river at Mallard Slough, about two miles downstream from Pittsburg, and conveyed by a pipe line to a reservoir near Clyde, a little south of Bay Point. Water is pumped only during periods when it is fresh and free from saline invasion, and storage is provided sufficient in amount for the balance of the year's supply. After proper treatment, the water supply is said to be satisfactory. This development is of considerable importance and interest, inasmuch as it has eliminated a serious shortage which existed prior thereto in the territory served by this company. This company serves all of the municipal needs in the entire area along the south shore of the bay from Pittsburg to Hercules and also the towns of Concord, Walnut Creek and Danville. Several of the industries as well are served by this company. The city of Martinez obtains its supply from this company and retails it to its consumers through a municipally-owned distribution system. It is reported that some water also has been furnished by this company to Benicia, which has had considerable difficulty in supplying its demands from its available local sources of supply.

Crockett, where the California-Hawaiian Sugar Company is situated, will shortly obtain its water supply through the sugar company's new private water system now nearing completion. The water supply will be obtained from wells operated in the lower end of the Napa Valley and conveyed by pipe line to Crockett. The company expects to obtain an excellent supply from this source which will be ample for some time to come for both the requirements of the city and the industry.

After experiencing years of difficulty in obtaining suitable and sufficient water supplies, the city of Vallejo now is obtaining most of its supply from the recently constructed "Gordon Valley" project, which is said to be not only very satisfactory, but also sufficient for some years to come. Water is stored in the Gordon Valley reservoir on an upper branch of Suisun Creek and conveyed by pipe line some 21 miles to the city. The city of Napa also has an excellent municipal supply furnished through a municipally-owned and operated system with storage on Milliken Creek. Petaluma is served by a water supply system owned and operated by a public utility. The supply is obtained partly from wells and partly from local surface streams. Although sufficient for present needs, the supply is believed to be somewhat limited and inadequate for any large future growth. Fairfield and Suisun, with municipally owned and operated systems, obtain their supplies largely from wells, but partly from local surface streams. The supply is said to be fairly satisfactory in quality and sufficient in quantity for present needs.

Table 19 summarizes the sources of supply, the amount of water developed and the annual amount and cost of water used for the more

TABLE 19

DEVELOPED RESOURCES, USE AND COST OF PUBLIC WATER SUPPLIES IN UPPER SAN FRANCISCO BAY REGION

(Compiled from data obtained from municipalities and public utilities)

Area	Water system	Sources of supply	Water supply developed in 1929, in million gallons per year	Use in 1929, in million gallons		Annual cost per thousand gallons, in 1929
				Maximum daily	Annual	
Above Chipps Island site	Antioch municipal water works	San Joaquin River	292	0.75	212.0	
	Pittsburg municipal water works	Wells	730	0.73	200.0	
Subtotal and average cost			1,022	1.48	412.0	$0.25
Between Chipps Island and Dillon Point sites	Benicia Water Company	Local streams	140	0.60	94.0	
	California Water Service Company (Contra Costa County)	Sacramento River	1,095			
		Wells	1,278	2.86	891.8	
	Fairfield municipal water works	Wells	91	0.15	35.0	
	Martinez municipal water works	California Water Service Company	0	.75	213.2	
Subtotal and average cost			2,604	4.36	1,234.0	0.34
Between Dillon Point and Point San Pablo sites	California Water Service Company (Petaluma)	Wells and streams	548	0.69	190.2	
	Hercules Water Company	Wells and East Bay Municipal Utility District	29	0.40	94.1	
	Napa municipal water works	Local streams	650	1.18	211.4	
	Sonoma Water and Irrigation Company	Wells	215	0.20	33.5	
	Vallejo municipal water works	Local streams	1,460	2.25	570.5	
Subtotal and average cost			2,902	4.72	1,099.7	0.38
Average cost for upper San Francisco Bay region						0.34

important cities and towns in the upper bay region, based upon data obtained from the various municipalities and public utilities. The data are subdivided as to location of the towns above the three typical barrier sites. There are a few smaller towns not shown, because complete data were not available.

The public water supply systems shown in Table 19 report developed water resources of about eighteen million gallons per day with an average use of 7.5 million gallons per day in 1929. The cost of water per thousand gallons to the companies and municipalities averages 34 cents for the entire upper bay region, ranging from an average of 25 cents for the area above Chipps Island to 38 cents for the area between the Dillon Point and Point San Pablo sites. The relatively high cost of water is due to the large expenditures required for development of the limited local water resources and the small use relative to the amount of developed supplies. Actual water rates to consumers are somewhat larger on the average.

Future Water Supply and Service.

Looking forward to the future, it is evident that additional sources of water supply will become necessary to provide for the increasing water demands of urban and suburban districts as they gradually grow with the future increase of industrial, agricultural and commercial activities. The studies in regard to a plan for meeting the future municipal water supply requirements are presented in Chapter IV.

SEWAGE AND INDUSTRIAL WASTE

The problems of sewage and industrial waste disposal are of such a nature that they have been the subject of a special study and report made by the Bureau of Sanitary Engineering of the State Department of Public Health, presented as Appendix E. The present sources, amounts and character of pollution and its effect on the quality and redeemability of water supply have been determined by field surveys and laboratory analyses. Studies have been directed to a consideration of the effect of present and predicted future sewage and industrial waste pollution, under present methods and means of disposal, upon the quality and redeemability of water in a barrier lake, and of disposal and treatment works required with a barrier.

Present Conditions and Effects of Pollution.

At the present time, the channels of San Pablo and Suisun bays and the Sacramento and San Joaquin rivers receive most of the sewage and industrial waste from cities, towns and industries in the upper bay and delta regions. On the Sacramento and San Joaquin River channels below Sacramento and Stockton, respectively, even the present amounts of sewage pollution during the period of low stream flow seriously affect the quality and redeemability of the water supplies for some distance downstream, both from a bacterial and organic standpoint. However, the natural processes of oxidation which result in the consumption of organic matter and the extinction of harmful bacteria are so effective that redeemability of the waters is regained a few miles below the sources of pollution. The studies show that, by the time the waters reach the lower channels of the Sacramento-San Joaquin Delta, they are satisfactory and redeemable for all purposes under present conditions of pollution and would probably be satisfactory and redeemable for a long time in the future. The water in the lower delta would be practically normal as regards oxygen content and the bacterial content would be small and easily taken care of by the usual treatment methods. In the bay region below the mouth of the rivers, tidal action materially assists in the removal of sewage and industrial waste discharged into the channels and little if any nuisance results therefrom. It is believed by the Bureau of Sanitary Engineering that the present methods of disposal under the same or similar tidal conditions as the present would probably be satisfactory for an indefinite period in the future.

Effect of Salt Water Barrier on Sewage and Industrial Waste Disposal.

If a barrier were constructed creating a lake in the upper bays, tidal action would be eliminated above the structure and its present effectiveness in removal and disposal of the pollution would be lost. Probable results of discharging sewage and industrial waste into a barrier lake can best be measured by the effect of sewage pollution in the Great Lakes region, where conditions are closely comparable to those which would obtain for a barrier lake. Based upon the effect of sewage pollution in Lake Erie, it is concluded that the continued discharge of sewage and industrial waste into a barrier lake, especially in the increasing amounts to be expected with the future growth of industries and municipalities, would pollute the lake to such an extent that the water would be unredeemable for domestic and higher industrial process uses. The pollution would be particularly serious in the portion of a barrier lake in what is now Suisun and San Pablo bays, where industrial and urban developments along the shores are now and would continue to be of greatest density and would discharge heavy pollution loads into the lake. There would also be polluted areas in the river channels, especially below Stockton and Sacramento, and at other points of pollution, but their effect would be local as far as redeemability of water supply is concerned and a satisfactory supply would be available in the lower delta channels.

In order to preserve the quality of water supply in a barrier lake so that there would be no limitation upon its use for all purposes, it would be essential to provide sewage and industrial waste disposal works to intercept and convey the effluents to some point below a barrier. It would be feasible to construct such necessary disposal and treatment works, but substantial expenditures would be involved. Preliminary designs and cost estimates for disposal and treatment works required indicate that, for a barrier at Dillon Point site, there would be involved a capital and annual cost of $3,800,000 and $400,000, respectively; for a barrier at Point San Pablo site, a capital and annual cost of $6,800,000 and $780,000, respectively. If anything, these figures of estimated cost are believed to represent the minimum amount of expenditures which might be required for this purpose. It is possible that temporary measures of relief might be obtained by a disposal at some point in a barrier lake far distant from the points where water supplies would be extracted. Studies of such projects have been made, but it is concluded that the safest and surest method of handling such a situation would be a disposal below a barrier. By such a plan, all of the sanitary sewage and the troublesome industrial wastes, consisting of various deleterious chemicals and wash waters from oil refineries, would all be conveyed below a barrier lake and the waters thereof thus preserved fresh in quality for industrial and domestic uses. Some of the industrial wastes now discharged with the cooling water effluent could be separated out with rather simple arrangements and the cooling water thus returned without pollution to a lake. In this way about 80 per cent of the waters diverted for cooling and condensing purposes could be saved and returned to the lake.

AGRICULTURAL DEVELOPMENT

The agricultural areas, comprising present and potential irrigation and reclamation developments, which might be affected by construction and operation of a barrier include the Sacramento-San Joaquin Delta, and the marshlands and uplands adjacent to Suisun and San Pablo bays. (See Plate II.) At present there is considerable variation in the character and intensiveness of agricultural development and activities in these several areas. The most intensive development and utilization of lands for agricultural purposes is within the delta. The bay marshlands have been only partially developed and are utilized to a limited extent for agricultural purposes at present. On the upland areas adjacent to the two bays, the lands are mostly dry farmed, with irrigation applied on but a small part of the area.

Sacramento-San Joaquin Delta.

The Sacramento-San Joaquin Delta, embracing a gross area of about 500,000 acres, contains some of the richest and most highly developed agricultural lands in the state. These lands were originally swamp and overflow areas, built up by deposits of silt and accumlations of decayed vegetation. Reclamation development was started prior to 1860 and was continued at a more or less uniform rate until the lands were practically all reclaimed at the beginning of the last decade. The entire area is a typical delta formation, consisting of numerous islands separated by a network of channels through which the Sacramento and San Joaquin rivers discharge their waters into Suisun Bay.

Lands and Crops.—The total net area of present reclaimed agricultural lands within levees aggregates 421,000 acres, of which about 350,000 acres are now devoted to crop production. In 1929, about 9000 acres of these reclaimed lands were temporarily flooded. The crops grown include asparagus, potatoes, sugar beets, corn, beans, celery and other truck crops, alfalfa, wheat and barley, and a considerable acreage in orchards, mostly of pears and peaches. The value of crops raised in 1929 is estimated at $30,000,000. The taxable wealth of the delta area is approximately $45,000,000. A large part of the soils on these delta islands, especially the southern portion of the delta on the San Joaquin River side, consists of peat. These peat soils extend for some little distance up the lower channels of the Sacramento River and the lower reaches of the Mokelumne River. The northern portion of the delta along the Sacramento River is composed mostly of silt soils built up by deposits from the river.

Water Supply and Irrigation Operations.—Most of the crops in the delta are irrigated. Water supplies for irrigation are obtained directly from the delta channels surrounding the islands. A large portion of the delta lands lie at an elevation below mean sea level and even below low tide level. Water is diverted from the channels very generally by means of siphons over the levees or through large gates in the levees. However, for the higher lands along the Sacramento River above Rio Vista and in the southerly part of the delta on the San Joaquin River, water is diverted by pumping.

As a general rule, the irrigation supply diverted through siphons or gates is carried in the same system of main ditches that are used for draining the lands and controlling the water table. These main ditches are filled and water diverted therefrom through smaller ditches, ten inches wide by eighteen inches deep and from 70 to 200 feet apart, depending on the crops, and held therein six to eight inches below the ground surface and allowed to seep out into adjoining fields. After the water table has arisen sufficiently, the drainage pumps are operated to lower the water in the ditches so that the water table can be controlled within the desired limits. This is the typical method of irrigation throughout the delta with the exception of the higher lands, along the upper part of the Sacramento and San Joaquin rivers, where the usual methods of surface irrigation are practiced.

In a large part of the delta lands natural seepage from the adjacent channels is of considerable amount. The water which enters the islands by natural seepage contributes materially to the moisture consumed by crops, vegetation and soil evaporation on the delta lands. In some cases of deep-rooted crops, such as asparagus, the ground water originating from natural seepage is depended upon to furnish moisture requirements of the crop. In general, however, irrigation is necessary to obtain a more flexible and more rapid regulation of the moisture requirements of different crops and different depths of water table best suited to the different crops grown. Extensive systems of drainage ditches and drainage pumping plants are an essential part of the regulation of the water table and moisture requirements.

Levees.—The levees which have been constructed for the reclamation of the delta lands have been brought to a grade and cross section which at the present time afford protection, except for extreme floods. The construction of the levees has involved many years of continuous work and large expenditures. This is especially true for the levees which have been built in peat formation. These peat formations subside under the weight of levee material and it has been only by continued work year after year that such levees have been brought to desired grade and cross section. Even at the present time, there still exists many weak sections of levee which require constant attention. Settlement of the levees is still being experienced on many of the islands and it is necessary to operate dredges periodically in order to maintain the grade and cross section. In the areas of silt formation, especially along the Sacramento River, no difficulties of this kind are experienced.

However, considerable maintenance work is required from time to time, especially along the main channel of the Sacramento River, consisting of revetments and bank protection devices to repair the damage of erosion caused by floods.

Throughout the delta, much levee maintenance work consisting of bank protection to repair and resist wave erosion is required. This is true especially for unprotected sections of levees which lie in a direction across the main path of the prevailing winds. In addition to wind erosion, the waves set up by passing vessels and small craft, cause considerable erosion damage. Remedial measures to repair the effects of this erosion are necessary from time to time.

Salinity Conditions.—During certain years since 1917, the invasion of saline water into the delta channels has been of rather serious magnitude and has threatened the dependability of water supply used for irrigation. Notably in 1920, 1924 and 1926, the invasion of saline water extended a greater distance up the channels of the delta than had ever occurred before as far as is known. At the time of maximum extent of invasion in 1924, the water in the channels of nearly one-half of the delta had a salinity in excess of 100 parts of chlorine per 100,000 parts of water. The amount of salinity in irrigation water that crops can stand varies with different crops and different soil and drainage conditions. Information is not available to fix a definite limit of suitability, but it has been generally assumed for average conditions in the delta that a salinity of 100 parts of chlorine per 100.000 parts of water is about the maximum amount which would be safe for use on most crops. In 1920 and 1926, about one-fifth of the delta was similarly affected. These saline invasions have made it necessary to cease irrigation diversions in certain areas of the delta during the latter part of the irrigation season. This has resulted possibly in some decrease in crop yields but no definite information has been found as to any losses in crops for any year up to 1930. Earlier and more prolonged invasions of salinity than have occurred up to 1930 might result in material loss in crop production.

There has been considerable speculation upon the effect of saline invasion on the quality of the lands within the delta. In so far as can be ascertained by the present investigation, the invasions of salinity which have occurred up to 1930 apparently have not affected the quality of land. This appears to be true even for those lands which lie nearest the lower end of the delta, including such areas as Sherman. Jersey, Bradford, Twitchell, and Brannon islands and the Webb Tract. The waters in the channels adjacent to these lands have been invaded by saline water to an extent sufficient to make the water unfit for irrigation use during limited periods in several of the past ten years. However, the period of saline invasion into the delta is usually of relatively short duration, comprising about three to six months of the summer and fall in the lower delta channels and correspondingly lesser periods at points farther upstream.

It appears that the period of saline invasion has not been sufficiently extended during any year up to 1930 to seriously affect the quality of the lands adjacent to the invaded channels. Any effect of saline water entering the islands from the adjacent channels would presumably be indicated first by an increase in the salinity of ground water within the islands. Samples were taken in 1929 and 1930 of the water in the drainage ditches inside of both Jersey and Sherman islands. These records show that, for these years at any rate, the salinity of the waters inside the islands was not seriously affected or increased by reason of the greater salinity present in the adjacent channel waters during the period of invasion. Usually, no water is diverted into these islands when the water in the adjacent channels is of harmful saline content.

Just what the effect of a longer period of saline invasion than has been experienced up to 1930 would be on these delta lands is impossible to state, nor can a statement be made with any degree of certainty as to what period of saline invasion could be experienced by these lands without affecting their quality. It appears probable that the saving feature in the conditions which have been experienced during the past ten years or even farther back is the fact that fresh water is present in the adjacent channels during a major portion of the year and is therefore the predominating source of the ground water supplies which fill the voids in the island masses. A fresh water supply thus stored up in the ground is available for a considerable period of time and apparently its quality within the reach of plant roots is unaffected by invasions of saline water in the adjacent channels which extend over periods of considerable duration. However, if water of a high salinity were to remain present in the channels of the delta during a larger portion of the year, it appears possible that the ground waters in the islands would gradually become saline and thus affect the quality and utilization of the soil. Conditions would tend to approach those which are found in the marshlands of Suisun Bay, where saline water conditions have predominated over a longer period of time.

Although the evidence appears to show that the delta lands and crops have not been materially damaged by saline invasions which have occurred up to 1930, the salinity menace has tended to depreciate land values in the delta. Until this menace is removed there exists a more or less constant threat of more extensive and prolonged saline invasions than have occurred up to 1930, which might result in material damages to crops and lands in the delta.

There does exist a more or less serious problem of salt accumulations in the soils of the delta islands which it is deemed desirable to discuss in this connection, inasmuch as there has been a considerable tendency to confuse this problem with the invasions of saline water from the bay. Because of the method of irrigation in the delta with ground water levels held from six inches to three feet below the ground surface to supply the moisture requirements of the crops, there results a positive tendency for the gradual accumulation of salts in the surface layers of the soil. This is due to the fact that capillary action draws the moisture from the water table to the ground surface and, upon evaporation, leaves in the surface layers of the soil whatever salt content it had. Where the water is generally very pure and contains but a small amount of salts, the accumulation of salt by this action is extremely slow and it takes many years to accumulate enough salt to affect crop production. While the water supply in the delta is comparatively free from salt, the many years of irrigation under the methods used tends to result in the gradual accumulation of salt in the surface layers of the island soils. Direct rainfall, when of sufficient quantity, helps considerably in leaching out such accumulations. However, during periods of subnormal precipitation such as the last thirteen years, the leaching action of rainfall is greatly diminished. Thus far the problem has not reached serious proportions except in a few isolated instances. However, the evidence of actual accumulations is sufficiently clear to have brought it to the attention and serious consideration of many of the delta landowners. It is evident that measures should be taken before many years to eliminate these accumulations of salt which tend to gradually occur.

The evidence shows that the salt which has been accumulated in the surface layers of soils in the delta is chiefly the result of the methods used in irrigation involving the maintenance of high water tables for the growing of crops. Fresh water is especially important with this method of irrigation, as the use of water of greater salinity would tend to increase salt accumulations in the soil.

Protection of Delta from Saline Invasion.—The delta could be protected from saline invasion by a salt water barrier at some point below the confluence of the Sacramento and San Joaquin rivers; or, without a barrier, by stream flow. The detailed consideration of these two alternate methods of salinity control is presented in Chapter IV. With either method of control, adequate and dependable water supplies could be provided for the needs of the delta by furnishing additional supplies from mountain storage reservoirs to supplement the stream flow available to the delta under existing upstream irrigation and storage developments.

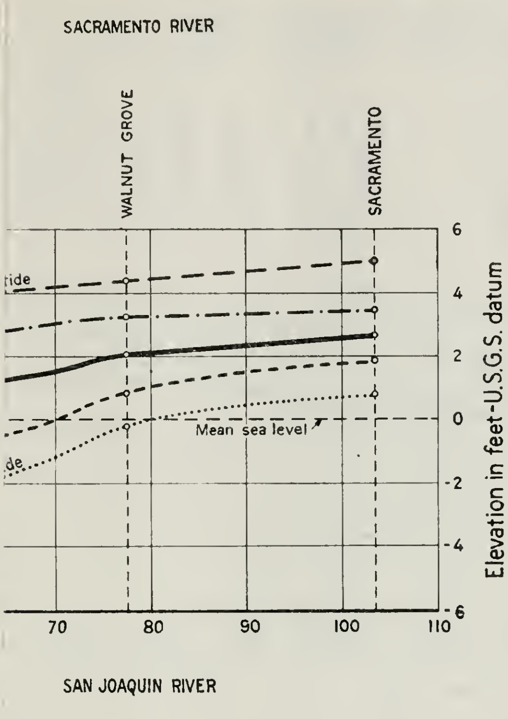
With the method of control by streamflow without a barrier, the present regimen of the delta channels and the operations in the delta would be unaffected. If salinity were controlled with a barrier, however, the physical conditions would be considerably altered, and hence consideration must be given to the effect such changes might have on the developments and operations in the delta. The principal change would be the elimination of tidal action and the maintenance of a fairly constant barrier-lake level in place of the present fluctuating level in the delta channels. Such a change would have some effect on operations in the delta, including irrigation, drainage and levee maintenance, and the costs of the same. The proposed level, which would be more or less continuously held in a barrier lake, is about three feet above mean sea level, or a higher level than the present average water level in most of the delta throughout a major portion of the year. The present average, maximum and minimum water levels in the delta channels during the period of low stream flow are graphically shown on Plate III, "Tidal Reference Planes in San Francisco Bay and Delta of Sacramento and San Joaquin Rivers."

Effect of Barrier on Irrigation in Delta.—The effect of a barrier upon irrigation operations and costs in the delta would be somewhat variable. For most of those portions of the delta where water is now diverted through siphons or gates, conditions probably would be equally satisfactory. In other portions of the delta, notably in the upper reaches of the San Joaquin River channels, where the present levels at high tide are above the level proposed in a barrier lake and permit of gravity diversions, it would be necessary to divert water by pumping. For these areas, cost of irrigation would be increased. For such delta lands as now are irrigated by pumping from adjacent channels, irrigation costs would tend to be decreased by reason of a higher average level and a resulting smaller pumping head. The studies indicate that the increased irrigation costs which would be entailed in some areas would probably be about balanced by the decreased cost which would be realized in other areas. In any case, the increase or decrease in cost would be relatively small and not important in this economic study.

Effect of Barrier on Drainage Operations in Delta.—In the matter of drainage cost, however, a constant barrier-lake level higher than the present average level in the delta would tend to increase drainage costs, both by reason of increased seepage and greater pumping head. This would be especially true for the islands in peat formation where there is apparently a considerable amount of seepage from the adjacent channels.

No exact information as to the quantity or rate of seepage into the islands is available as there is no method by which an exact measurement can be made of the same. It is possible, however, to obtain a fairly close approximation of the amount and rate of seepage on the basis of available records for three of the islands. On Staten Island, Jersey Island and District 999, data have been obtained upon which fairly accurate estimates have been made of the amount of water pumped from the island by the drainage pumps, the amount of water artificially diverted into the islands, and the amount of water added by rainfall. In addition to these records, an estimate has been made of the consumption of water by crops and vegetation. Records of this kind are available for Staten Island covering the period January, 1929, to June, 1930; for Jersey Island from June, 1929, to May, 1930; and for District 999 for the period May to October, 1927.

Over a long period of time it may be assumed that the total amount of water put into an island from all sources would be equal to the total amount of water taken out of the island by all agencies during the same period. This assumption would be exactly true if the average elevation of the water table at the beginning and end of the period considered were exactly the same. Unfortunately, no detailed records are available of the fluctuation of the ground water level in these islands, except for District 999. However, over the period of a year, it appears reasonable to assume that the average level of the water table at the beginning and end of the period would be practically the same. The total amount of water put into an island emanates from three sources, namely, rainfall, irrigation diversions, and seepage. The total amount of water taken out of the island consists of the water actually consumed by crops, vegetation and evaporation and the amount of water pumped by the drainage pumps. Actual records are available for estimating all of these quantities on these three islands, with the exception of seepage. On the assumption of a balance between the total amount of water put in and the total amount taken out, it has, therefore, been possible to finally make an estimate of the total amount of seepage into these islands for the period during which records were available. As a



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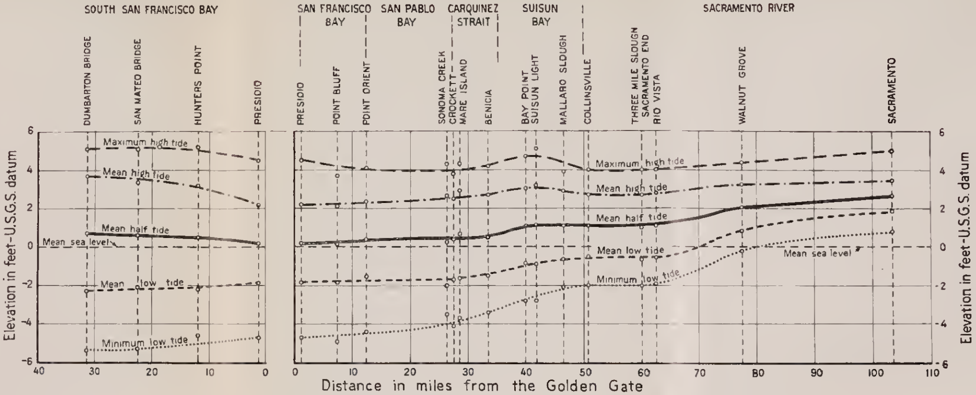
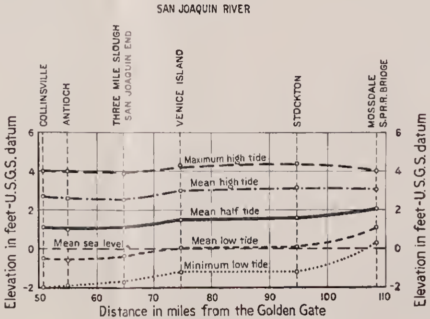
TIDAL REFERENCE PLANES
IN
SAN FRANCISCO BAY AND DELTA OF SACRAMENTO AND SAN JOAQUIN RIVERS





NOTE:
Compiled from automatic tide gage records obtained during 1929 and 1930. The tidal levels for the Sacramento and San Joaquin river channels are representative of low stream flow conditions in the summer and fall months.

TIDAL REFERENCE PLANES
IN
SAN FRANCISCO BAY AND DELTA OF SACRAMENTO AND SAN JOAQUIN RIVERS

result of these studies, the estimated amounts of seepage computed as an average rate during the period of record for the several islands are as follows:

Staten Island, 1929	0.135 acre-foot per acre per month
Jersey Island, June, 1929, to May, 1930	0.174 acre-foot per acre per month
District 999, lower unit, May to October, 1927	0.083 acre-foot per acre per month

In the computations from the records in District 999, a correction was made for the lowering of the ground water level during the six months' period. In the case of both Staten and Jersey islands, however, covering a full year's period, no correction was made for any difference in ground water level, it being assumed that the average ground water level was the same at the beginning and end of the yearly period considered. The estimated seepage rates for these three islands, while not to be considered exact, nevertheless are believed to be approximately correct. It is interesting to note that the computed figures indicate that the greatest average rate of seepage is on Jersey Island, which is probably representative of a typical peat soil formation, while on Staten Island, which is partly composed of peat and partly of silt, a smaller average rate of seepage is indicated; and that the average rate of seepage on District 999, which is probably typical of the delta islands of silt formation, is about half that for the typical peat formation as shown on Jersey Island.

If the water level in a barrier lake were held at a constant elevation higher than the average level under present conditions, it is evident that the rate of seepage into the islands would be increased. This is demonstrated not only by actual observations of increased seepage occurring during periods of high water in the delta, but also from the fundamental laws and experiments of hydraulics. The rate of seepage is a function of the differential head between the water level in the delta channels and the ground water level in the adjacent land area. Hydraulic experiments have shown that the rate of seepage flow through soil varies directly with the differential head. Thus, the seepage rate would be increased in the ratio of the differential head with the higher barrier-lake level to the average differential head now experienced.

In addition to the increase in seepage into the islands, a higher barrier-lake level would increase the pumping head through which all drainage water would have to be lifted. The actual cost of pumping operations, especially energy consumption, varies directly with the pumping head and hence the actual cost of drainage pumping would be increased in proportion to the increase in pumping head.

The total amount of drainage water pumped emanates from three sources, namely: rainfall, irrigation diversions, and seepage. The portion of the total quantity supplied from each of these three sources, which is not consumed by crops, vegetation and evaporation, must be pumped by the drainage pumps. It appears reasonable to assume that the relative amounts of water contributed from these three sources to the total amount of drainage water to be pumped out would be in about the same proportion as the ratio of the quantity from each source

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If the water level in a barrier lake were held at a constant elevation higher than the average level under present conditions, it is evident that the rate of seepage into the islands would be increased. This is demonstrated not only by actual observations of increased seepage occurring during periods of high water in the delta, but also from the fundamental laws and experiments of hydraulics. The rate of seepage is a function of the differential head between the water level in the delta channels and the ground water level in the adjacent land area. Hydraulic experiments have shown that the rate of seepage flow through soil varies directly with the differential head. Thus, the seepage rate would be increased in the ratio of the differential head with the higher barrier-lake level to the average differential head now experienced.

In addition to the increase in seepage into the islands, a higher barrier-lake level would increase the pumping head through which all drainage water would have to be lifted. The actual cost of pumping operations, especially energy consumption, varies directly with the pumping head and hence the actual cost of drainage pumping would be increased in proportion to the increase in pumping head.

The total amount of drainage water pumped emanates from three sources, namely: rainfall, irrigation diversions, and seepage. The portion of the total quantity supplied from each of these three sources, which is not consumed by crops, vegetation and evaporation, must be pumped by the drainage pumps. It appears reasonable to assume that the relative amounts of water contributed from these three sources to the total amount of drainage water to be pumped out would be in about the same proportion as the ratio of the quantity from each source of supply to the total quantity of water from all three sources. Based upon studies of the data available on Staten and Jersey islands, the estimates indicate that the total supply from seepage amounted to from 40 to 60 per cent of the total inflow during 1929 and 1930, the period of record studied. Therefore, for the purposes of this analysis, it has been assumed that, for the islands in peat or predominately peat formation, seepage water is responsible for about 50 per cent of the total drainage pumping and pump operating costs. This would apply to a large portion of the delta, comprising about 200,000 acres in the central portion of the area. It also is within this area that the higher water level in a barrier lake would exceed the present average level during a large portion of the year.

It has been pointed out previously that the rate of seepage into the areas of silt formation is considerably smaller than in the islands of peat formation. In addition to this fact, it has been observed that, for the islands of silt formation, there is usually little, if any, drainage pumping during a large part of the growing season. Drainage pumping operations are confined largely to the winter season during periods of heavy rainfall and minimum consumptive use. This condition is especially true in the portion of the delta along the upper Sacramento River, where operations are so conducted that the water supply diverted together with that from natural seepage, is usually just sufficient to take care of consumptive use. In the central portion of the delta, however, drainage pumps are operated throughout the year. The monthly amounts of drainage pumping are greater usually during the irrigation season than in any other part of the year because of the general practice of diverting water in amounts considerably in excess of consumptive requirements.

The area in the delta where drainage pumping operations would be affected by reason of increased amounts of seepage and increased pumping heads is therefore largely confined to the central portion of the delta wherein most of the peat or predominately peat islands lie and wherein a proposed barrier-lake level of three feet above mean sea level would exceed the average water level now experienced in this portion of the delta during a large part of the year. Within this area, information on the capital and annual cost of drainage pumping plants has been obtained for fourteen separate islands comprising a total area of about 52,000 acres. The drainage pumping plants on these tracts have an estimated capital investment of $207,000. The annual cost of drainage pumping, including interest at 6 per cent, depreciation on a 5 per cent sinking fund basis on an assumed life of 30 years, and actual records of operation and maintenance costs obtained from the owners, amounts to about $95,000 or about $1.85 per acre per year. Of this amount, the total annual cost for operation and maintenance alone, which chiefly comprises the cost of energy, amounts to about $80,000 or about $1.55 per acre per year. The portion of this total amount of pump operating costs ($1.55 per acre per year) which may be considered to be attributable to seepage water is about half the total or 80 cents per acre per year.

With a higher barrier-lake level than the average level now experienced, the quantity of seepage water would be increased in the ratio of the differential heads between the channel-water level, with and without a barrier, and the ground water level in the adjacent land area. At the same time this additional quantity of water would have to be pumped against a greater head than now experienced, the increased cost of which would be in direct proportion to the increased pumping head with a barrier lake. The present operating costs for pumping of seepage water, estimated at half of the total operating costs as above shown, therefore would be increased with a higher barrier-lake level in direct proportion to the ratio of the squares of the differential heads with a barrier lake and with the present average water level. The estimated cost of pumping seepage water alone with a higher barrier-lake level is expressed by the following formula:

Let C_b = Cost of pumping seepage water with a barrier lake
C_p = Present cost of pumping seepage water
H = Present average pumping head assumed as the difference in elevation in feet between the ground water surface and the channel water surface at mean half tide.
h = Additional pumping head with a barrier lake (equals the difference in elevation between a barrier-lake level and the elevation of mean half tide).

Then, $$C_b = C_p \left\{\frac{H + h}{H}\right\}^2$$

Finally, increased cost for pumping seepage water = $C_b - C_p$

In addition to the increased cost of pumping seepage water alone, the operating cost for pumping the drainage water from other sources, representing the remaining half of the total operating cost, also would be increased by reason of the greater pumping head. The amount of increase would be in direct proportion to the ratio of the pumping head with a barrier lake and the present average pumping head. Both of these increases in drainage pump operating costs would apply to that period of the year when a barrier-lake level would exceed the average level now experienced in the delta. During the winter season of large stream flow, present average levels would tend to approach the proposed barrier-lake level. It may be assumed that, under average conditions in the central portion of the delta wherein this study of increased drainage cost directly pertains, the increase in drainage cost would apply to a period of about nine months each year.

Based upon the above assumptions, an estimate has been made of the probable increased cost of drainage pumping operations in the delta which would result from the maintenance of a barrier-lake level of three feet above mean sea level. This estimate is confined to the central portion of the delta wherein the islands of peat or predominantly peat formation lie and wherein a barrier-lake level would be higher than the present average water level during the greater portion of the year, assumed at nine months for the purpose of the estimate. In arriving at the total estimated increased cost, consideration was given to the difference in seepage rates, as shown by the data available on two of the typical islands within this area, and also to the variable difference between the present average level in different portions of the area and a barrier-lake level. Based upon these considerations, it is estimated that the cost of drainage pumping operations in the delta with a barrier would be increased on the average about $100,000 annually.

Effect of Barrier on Levee Maintenance.—There is considerable uncertainty as to the effect of a constant barrier-lake level on the maintenance of levees in the delta. At present, the exposed sections of levees lying at right angles to the prevailing winds are subjected to serious erosion and damage due to wave action. Of perhaps greater importance, however, there also is a considerable erosion damage on exposed levee slopes due to the waves set up by passing boats. This latter is reported to be much more serious than is generally known or realized. It is stated by representatives in the delta, who are best qualified by knowledge of conditions in this region, that the erosion from waves of passing boats would be more serious, both as to magnitude and effect, if concentrated at a constant elevation of water instead of the fluctuating level as at present. The integrity of the levees in the delta must be constantly guarded and damages due to erosion must be repaired periodically in order to maintain their strength. The capital investment in levees in the delta is estimated at $27,000,000 and hence it is essential to protect this large investment from serious damage as far as possible.

Maintenance work to repair erosion damage caused by passing boats usually consists of removing the undercut portion of the levee cross section and placing the same, with additional new material, on the landward slope of the levee so as to once again provide a stable levee section and slope on the water side. Maintenance work of this kind is said to be necessary about once in twenty years. With a constant water level, it is estimated that this maintenance work would have to be done perhaps every ten to fifteen years. The cost of such maintenance work has been estimated from typical cross sections of eroded levees obtained for representative levee sections in the delta. The amount of earth work involved in removing the undercut portion of the levee cross section, providing a smooth slope on the water side, and reinforcing the levee on the landward side, is estimated at ten yards per foot of levee, with an estimated cost of $1.15 per foot or about $6,000 per mile. To supply the funds on a 5 per cent sinking fund basis to do this maintenance work once in 20 years would require an annuity of $181 per mile, while, for once in twelve and one-half years, an annuity of $357 per mile would be required. The annual cost of such maintenance work with a barrier would therefore be increased an indicated annual amount of $176 per mile.

The total number of miles of levee which would be affected under this consideration is uncertain. However, it appears probable that it would apply mostly to those levees which lie in the San Joaquin Delta and the lower Sacramento Delta. There is a total of about 1100 miles of levees in the entire delta. It is estimated that 700 miles of this total should be considered as being affected by increased rate of erosion requiring more frequent maintenance work by reason of a constant barrier-lake level. Based upon the foregoing assumptions, the increased annual cost of levee maintenance in the delta with a barrier is estimated at about $120,000.

Benefits of Protection from Saline Invasion.—The prevention of saline invasion into the delta either by means of a barrier or by stream flow without a barrier and the furnishing of dependable fresh-water supplies for irrigation in the delta channels would materially benefit the delta area. There would be no curtailment in irrigation supplies and hence there would be no diminution in crop yields such as may have occurred in certain years of the period 1920 to 1930. Of much greater importance, however, would be the benefits resulting from the removal of the menace of saline invasion, which now threatens the integrity of crop production and land values in the delta. If coupled with the furnishing of necessary supplies to take care of the full consumptive needs of the delta, the control of salinity would tend to increase land values in the delta and would eliminate the possibility of expensive water litigation as between the delta and up-river users. The value of these benefits might be estimated but such estimates would involve intangible and uncertain elements. However, it is evident that the beneficial results of whatever nature or value would be the same with either method of salinity control. Hence, no evaluation of these benefits has been made in the economic studies presented in Chapter IV.

Suisun and San Pablo Bay Marshlands.

Adjacent to Suisun and San Pablo bays there is a gross area of about 130,000 acres of marshlands which are partially farmed at present and which might be completely reclaimed ultimately and developed for agriculture. As shown on Plate II, these marsh areas are about equally divided between the two bays, 69,000 acres of the total lying in the Suisun Bay area and 61,000 acres in the San Pablo Bay area.

Information as to the natural conditions and original character of the marsh lands and the history of developments and activities thereon has been obtained mostly from old time residents of these areas, and is believed to be the most authentic information available. The data presented hereafter with reference to these matters is based upon this source of information, supplemented to some extent by information found in previous federal and state reports, early newspapers, and other publications.

Natural Conditions Prior to Reclamation.—In their original state of nature, these areas had the typical characteristics of salt or brackish water marshlands, consisting of islands separated by a network of tidal sloughs. Before reclamation, a large part of these lands were submerged by the high tides occurring each day. Limited areas of higher ground bordering the sloughs and along the exterior borders of the marsh area were submerged only by the occasional extremely high tides. During the winter season, however, when large floods occurred, most of the marshland area adjacent to both bays was submerged for considerable periods of time. The quality of the water in the sloughs of the marsh area varied considerably during different periods of the year. In the Suisun Bay area, the winter floods from the Sacramento and San Joaquin rivers and the adjacent local streams usually provided fresh water in the marsh channels for a considerable period of each year. During the period of low stream flow, however, saline water from the lower bay gradually replaced the fresh water in these channels, generally resulting in the presence of water of considerable salinity for a period of five to six months or more each year. The amount of salinity was not uniform throughout the entire marsh area, but was greatest in the channels downstream near the lower end of

Suisun Bay and gradually decreased to smaller amounts in the extreme upstream portion immediately below the confluence of the Sacramento and San Joaquin rivers. In the San Pablo marsh area conditions were similar. The flood waters of the Napa River and Sonoma and Petaluma creeks generally put fresh water in the sloughs and channels interspersing the marsh area during the winter. It is probable, however, that the water in the San Pablo marsh sloughs has always been of greater average salinity and has remained saline a longer period of time each year than commonly has been the case in the Suisun marsh area.

The old time residents of the marsh areas state that the original native vegetation on these lands consisted of various aquatic plants (tules, cat-tails, sedges and wire grass), salt grass, pickle weed, and some red top and clover on the high lands bordering the sloughs. The aquatic plants generally grew where water was normally present continuously, whereas the salt grass grew on the higher ground not usually flooded and the pickle weed in isolated pockets lacking drainage. Salt grass was the predominating growth over most of the marsh area. Before any reclamation occurred, these marshlands were used for pasturing beef and dairy cattle with generally satisfactory results. Their use for grazing was usually alternated with upland pastures. However, it was necessary each year to remove the stock during periods of high water when the marshlands were inundated. Frequently, delays in removal of the stock resulted in serious loss from drowning.

Reclamation Development.—No exact data are available as to the time when the first reclamation work was initiated on these marshlands. In the Suisun Bay area, the available information indicates that the earliest reclamation efforts were started subsequent to 1860. The "Arkansas Act" was passed by Congress on September 28, 1850, granting all swamp and overflow lands to the state. This was followed in 1855 by State legislation providing for the transfer of swamp lands to private individuals and, in 1861, by the first reclamation act of the State Legislature creating a board of swamp land commissioners. The first report of the Swamp Land Commission, made about six months after the passage of this act, listed some 28 districts formed under the act. Two of these, containing about 3000 acres, were in the Suisun marsh area. More than 20 districts, embracing practically all of the swamp lands east of Suisun and Goodyear sloughs on the north side of Suisun Bay, were formed during the period, 1860 to 1880. Following their formation, most of these districts completed a partial reclamation system, consisting largely of levees high enough to protect the lands from normal tidal inundation. A few districts have been formed in this locality during the last 20 years. At present, most of the reclamation districts are practically inactive or inoperative.

In the San Pablo Bay area, the first definite information as to the initiation of reclamation work appears to place the same about 1880. Most of the reclamation work in this area has been carried out by private individuals, with only a few swamp land or reclamation districts being formed. The earlier reclamations were made on the rim lands bordering the main marsh area. These were followed by construction of levees and reclamation works covering various island units.

The first reclamation works consisted of the so-called "China levees." These were small embankments built with Chinese labor by cutting out sections of the sod, approximately eighteen inches square and a foot thick, and piling them up to form an embankment, averaging three to five feet high and with a narrow top width and steep side slopes. It is reported that the contract price for these levees was \$1.12½ a rod. As the sod dried out an additional layer was placed and an effort made to cause the roots to unite the sod into a solid mass. When built of silt sod, the levees were tight and would withstand overtopping. When built of peat sod, considerable difficulty was experienced, due to shrinkage and cracking, resulting in leakage and frequent failures. To drain off seepage and water slopping over the top of the levees, simple wooden floodgates were provided in some of the sloughs that naturally drained the enclosed lands. These levees were built only slightly above the normal high tide level. The lands still were subjected to flooding during the river flood stage, but the embankments were quite successful in keeping out the high June tides, unless they were coincident with a strong southwest wind. Following this initial levee construction work, more effective utilization of the lands was made for cattle grazing by filling up the smaller sloughs with material borrowed from the higher ground adjoining. However, the larger sloughs were generally left open for drainage purposes. This improvement work resulted in the gradual replacement of aquatic vegetation with salt grass and some red top.

The earliest attempts to grow crops on the Suisun and San Pablo Bay marshlands were confined chiefly to the raising of hay and grain. Hay and grain were successfully raised on several of the reclaimed areas after leaching operations had effected a sufficient removal of the salt from the soil. This leaching was effected partly by utilization of direct rainfall which was allowed to accumulate on the land and, after standing a few days, drained off through flood gates; and partly by flooding the land with fresh water diverted when available from the adjacent channels. Early efforts in raising crops such as sugar beets, beans, and other field crops, are reported to have been largely unsuccessful. There are, however, certain isolated instances reported of potatoes and other crops grown on small areas in the Suisun Bay marshes. Winter Island, lying in the extreme upstream portion of the Suisun Bay area, is reported to have been farmed some 30 or 40 years ago. Much difficulty was encountered in maintaining levees against high river flood stages and June tides and this is reported to have been the chief reason for the abandonment of farming operations on this island. Similar difficulties in maintaining levees, resulting in the failure of efforts to produce crops, were encountered on Chipps and Van Sickle islands and other marshlands of peat formation. The information available indicates that the area cropped on the Suisun Bay marsh lands has always been relatively small and probably never much greater, if any, than the present cropped area. The principal utilization of these marshlands always has been for cattle and dairying.

Up to about 20 years ago the original "China" levees formed the only protection to these marshlands. Incidental maintenance work and necessary repairs were made from time to time but the construction of the present levee system is a development of the last 20 years. The original levees have been strengthened and raised by dredges to their present sections. This has been a more or less continuous process due to the fact that the levees continually settle on the soft marsh formations. Therefore it has been necessary to place the material in thin layers gradually building up the levees to grade and cross section over a considerable period of years.

As a matter of fact, settlement still continues in many sections of the levees and additional work will be required for a considerable period in the future. The present levees have an average height of five or six feet, a top width of six to eight feet and side slopes of about two or three to one. Except for very high tides, combined with strong southwest winds, or high river flood stages, the existing levees successfully protect the enclosed land. Within a few years from the time of construction, most of the levees are reported to silt up and compact to such an extent that the seepage through them is relatively small. The levees built in the sections of peat formation have always given trouble and require continuous maintenance even at present.

At present about 67 per cent of the marshlands adjacent to Suisun Bay and 76 per cent of those adjacent to San Pablo Bay are enclosed in levees. Table 20 shows the areas within and outside of levees in the two areas.

TABLE 20

LEVEED AND UNLEVEED MARSHLANDS ADJACENT TO SUISUN AND SAN PABLO BAYS

Location	Area of marshlands in acres			Leveed land in per cent of total
	Leveed	Unleveed	Total	
Suisun Bay				
North side	44,600	14,100	58,700	76
South side	1,900	8,300	10,200	19
Subtotal	46,500	22,400	68,900	67
San Pablo Bay				
North side	45,400	13,200	58,600	77
South side	500	1,700	2,200	23
Subtotal	45,900	14,900	60,800	76
Totals	92,400	37,300	129,700	71

As shown by Table 20, 71 per cent of the entire area of marshlands adjacent to both bays now is enclosed within levees. The chief development is for the areas lying north of both bays where the main bodies of marshlands lie. The marshlands along the south side of Suisun Bay and along the southerly or easterly side of San Pablo Bay comprise only a small area and have received very little attention from an agricultural standpoint and it appears probable that their future utilization will be largely devoted to industrial and commercial activities, and that little, if any, agricultural development will be made thereon. Considerations of future agricultural development of these upper bay marshlands may therefore be confined to the main marshland areas lying north of the two bays.

Character of Present Development and Operations.—Although a large portion of the marshlands are reclaimed to the extent of being enclosed within and protected by levees, the provision of drainage works and the improvement of the soil for the utilization of the lands for crop production is not only extremely variable but far from complete. In the Suisun Bay area, only 5000 acres, or 11 per cent of the land within levees, now are farmed. In the San Pablo Bay area a much larger percentage of the leveed land, amounting to 24,000 acres, or 52 per cent of the total within levees, now is farmed.

In the Suisun Bay area, most of the lands are poorly drained, with no adequate system of drainage ditches. Only a few drainage pumping plants are installed and drainage of the lands is effected for the most part by operation of tide gates, which allow the interior waters to drain out during periods of low tide only. Owing to the fact that most of the marshland lies at an elevation at or below mean tide level, the soil drainage is very imperfect as far as crop production is concerned. On lands farmed at present, drainage systems are in operation with fairly satisfactory results. In connection with two small areas devoted to crop production, tile drainage systems have been installed connecting with main open drains and drainage pumping plants. The tile used is four to six inches in diameter and spaced in lines 30 to 150 feet apart. Where the larger spacing is used the tile drains are usually supplemented with ''gopher hole'' drains made with a special subsoiler run at right angles to the tile drains and spaced at intervals of six to eight feet. The depth to tile drains averages four to five feet and the ''gopher hole'' drains are about one foot shallower. The cost of tile drainage is stated to be relatively high. The lands farmed in the San Pablo Bay area are generally provided with adequate open drains. Drainage is controlled mostly by tide gates, and only a few drainage pumps are operated.

A large part of the Suisun marsh area now is devoted to private duck preserves, which at present occupy about 28,000 acres, or 60 per cent of the total area within levees. Although the first private duck clubs in the Suisun area were started many years ago, their rapid development and expansion has occurred largely during the past ten to twenty years. Due to the splendid duck hunting in this area and its nearness to metropolitan centers, a situation has developed wherein the bulk of the Suisun marshlands now appear to be more valuable as duck hunting preserves than for any other purpose. Thus, a large portion of these leveed lands adjacent to Suisun Bay are operated primarily for duck hunting, supplemented in some cases by cattle grazing outside the duck hunting season. In the normal course of operations most of these duck preserves are flooded with water by means of floodgates in the month of August or September and remain flooded until the end of the duck hunting season and for a considerable period thereafter before they can be drained. The water which is used to flood these lands in the fall is usually rather heavily impregnated with salinity. Hence, this general practice of operation by the duck clubs probably has increased the saline content of the lands. In the San Pablo Bay area there has also been some development of duck preserves, about 4500 acres now being occupied for this purpose. The lands so occupied have gone back to their original salt marsh character and whatever improvements might have been made by previous leaching operations have been entirely lost.

The lands which have been cultivated and farmed continuously have also tended to become more saline due to the fact that the saline water is generally present in the adjacent channels during a large portion of the year, thus resulting in no fresh-water supply being available for a considerable period to freshen the ground water inside. Due to capillary action, there tends to be a gradual accumulation and increase of salinity in the surface layers of the soil. Rainfall is effective and is largely depended upon for leaching out the salts which tend to accumulate in the surface of the soils on which hay and grain are grown. It is reported that there appears to be an increase in salinity in these soils during recent years, probably due to deficient rainfall. In the uncultivated areas within levees, there also has tended to be a gradual increase in the saline content of the soil, as a result of the elimination of periodical floodings of the land with fresh water which occurred under natural conditions.

Present Crops and Vegetation.—A field survey has been made of the entire marshland area to classify the present natural vegetation and cultivated crops. The results of this survey are summarized in Table 21, and graphically shown on Plate IV, "Crops and Vegetation on Lands Adjacent to Suisun and San Pablo Bays." Only about 7 per cent of the total marsh area adjacent to Suisun Bay is cultivated and farmed, whereas about 40 per cent of the total adjacent to San Pablo Bay is at present under cultivation. By far the most important and extensive crop in both areas is grain and hay, three-fourths of the farmed area in Suisun Bay marshes and 98 per cent of that in San Pablo Bay marshes being devoted to this crop. The other crops cultivated are small in extent and economic importance. The asparagus culture in the Suisun Bay area, which comprises 500 acres on Grizzly Island, is a recent venture. The greater portion, consisting of a 400-acre tract, is just coming into bearing in the third year since planted and, while it appears to be growing with satisfactory results, the final success of the undertaking can not be predicted at this time. No expense has been spared in the development and preparation of this land, on which a complete tile drainage system, open drains, and drainage pumping plants have been installed. Beans and other crops grown in 1930 were only partially successful where the soil conditions were sufficiently favorable.

The native vegetation of pickle weed, salt grass, foxtail and various aquatic growths are of particular interest because of their consumptive use of water and also because they indicate, with a fair degree of accuracy, the character and quality of soil, especially in respect to salt content. It will be noted from the data shown in Table 21 that pickle weed comprises about one-quarter and one-third of the total area of native vegetation in the Suisun and San Pablo Bay marshes respectively; while salt grass comprises about three-eighths and one-eighth, respectively, of the total.

Soils.—The soils of the Suisun and San Pablo Bay marshlands consist of deposits of silt brought down by the rivers and adjacent local streams

PLATE IV

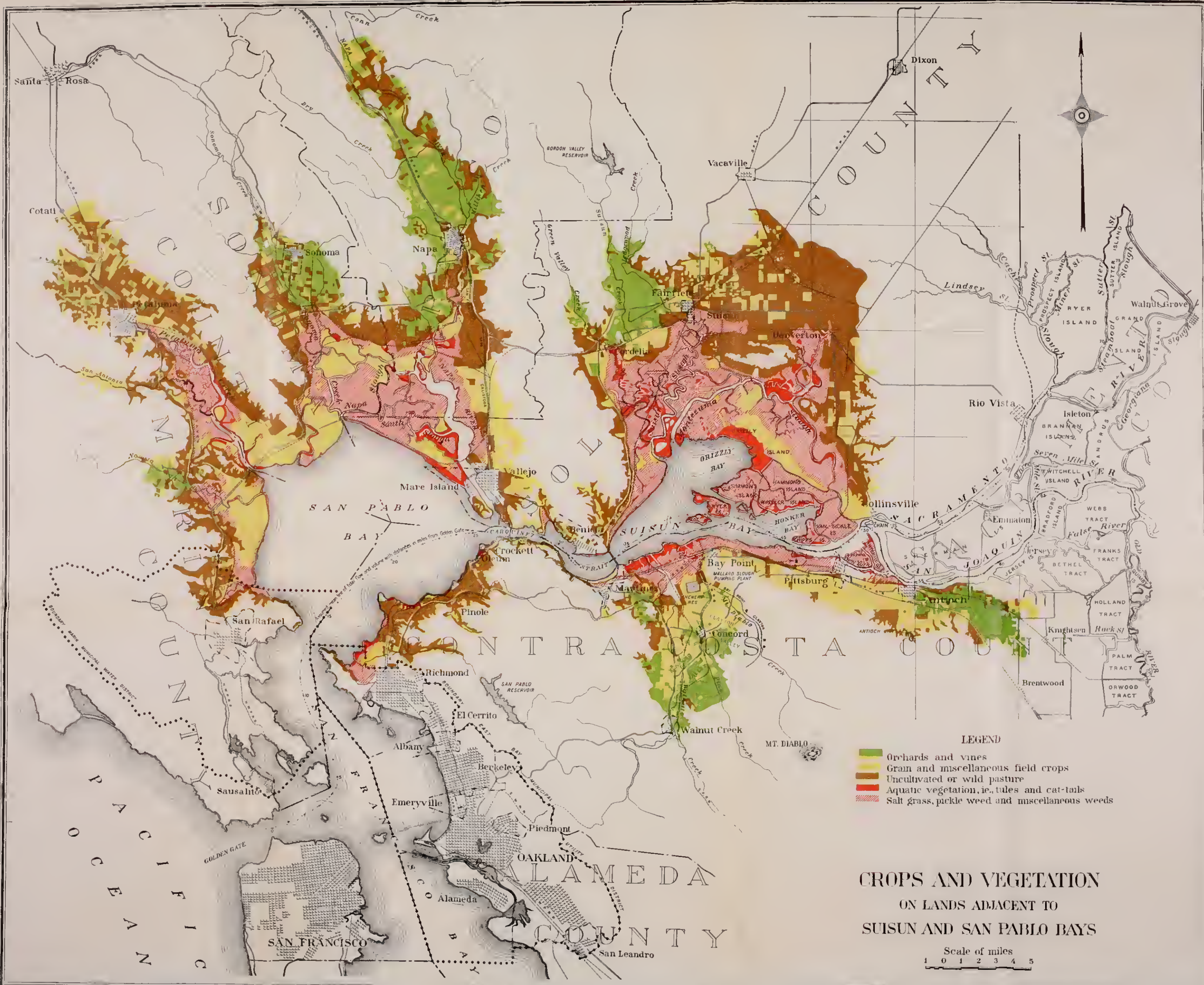
CROPS AND VEGETATION
ON LANDS ADJACENT TO
SUISUN AND SAN PABLO BAYS
Scale of miles
1 0 1 2 3 4 5
LEGEND
Orchards and vines
Grain and miscellaneous field crops
Uncultivated or wild pasture
Aquatic vegetation, ie., tules and cat-tails
Salt grass, pickle weed and miscellaneous weeds
Santa Rosa
Cotati
Sonoma
Napa
Vacaville
Dixon
Fairfield
Suisun
Denverton
Cordelia
Rio Vista
Isleton
Walnut Grove
Vallejo
Mare Island
Benicia
Crockett
Collinsville
Emmaton
Bay Point
Pittsburg
Antioch
Martinez
Concord
Pinole
San Rafael
Richmond
El Cerrito
Albany
Berkeley
Emeryville
Piedmont
OAKLAND
Alameda
San Leandro
Sausalito
SAN FRANCISCO
Walnut Creek
MT. DIABLO
Knightsen
Brentwood
SAN PABLO BAY
SUISUN BAY
GRIZZLY BAY
PACIFIC OCEAN
GOLDEN GATE
CONTRA COSTA COUNTY
ALAMEDA COUNTY
SOLANO COUNTY
SONOMA COUNTY
MARIN COUNTY
SACRAMENTO RIVER
SAN JOAQUIN RIVER
RYER ISLAND
GRAND ISLAND
TWITCHELL ISLAND
WEBB TRACT
FRANKS TRACT
BETHEL TRACT
HOLLAND TRACT
PALM TRACT
ORWOOD TRACT
HONKER BAY
SAN PABLO RESERVOIR
GORDON VALLEY RESERVOIR

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TABLE 21

PRESENT CROPS AND NATURAL VEGETATION ON SUISUN AND SAN PABLO BAY MARSHLANDS

(From survey of August, 1930)

Classification	Suisun Bay						San Pablo Bay						Combined Suisun and San Pablo bays	
	North side		South side		Combined north and south sides		North side		South side		Combined north and south sides			
	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total
Cultivated crops														
Grain and grain hay	3,680	6	40	0	3,720	5	23,780	41	130	6	23,910	40	27,630	22
Blue grass	560	1	-----	0	560	1	-----	0	-----	0	-----	0	560	0
Alfalfa	10	0	-----	0	10	0	-----	0	-----	0	-----	0	10	0
Asparagus	500	1	-----	0	500	1	-----	0	-----	0	-----	0	500	0
Corn	-----	0	-----	0	-----	0	30	0	180	8	210	0	210	0
Truck and field crops[1]	210	0	-----	0	210	0	30	0	110	5	140	0	350	0
Subtotal	4,960	8	40	0	5,000	7	23,840	41	420	19	24,260	40	29,260	22
Native vegetation														
Salt grass	19,600	33	2,970	29	22,570	33	4,130	7	180	8	4,310	7	26,880	21
Pickle weed	11,180	19	3,200	31	14,380	21	10,120	17	1,090	50	11,210	19	25,590	20
Aquatic growths (tules, sedges, wire grass, etc.)	14,500	25	2,700	26	17,200	25	5,720	10	380	17	6,100	10	23,300	18
Foxtail	3,250	6	180	2	3,430	5	8,580	15	-----	0	8,580	14	12,010	9
Wild oats	720	1	50	1	770	1	2,670	4	-----	0	2,670	4	3,440	3
Miscellaneous	660	1	110	1	770	1	940	2	-----	0	940	2	1,710	1
Subtotal	49,910	85	9,210	90	59,120	86	32,160	55	1,650	75	33,810	56	92,930	72
No vegetation														
Water surface (drains, pools, etc.)	2,380	4	160	2	2,540	4	1,400	2	90	4	1,490	2	4,030	3
Roads and bare land, levees and mud flats	1,450	3	790	8	2,240	3	1,200	2	40	2	1,240	2	3,480	3
Subtotal	3,830	7	950	10	4,780	7	2,600	4	130	6	2,730	4	7,510	6
Totals	58,700	100	10,200	100	68,900	100	58,600	100	2,200	100	60,800	100	129,700	100

[1] Includes all crops for human consumption, such as tomatoes, beans, cabbage, beets, onions and celery.

TABLE 21

PRESENT CROPS AND NATURAL VEGETATION ON SUISUN AND SAN PABLO BAY MARSHLANDS

(From survey of August, 1930)

Classification	Suisun Bay						San Pablo Bay						Combined Suisun and San Pablo bays	
	North side		South side		Combined north and south sides		North side		South side		Combined north and south sides			
	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total
Cultivated crops														
Grain and grain hay	3,680	6	40	0	3,720	5	23,780	41	130	6	23,910	40	27,630	22
Blue grass	560	1		0	560	1		0		0		0	560	0
Alfalfa	10	0		0	10	0		0		0		0	10	0
Asparagus	500	1		0	500	1		0		0		0	500	0
Corn		0		0		0	30	0	180	8	210	0	210	0
Truck and field crops[1]	210	0		0	210	0	30	0	110	5	140	0	350	0
Subtotal	4,960	8	40	0	5,000	7	23,840	41	420	19	24,260	40	29,260	22
Native vegetation														
Salt grass	19,600	33	2,970	29	22,570	33	4,130	7	180	8	4,310	7	26,880	21
Pickle weed	11,180	19	3,200	31	14,380	21	10,120	17	1,090	50	11,210	19	25,590	20
Aquatic growths (tules, sedges, wire grass, etc.)	14,500	25	2,700	26	17,200	25	5,720	10	380	17	6,100	10	23,300	18
Foxtail	3,250	6	180	2	3,430	5	8,580	15		0	8,580	14	12,010	9
Wild oats	720	1	50	1	770	1	2,670	4		0	2,670	4	3,440	3
Miscellaneous	660	1	110	1	770	1	940	2		0	940	2	1,710	1
Subtotal	49,910	85	9,210	90	59,120	86	32,160	55	1,650	75	33,810	56	92,930	72
No vegetation														
Water surface (drains, pools, etc.)	2,380	4	160	2	2,540	4	1,490	2	90	4	1,490	2	4,030	3
Roads and bare land, levees and mud flats	1,450	3	790	8	2,240	3	1,200	2	40	2	1,240	2	3,480	3
Subtotal	3,830	7	950	10	4,780	7	2,600	4	130	6	2,730	4	7,510	6
Totals	58,700	100	10,200	100	68,900	100	58,600	100	2,200	100	60,800	100	129,700	100

[1] Includes all crops for human consumption, such as tomatoes, beans, cabbage, beets, onions and celery.

intermixed with variable amounts of accumulated decayed vegetation. The Bureau of Chemistry and Soils of the United States Department of Agriculture, in cooperation with the Division of Soil Technology of the University of California, has recently completed a field soil survey of the marshland area on the north side of Suisun Bay and the portion of the marshlands north of San Pablo Bay within Solano County. The results of this survey are as yet unpublished but preliminary information has been obtained for the purpose of this investigation. In the Suisun marsh area, about 25,000 acres have been fully classified. The balance, or somewhat more than half, has not as yet been classified in detail and has been designated preliminarily as "undifferentiated marshlands." The detailed survey covered all of Grizzly Island and most of the marshland to the south and east thereof. The "undifferentiated marshlands" include the area north and west of Grizzly Island, the westerly part of Wheeler Island, and Roe, Ryer, Simmons, Freeman, Dutton and Snag islands. Independent observations and comparisons, however, indicate that the soils in this latter area comprise the same types as found in the area classified in detail.

There are three main soil types classified by the soil survey: namely, Ryde clay loam, muck and peat, and Ryer silt loam. The names "Ryde" and "Ryer" are provisional. The "Ryde" will probably be correlated with the "Sacramento" series of soils and the "Ryer" with the "Columbia" series of soils. In addition, there is a recently filled-in area of about 1700 acres in the northeastern part of Grizzly Bay that is as yet unreclaimed and which has been classified as tidal marsh. The three principal types of soil are described as follows:

"Ryde Clay Loam" has a light grayish brown or brownish gray surface soil eighteen to twenty-four inches in depth. It is friable, easily handled, tillable, noncalcareous, has a good water-holding capacity, and is moderately well supplied with organic matter. The subsoil is stratified with alternate layers of peat and sediment. The same type of soil, in a slightly different phase, occurs on Ryer, Grand and Sutter islands in the Sacramento River Delta, particularly in the interior of the islands. About 60 per cent of all the Suisun marshlands and most of the San Pablo marshlands evidently come under this classification. This type of soil occurs along the slough banks and extends out therefrom for appreciable distances. It was upon this soil that the redtop and clover were reported as growing up to about ten to twenty years ago.

"Muck and peat" has a surface layer about 24 to 36 inches deep, is dark brown in color, fibrous and spongy and contains no great amount of mineral matter. Underlying the surface soil is decomposed organic matter, which is finely divided and described as muck. This soil has enough mineral matter in it to be satisfactory for crops and has a very high water-holding capacity. It occurs largely in the interior of the islands, away from the slough banks, and makes up about one-third of the total Suisun marsh area. Only small areas exist between the Napa River and Sonoma Creek in the San Pablo Bay area.

"Ryer silt loam," covering less than 5 per cent of the Suisun marsh area, occurs in a strip from half a mile to a mile wide along the southerly side of Grizzly Island and in a narrow strip extending westerly from Collinsville for about two miles. It is very similar to a soil found on Ryer, Grand and Sutter islands in the Sacramento River Delta. The soil is of a light brown or light yellowish brown color, is friable, has a good water-holding capacity, and has only a moderate content of organic matter in the top soil. The subsoil is about the same in color, but mottled because of poor drainage. The soil is noncalcareous, has a rather uniform texture throughout the top six feet and is apparently a rather new soil. The portion near Collinsville is used at present for raising a mixture of blue grass and oats for feed, while that on Grizzly Island is planted to barley, except for about 300 acres in asparagus and beans.

Alkali Content of Soils.—Neither the present soil survey nor previous ones have included field determinations of alkali or salt content. Therefore, the quality of the soils, as regards alkali or salt content, must be based upon the visible evidence from inspection of the lands, together with the indications of native vegetation and the results of farming operations. An examination and estimate of alkali or saline conditions have been made by representatives of the state and the soil experts of the United States Bureau of Chemistry and Soils and the University of California. Over considerable areas, evidence of the presence of salts in the soil is clearly visible on the ground surface. For the uncultivated areas, the native vegetation forms the best index of the presence and amount of alkali or salt.

At present the uncultivated marshland area is largely covered with salt grass and pickle weed. The amount of alkali salts indicated by salt grass and pickle weed is somewhat uncertain, because of variable conditions of soil and soil moisture. Extensive investigations by the United States Department of Agriculture and experiment stations of various states have been made in the arid-west region, including California, to determine the indicator value of these plants as to presence and amount of alkali. The published results of these investigations in many reports have been used as authority for the following data on alkali content indicated by these plants, and the tolerance of various crops to alkali. General statements to follow are based upon the average chemical character of the so-called "white alkali" salts. The so-called "black alkali," which, unlike the white alkali salts, is chemically alkaline in reaction and of corrosive character, is generally absent or occurs only locally as traces in this region.

Salt grass and pickle weed are two of the most salt resistant plants which will grow with a high water table. Of the two, pickle weed grows in the presence of greater concentrations of salt, usually with not less than two per cent and frequently with four per cent or more, expressed in terms of dry weight of soil. Salt grass will grow on lands containing salt concentrations from as low as 0.2 per cent to as high as two per cent or more, and hence is not as valuable as pickle weed as a quantitative index of salt content. It is believed, however, that presence of salt grass will usually indicate an alkali content averaging one per cent or more. The presence of the various aquatic plants such as tules, cat-tails and sedges, found by actual observation along the borders of the sloughs and channels of both the Suisun and San Pablo Bay marshes, indicates that these plants will stand a considerable range of salinity without appreciable effect. However, at present, tules and cat-tails predominate in the Suisun Bay area, while sedges predominate in the San Pablo Bay area. Inasmuch as the average saline content and period of salinity are greater in the San Pablo marsh channels than in the Suisun marsh channels, it may be concluded that the tules and cat-tails indicate fresher water conditions than the sedges. Foxtail and similar grasses will grow under salt concentrations of 0.6 to 0.8 per cent.

On the uncultivated marshlands of both the Suisun and San Pablo Bay areas, pickle weed and salt grass occur mixed in various proportions all the way from a pure stand of one to a pure stand of the other. Quite frequently the pure stands of pickle weed are found growing in clumps several feet in diameter with bare ground in between which was apparently too strongly impregnated with salt for even pickle weed to get started. These bare spots often clearly show white crystalline deposits of salt on the surface. Based upon this evidence of present natural vegetation, it may be reasonably concluded that the salt content of the soil in the upper few feet of depth will probably average about two per cent.

Tolerance of Crops to Alkali.—The alkali or salt content of a soil which prevents successful growing of various crops is generally expressed on the basis of the percentage of salts to the dry weight of soil. However, inasmuch as the amount of soil moisture and hence the strength of the saline solution has a wide range, the effect of given amounts of alkali is subject to considerable variation. The more moisture in the soil, the lower will be the concentration of alkali in the soil moisture, and the less harm will the alkali do. Sandy soils hold much less water for any particular depth than loam or clay soils and hence a given percentage of alkali in terms of dry weight of soil will produce a much more concentrated saline solution. A large amount of organic matter such as is contained in a peat soil greatly reduces the harmful effects of alkali. In setting up the limits of tolerance of various crops to alkali, it is generally assumed that the soil contains a degree of moisture favorable for the growth of the particular crops. The normal limits of alkali tolerance also generally refer to the more common types of soil encountered of a loam or clay loam nature.

The limiting amounts of alkali which crops can resist generally apply to maturing crops. For germination and growth during the seedling stage the limits will in many cases be considerably lower than those commonly stated. The limiting amounts of alkali which crops will stand also depends upon the kind of alkali salt present. Crops will generally tolerate a greater amount of the sulphates than chlorides, whereas the presence of black alkali (sodium carbonate) will prevent growth of practically all crops. If the alkali is largely concentrated in the surface of the soil, the limiting amount which a given crop can resist will be lower, especially at the time of seeding. In the following data on limiting amounts of white alkali salts under which various crops can be successfully grown, the amount of alkali is expressed in terms of percentage of dry weight of soil within the depth penetrated by the plant roots. The data have been taken from the published reports of the investigations of the United States Department of Agriculture and various state experiment stations previously referred to.

Where the surface foot of a soil contains an alkali content of 0.2 to 0.5 per cent, the soil is usually considered unfit for the cultivation of most crops. However, the toxicity of alkali to various crops varies considerably. Crops such as oat hay, grain, barley and asparagus successfully withstand alkali concentrations of from 0.4 to 0.6 per cent, and barley hay 0.6 to 0.8 per cent. These are the crops that have been grown most successfully in the marshland areas adjacent to both bays. The areas which are now farmed to these crops may be assumed to have an alkali content in the top soil of as much as 0.5 to 0.6 per cent on the average. The present freedom of these particular areas now farmed from a harmful degree of salt content has been effected by continuous farming operations, utilizing the leaching action of direct rainfall and inundations of fresh water when present in the adjacent channels to carry off the accumulations of salt which naturally tend to occur in the soils. Efficient drainage works are an essential feature to the success of present farming operations.

Possible Future Development of Marshlands.—If the marshlands of Suisun and San Pablo bays are to be developed and utilized for general agricultural purposes, extensive improvements in drainage and reclamation works and much development work would be required. The present soil conditions, as previously described, are characterized by heavy concentrations of alkali salts, which must be removed at least from the upper three feet or more of the soil before crops of all kinds can be grown successfully. It is possible that this could be accomplished over a considerable period of development by means of adequate works, but the expenditures required would be large.

In order to successfully accomplish the leaching out of salts from these soils, a thorough and complete drainage system is essential. As a second essential, ample quantities of fresh water must be available at all times. These fresh-water supplies must be applied to the surface of the land, allowed to percolate through the soil, and immediately carried away by adequate drains. It is only by this process that the salts can be gradually leached out so that the soil may become suitable for general crop production. Inasmuch as these lands all lie at a low elevation with respect to the water levels in the adjacent channels, adequate drainage pumping plants, which could be operated continuously, if necessary, also would be essential. During the period required to completely leach out the salts, it probably would be possible to successfully grow certain crops, such as hay, which would assist in carrying the expense of development. Thus, if these essential elements for the successful development of these lands were provided, it is probable that the bulk of the marshlands of both Suisun and San Pablo bays could be put into condition for general crop production. However, there are probably some areas in which the saline content of the soil is so heavy that leaching operations would prove unsuccessful.

In addition to the drainage systems required and the development operations of leaching out the soils, the complete reclamation of these lands also would involve ultimately substantial improvements in the present levee systems, which would have to be strengthened and enlarged to protect the lands from the highest floods and tidal waters, or combinations thereof, likely to occur.

When the demand arises for the complete development and utilization of these marshlands for agricultural purposes, consideration must be given to the best means of accomplishing their successful development and especially as to the best means of providing these lands with adequate and dependable fresh-water supplies, which would be essential. The creation of a fresh-water lake by construction of a barrier at some site below these marshlands would result in placing fresh water in the channels and bays interspersing and surrounding these lands. If necessary supplemental water supplies were furnished from mountain storage to take care of all the consumptive demands from a barrier lake, including those of the marshlands, the water requirements of the marshlands would be conveniently served by this means. However, a constant barrier-lake level held at about three feet above mean sea level would offer an unfavorable element for drainage and leaching operations. This constant level at a considerably higher elevation than the present average tide level would tend to increase seepage into the islands, increase the pumping head for all drainage water to be pumped, and thus increase the cost and difficulties of drainage operations.

The present range of water levels in Suisun and San Pablo bays is shown on Plate III. It will be noted that the mean tide level ranges from about 0.5 foot in San Pablo Bay to 1.0 foot in Suisun Bay above mean sea level, while mean low tide is 2 to 2.5 feet lower. Thus, under present tidal conditions over a large part of the year and during a considerable portion of each day, the water level surrounding these marshlands is at or below the elevation of the lands themselves. These conditions and the occurrence of the low low tides each day, which drop to an elevation of two and one-half to four feet below mean sea level, afford the present possibilities of draining these lands by gravity through the operation of automatic tide gates. The maintenance of a high barrier-lake level, about three feet above mean sea level, which is desirable and necessary to accomplish more important functions of a barrier, would be a detriment to the marshlands due to its increasing the difficulties and expense of drainage. Therefore, from the standpoint of the marshlands it would be much more satisfactory if a plan could be devised which would not raise the surrounding water level, but, if possible, would lower the level so that drainage operations would be simplified and costs reduced.

If fresh-water supplies were to be furnished these marshlands in both Suisun and San Pablo bays directly from a barrier lake, it would be necessary to construct a barrier at some point below San Pablo Bay such as at the Point San Pablo site. A barrier constructed at an intermediate site such as Dillon Point would afford fresh-water supplies for the Suisun Bay marshlands, but would not furnish a direct supply to the San Pablo Bay marshlands. Thus, with a barrier at an intermediate site, the San Pablo Bay marshlands could only be supplied with fresh water by conveying the same from a barrier lake through conduits. If a barrier were constructed at an upper site, such as at Chipps Island, conduits would be required to furnish water to both of these marsh areas. This would be physically feasible of accomplishment.

The marshlands of both Suisun and San Pablo bays could be furnished with ample and dependable fresh-water supplies without the construction of a barrier. As will be described in more detail in Chapter IV, necessary fresh-water supplies could be conveyed through conduits from the controlled fresh-water channels of the delta and the water demands taken care of equally as well as from a barrier lake.

A plan of development for these marshlands, which appears to have many advantages, would be the leveeing-off of the entire area of marshlands adjacent to each bay with master levee systems. Development within these master levees could be carried out in several different ways. It could be accomplished either in units or with a comprehensive unified scheme to take care of the entire marsh area. The natural channels could be used for the combined purposes of distributing irrigation supplies and receiving and carrying off the drainage water from the islands; or separate conduit systems could be provided for irrigation supplies and the present channels utilized only for receiving and carrying off drainage water. Drainage pumping systems could be provided for separate units in each marsh area, or it would be possible to provide large central drainage pumping plants to take care of larger units. The latter would have the advantage of greater efficiency and smaller operating expense per unit of area served. A unified plan of development with master levee systems for the marshlands of each bay would attain the great advantage of a considerably smaller length of protective levee to construct and maintain. Moreover, regardless of the variations in the detail character of development inside these master levees, the plan would have the added advantage of making possible the holding of a water level in the interior channels at an elevation considerably lower than a barrier-lake level. The water level could be held at an elevation most desirable, both from the standpoint of drainage and irrigation. All operating conditions, both as to irrigation and drainage, would be under control and would be much more flexible, and therefore of considerably greater advantage, than the conditions which would be obtained either with a barrier lake or present fluctuating tidal conditions.

If it should prove undesirable or impractical to carry out plans of unified development involving chiefly the master levees to cut off the entire marsh areas from the bay, it would be possible to carry out a development of these marshlands in smaller units and furnish them fresh-water supplies required, without the construction of a barrier. The plan of development would be similar in character to that of a unified plan. The main difference would be that the natural channels could be used only as drainage outlets and the water levels in the same would be subject to tidal fluctuation as at present; and the necessary fresh-water supplies would be brought to the various units by separate conduits.

From the above considerations it is evident that a barrier is not essential to the feasibility of fully reclaiming and developing the marshlands of Suisun and San Pablo bays. When the demand arises for their complete development and utilization for agricultural purposes, the furnishing of fresh-water supplies and the additional works and operations necessary for improvement of the soil could be provided without a barrier. The comparative merits and costs of alternate plans, with and without a barrier, for serving and developing these marshlands will be discussed in Chapter IV.

Regardless of the means by which water supplies may be furnished to these marshlands, either with or without the assistance of a barrier, the operations, facilities and expenditures required to improve these lands and make them suitable for general crop production would be practically the same. The principal cost would be the removal of alkali salts from the soil, requiring the installation of expensive drainage systems and large operating costs. Moreover, their complete reclamation would involve the construction of levees of ample height and cross section to protect the lands from the highest flood stages likely to occur, and the cost would be the same with and without a barrier. Furthermore, it appears that the most advantageous plan of development, either with or without a barrier, would include the construction of a master levee system, which would protect and cut off the marshland areas from the main bay waters and thus provide more flexible and advantageous conditions for the reclamation of the lands inside.

It is believed that the demand for the development and utilization of these marshlands for agricultural purposes may be considered to be postponed to some future time when conditions justify the costs of development. Preliminary estimates of cost of physical works alone required for complete reclamation show that the cost per acre probably would exceed the present average market value of fully improved and cultivated lands in the Sacramento-San Joaquin Delta. Moreover, at the present time, there are some million acres of good agricultural land in the Sacramento and San Joaquin valleys, served with a water supply and ready to be farmed, which can be obtained at a price much smaller than the cost of developing and improving these marshlands. Therefore, it appears evident that large expenditures for the development of these marshlands to agriculture would not be economically justified at present.

Uplands Adjacent to Suisun and San Pablo Bays.

The uplands adjacent to Suisun and San Pablo bays comprise what may be considered chiefly an agricultural area, both as to present and future potential development. Within this area are splendid farming lands, a large portion of which are already devoted to intensive crop production of considerable economic value. The more important present agricultural developments and better lands are located in the several valleys which lie within this upland area. These major valleys include Ygnacio and Clayton valleys in Contra Costa County, Suisun and Green valleys in Solano County, Napa Valley in Napa County, Sonoma and Petaluma Creek valleys in Sonoma County, and Novato Valley in Marin County. In addition to these valley lands, there are also some foothill areas having excellent soils for crop production. Some of these areas are at present farmed mostly to grain. The orchard and vineyard development in the area south of the San Joaquin River from Antioch to Knightsen is included with the upper bay uplands because it naturally would be served from the same general source of water supply.

The present investigation has included a field survey of the larger portion of these adjacent uplands, including the entire area from the limits of the marsh, or approximately mean sea level, up to an elevation of 150 feet above mean sea level, which at present may be considered to be the upper limit of economical pumping lifts for the irrigation of the upper bay lands from the lower Sacramento or San Joaquin rivers or upper bay channels. This field survey has included the classification of lands as to quality of soil and adaptability to irrigation, classification of crops and vegetation, and the gathering of available information as to extent of present irrigation, irrigation works and operations, available local water supplies and the desirability and necessity of additional water supplies for irrigation both for present and ultimate development. Information was obtained from representative land owners, county officials and farm organizations in each area to supplement the information obtained from the direct field survey, which embraced a total gross area of 246,200 acres.

Quality of Lands.—The lands embraced in the upland area were classified on a similar basis to that used in the Sacramento and San Joaquin valleys. The standards of land classification used were as follows:

Class 1. Lands where the soil texture, alkali or topography do not limit the feasibility of irrigation or crop yield. Lands capable of good yield at reasonable cost of preparation.

Class 2. Lands of medium ability to carry irrigation costs because of hardpan, roughness, alkali, deficient soil texture, and other detrimental factors.

Class 3. Lands which by present standards do not justify irrigation with regulated supplies, but which may eventually come into Class 2 with improvements in methods of alkali removal or reduction in cost of preparation.

Class 4. Lands suitable only for pasture and of too poor quality for the usual crops.

Supplementing this direct field classification in accordance with the above schedule, the results, as yet unpublished, of a recently completed soil survey by the United States Bureau of Chemistry and Soils and the published soil survey reports of the upper San Francisco Bay region by the same authority were used in making up the final classification of the quality of lands within this area.

Based upon this survey and supplemental information from soil surveys, the agricultural lands were classified in accordance with the above schedule and the urban and industrial areas were also determined. These are summarized in Table 22.

The total gross upland area comprises 117,800 acres adjacent to Suisun Bay and 128,400 acres adjacent to San Pablo Bay, or a total area below the 150-foot contour of 246,200 acres. Of this total about 115,000 acres, or 47 per cent, are classified as Class 1 land adapted to general crop production and warranting the expense of irrigation at some time for more intensive and profitable culture. Class 2 lands comprise an area of about 75,000 acres, or 30 per cent of the total. Most of these lands may be considered as suitable for general crop production, but somewhat limited, because of one or more unfavorable elements, in character and amount of crop production and ability to stand the expense of irrigation supplies. The ultimate intensive development of the agricultural uplands probably would result in a demand for the irrigation of most of the Class 1 and 2 lands, or over 75 per cent of the total area, if their fullest possible utilization is to be obtained. The remaining areas, classified as 3 and 4, doubtless would continue to be utilized as at present for pasture and some dry farming of grain and hay. The urban and industrial area amounts to 6400 acres in the Suisun Bay region and 5900 acres in the San Pablo Bay region, or a total of 12,300 acres.

TABLE 22

CLASSIFICATION OF UPLANDS ADJACENT TO SUISUN AND SAN PABLO BAYS

Location	Agricultural lands								Industrial and urban lands		Total area, in acres
	Class 1		Class 2		Class 3		Class 4				
	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	
Suisun Bay											
Knightsen to Antioch	7,960	76	1,840	17	200	2	0	0	500	5	10,500
Antioch to Bay Point	5,080	45	4,120	36	0	0	0	0	2,200	19	11,400
Ygnacio and Clayton valleys	16,550	67	5,000	20	0	0	450	2	2,600	11	24,600
Martinez to Dillon Point	50	12	50	13	60	15	140	35	100	25	400
Collinsville to Denverton	2,910	25	4,720	41	3,870	34	0	0	0	0	11,500
Denverton to Suisun	3,490	10	17,120	49	13,680	39	310	1	200	1	34,800
Suisun to Cordelia	10,860	57	4,660	24	3,320	17	260	1	100	1	19,200
Cordelia to Dillon Point	790	15	530	10	3,380	62	0	0	700	13	5,400
Subtotal	47,690	41	38,040	32	24,510	21	1,160	1	6,400	5	117,800
San Pablo Bay											
Dillon Point to Napa Valley	7,890	45	4,960	29	3,110	18	40	0	1,400	8	17,400
Napa Valley	20,080	66	8,710	29	510	2	0	0	900	3	30,200
Napa Valley to Sonoma Valley	2,190	25	6,510	75	0	0	0	0	0	0	8,700
Sonoma Valley	13,930	84	550	3	1,120	7	0	0	1,000	6	16,600
Sonoma Valley to Petaluma Valley	1,540	27	760	14	3,070	55	230	4	0	0	5,600
Petaluma Valley	11,190	51	8,760	40	950	4	0	0	1,100	5	22,000
Petaluma Valley to Novato Valley	2,840	49	1,160	20	410	7	1,390	24	0	0	5,800
Novato Valley	1,560	33	1,160	25	130	3	1,750	37	100	2	4,700
Novato Valley to San Rafael	3,040	45	960	14	920	14	1,780	27	0	0	6,700
Richmond to Dillon Point	2,640	25	3,240	30	3,120	29	300	3	1,400	13	10,700
Subtotal	66,900	52	36,770	29	13,340	10	5,490	4	5,900	5	128,400
Totals, upper San Francisco Bay	114,590	47	74,810	30	37,850	15	6,650	3	12,300	5	246,200

Present Crops.—A large variety of crops are raised in the upper bay uplands. Of these, by far the most important and valuable are the extensive orchards and vineyards, which comprise some of the best in the State as to yield, value and quality of production. The results of the survey of present crops within the area are summarized in Table 23, and their extent and location are shown on Plate IV.

The importance of the orchard and vineyard development in the upper bay uplands is at once evident from the figures shown in Table 23, and an inspection of Plate IV. The total area of deciduous orchards amounts to over 40,000 acres, while vineyards comprise an area of over 10,000 acres additional. Thus, over 50,000 acres, or 20 per cent of the entire upland area, now is devoted to orchard and vineyard culture. These developments are mainly located in the more fertile valleys, including Ygnacio, Clayton, Suisun, Green, Napa, Sonoma and Novato valleys, and in the area south of the San Joaquin River between Antioch and Knightsen. In Suisun Valley, the more important orchards include apricots, cherries, prunes and pears. In Napa and Sonoma valleys, apples, prunes, cherries, peaches and pears are the chief orchard crops. In Ygnacio and Clayton valleys, walnuts predominate, while in the Antioch-Knightsen area, almonds and various deciduous fruits are grown.

Grain and hay have an area about the same as the orchards and vineyards, over 50,000 acres now being devoted to these crops. The grain and hay areas are scattered over the entire upland region as shown on Plate IV, although perhaps the largest continuous areas so farmed lie in the region between Antioch and Bay Point on the south side of Suisun Bay and the region between Vallejo and Napa, east of Napa River. There also is considerable grain and hay now grown in Ygnacio and Clayton valleys.

It may be noted that over half of the upland area at present is uncultivated and is utilized only for pasture. The uncultivated areas include practically all of the poorer types of soil covered under Class 3 and 4 and portions of the Class 2 lands as previously presented. Practically all of the crops are grown on the best lands included under Class 1 and 2. It is probable that future extension of agriculture in the upland area would be mainly upon the present uncultivated portion of the Class 2 lands.

Local Water Supplies and Present Extent of Irrigation.—At present irrigation is practiced to only a limited extent in the upland areas adjacent to Suisun and San Pablo bays. The irrigated areas include a portion of the orchard developments and certain small areas of truck, alfalfa and miscellaneous field crops. The chief underlying reason for the small amount of irrigation is the fairly heavy precipitation which most of the area enjoys. This is particularly true of the valley regions north of San Pablo Bay, where normal rainfall has generally been sufficient for all crops grown. In the areas north and south of Suisun Bay, the annual precipitation is not usually as much as north of San Pablo Bay, although the normal amount has been sufficient apparently in past years for the successful culture of the various crops. During the past ten to thirteen years, however, which has been a period of subnormal precipitation, all of these areas have suffered in varying degrees from lack of adequate moisture. During this period, the orchards which

TABLE 23

PRESENT CROPS IN UPLANDS ADJACENT TO SUISUN AND SAN PABLO BAYS

(From survey of September, 1930)

Location	Deciduous orchards		Vineyards		Truck and field crops[1]		Forage crops[2]		Grain and grain hay		Non-cropped land: Uncultivated		Non-cropped land: Industrial and urban		Total area, in acres
	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	Area, in acres	Area, in per cent of total	
Suisun Bay															
Knightsen to Antioch	3,850	37	2,170	21	140	1	20	0	2,010	19	1,810	17	500	5	10,500
Antioch to Bay Point	30	0	20	0	0	0	60	1	7,090	62	2,000	18	2,200	19	11,400
Ygnacio and Clayton valleys	6,520	27	2,440	10	2,030	8	80	0	6,480	26	4,450	18	2,600	11	24,600
Martinez to Dillon Point	0	0	0	0	20	5	0	0	0	0	280	70	100	25	400
Collinsville to Denverton	0	0	0	0	0	0	0	0	3,050	26	8,450	74	0	0	11,500
Denverton to Suisun	590	2	250	1	50	0	40	0	5,070	14	28,600	82	200	1	34,800
Suisun to Cordelia	7,960	41	1,310	6	180	1	20	0	3,920	21	5,710	30	100	1	19,200
Cordelia to Dillon Point	30	1	50	1	120	2	10	0	1,040	19	3,450	64	700	13	5,400
Subtotal	18,980	16	6,240	6	2,540	2	230	0	28,660	24	54.750	47	6,400	5	117,800
San Pablo Bay															
Dillon Point to Napa Valley	100	1	50	0	160	1	10	0	7,020	40	8,660	50	1,400	8	17,400
Napa Valley	12,960	43	1,710	6	390	1	1,290	4	3,480	12	9,470	31	900	3	30,200
Napa Valley to Sonoma Valley	1,650	19	760	9	0	0	60	1	880	10	5,350	61	0	0	8,700
Sonoma Valley	4,470	27	980	6	50	0	140	1	2,650	16	7,310	44	1,000	6	16,600
Sonoma Valley to Petaluma Valley	40	1	0	0	0	0	0	0	710	13	4,850	86	0	0	5,600
Petaluma Valley	1,030	5	350	2	110	0	1,460	6	4,540	21	13,410	61	1,100	5	22,000
Petaluma Valley to Novato Valley	100	2	80	1	30	0	0	0	1,550	27	4,040	70	0	0	5,800
Novato Valley	880	19	360	8	30	0	40	1	250	5	3,040	65	100	2	4,700
Novato Valley to San Rafael	20	0	0	0	40	1	0	0	480	7	6,160	92	0	0	6,700
Richmond to Dillon Point	0	0	0	0	860	8	90	1	150	1	8,200	77	1,400	13	10,700
Subtotal	21,250	17	4,290	3	1,670	1	3,090	2	21,710	17	70,490	55	5,900	5	128,400
Total, upper San Francisco Bay	40,230	16	10,530	4	4,210	2	3,320	1	50,370	21	125,240	51	12,300	5	246,200

[1] Includes crops for human consumption, such as tomatoes, beans, melons, strawberries and sugar beets.
[2] Includes crops for animal consumption, such as alfalfa, kale, corn and maise.

have been able to obtain irrigation supplies have maintained normal yields, whereas unirrigated orchards have suffered some loss in yield.

The most extensive area irrigated at present in the upper bay uplands is the orchard development in Suisun and Green valleys. The first irrigation development in this district consisted of pumping from Suisun Creek in about 1895. The first irrigation well is stated to have been drilled and put in operation in 1897. The period of more extensive irrigation development, however, did not begin until about 1906. Since this latter date, many additional wells have been developed. The wells are generally about 200 feet deep. The ground water level at present fluctuates between depths of fifteen and thirty feet below ground surface, averaged over the valley. This is reported to be about ten feet below the original corresponding levels. The total amount of irrigation applied is stated to be about one acre-foot per acre each season, with a cost reported at $3 to $5 per acre-foot. The amount applied is only barely sufficient to keep the trees in normal growing condition and support normal yields. Although no detailed studies have been made of the amount of available underground water supply, it appears probable that it is completely utilized at present. Hence, any extension of irrigation would necessitate the development of new supplies from local surface streams or importation from outside sources. The city of Vallejo has completed a storage development in Gordon Valley on a branch of Suisun Creek and exports supplies for municipal use from this watershed. This development has been followed by considerable litigation between the city and the agricultural interests in lower Suisun Valley, which has not as yet been finally settled. It appears probable, however, that Vallejo's development on this watershed will have taken a large part of the surplus of the local sources of supply capable of economic development.

In Ygnacio and Clayton valleys south of Suisun Bay, irrigation is of rather recent development. Originally the water table over most of the valley floor was at comparatively shallow depth and, with the average rainfall conditions, orchards and other farm crops were successfully grown with profitable results without irrigation. More recently, however, due to a considerable period of subnormal precipitation, combined with drafts upon the underground water supply by a public utility and industries, ground water levels have dropped to such an extent that irrigation has become more and more essential to orchard development. The only irrigation practiced in early years was diversion of surface waters during freshets from the creeks in the valley in order to store up moisture for use during the growing season. It is stated that the first irrigation well was sunk in 1912 for a 50-acre walnut orchard. Since then several wells have been developed for orchard irrigation. These wells are limited in capacity, varying from 50 or less to 250 gallons per minute. The total seasonal irrigation applications are reported to vary from six to fifteen inches in depth. At present, only about 2200 acres are irrigated below the 150-foot contour, although some 3500 acres are under irrigation in the entire area of these valleys. In the fall of 1930, the depth to water table in Ygnacio Valley ranged from 20 to 90 feet, with an average of 35 feet, while in Clayton Valley it ranged from 50 to 100 feet, with an average of about 65 feet. These levels are from ten to thirty feet below the corresponding levels in 1919. The present cost of irrigation supplies obtained from wells is stated to amount to $10 to $20 per acre-foot of water applied.

Due to the apparent serious shortage in local water supply existing in Ygnacio and Clayton valleys, a special study was made of the availability and amount of ground water resources. As a result of this study, it was found that at present the average annual extractions from the underground basin amount to about 8000 acre-feet, over half of which is by a public utility and industries and the remainder for irrigation. With this amount of extraction, the water table in the two valleys has been lowered during the past eleven years (1919 to 1930) an average of about seventeen feet, showing that the extractions have exceeded the average replenishment during the period. It was concluded from this study that the safe annual yield of the underground water basin under these two valleys would average 5000 acre-feet under the present natural conditions of replenishment during a similar period of run-off as during the last eleven years. The amount of natural replenishment might be increased somewhat by the construction of works to artificially spread the stream flow and increase seepage and absorption into the underground formation. However, conditions in these two valleys are not favorable for carrying out such measures to any great extent. It also is possible that the average annual amount of natural replenishment might be greater than during the subnormal run-off period of the last eleven years. However, it is evident that the continuation of successful orchard culture and growing of other agricultural crops in these two valleys will necessitate irrigation, requiring water supplies from some suitable outside source. The present underground water supplies are being overdrawn, and the cost of obtaining water by wells is excessive.

In Napa Valley, irrigation is much less extensive than in either Suisun or Ygnacio valleys. Only about 1600 acres are under irrigation at present. Irrigation supplies are obtained partly by diversions from Napa River and partly by wells. Until the recent period of subnormal precipitation, the problem in much of the lower area of the Napa Valley was one of drainage, rather than that of the need of irrigation. The orchards and vineyards in Napa and Sonoma valleys have been successfully developed and favorable production obtained without the need of irrigation. However, since the advent of the series of subnormal precipitation seasons, increased attention has been paid to the desirability and need of irrigation supplies. In 1930 ground water levels in the valley ranged from an average depth below the ground surface of about ten feet in the spring to eighteen feet in the fall. Comparison with 1918 water levels indicates that there has been practically no lowering of the water table during the last thirteen years of subnormal precipitation and run-off. It appears that the available underground water supply in Napa Valley is capable of some greater utilization than at present. In addition there is at least one possibility and perhaps others of developing storage reservoirs on tributaries of Napa River, the consummation of which would greatly increase the availability of local water resources. Based upon the information obtained thus far, it appears probable that the local water resources, if properly developed and utilized within the valley itself, would be sufficient to take care of most of its ultimate water requirements.

In Sonoma Valley about 500 acres are irrigated by diversion from Sonoma Creek and from wells. Local water supplies are considerably less abundant than in Napa Valley and there appears to be no reservoir sites of any size which could be developed economically for storage of flood waters and increasing the availability of local supplies. Present conditions of available water supply and crop production appear to be satisfactory, but any more intensive future development and utilization of these lands for agriculture probably would require imported supplies to provide for irrigation. Inquiry within the area indicates that there is no present demand for additional irrigation supplies.

In the Petaluma Creek area, from Petaluma to Cotati, the chief agricultural activity is poultry raising, although there is a considerable area devoted to hay and grain. The poultry farms are generally in small units, averaging about six acres each. They usually have small fields planted to kale or similar green poultry feed irrigated by small individual pumping plants or windmills. The underground water supplies obtained are generally small in volume and only sufficient for the limited use to which they are put. Pumping lifts range from 70 to 100 feet. But very little of the feed required by the poultry interests in this district is raised within the area, most of the grain and meals used being imported. Under these conditions the poultry industry in this district evidently has flourished. Hence, there seems no reason to believe that the type of agricultural activity will change greatly in the future. There is little present demand for irrigation supplies and it seems probable that there would be no appreciable demand for many years in the future.

The principal agricultural development in Marin County within the upper bay uplands is in Novato Valley. Considerable areas are planted to orchards and vineyards on the fertile lands of the valley floor. There also are numerous poultry farms on the outer slopes of the valley. Very little irrigation is practiced in this area, with supplies obtained by wells. It is reported that some efforts have been made toward obtaining a water supply for irrigation from the Marin Municipal Water District. No study has been made of the amount of available local water supplies, nor of possibilities of storage development. As far as known, no reservoir sites economically feasible of development are available. Hence, when the demand arises for complete irrigation of the lands in this area, it appears probable that the necessary supplies would have to be largely imported from some outside source.

The orchard and vineyard development in the area lying south of the San Joaquin River between Antioch and Knightsen is practically all dry farmed at the present time. A few small tracts within the area are irrigated from wells. The underground supplies appear to be extremely limited in amount and are difficult to obtain in the quantities required for irrigation. The orchards and vineyards, during the subnormal period of precipitation of the last thirteen years, have suffered from lack of adequate moisture with resulting decrease in yields. The productivity of this area would be substantially increased by irrigation. The logical source for the necessary irrigation supplies would be from the channels of the lower delta.

Immediate Water Requirements.—As far as the present and immediate future needs of the upland agricultural areas are concerned, the most serious water shortage and need for supplemental water supplies from some outside source is in Ygnacio and Clayton valleys and the area south of the San Joaquin River between Antioch and Knightsen in upper Contra Costa County. Within Ygnacio and Clayton valleys, there are at present about 18,000 acres of cultivated lands with local underground water supplies sufficient for the irrigation of only about 3000 acres. There appears to be a demand for an extension of irrigation in this area and it is estimated that a gross area of 7000 acres in these two valleys might be expected to use an irrigation supply, if made available, in the near future. Likewise, in the area south of the San Joaquin River between Antioch and Knightsen, it is estimated that a gross area of about 6000 acres might be expected to use an irrigation supply. It appears probable that the utilization of the available local water supplies in Suisun Valley will be sufficient for the needs of this area, until there is a demand for an extension of irrigation to new lands in this territory. In the San Pablo Bay uplands, there appears to be no present or immediate future demand for an extension of irrigation that can not be cared for by utilization of available local water resources, with the possible exception of the Novato Valley in Marin County. This latter area would probably use irrigation supplies, if available, but it appears evident that, unless supplies can be developed locally or possibly obtained from the Marin Municipal Water District, there is no immediate possibility of importing water from a more distant source unless or until there is a general demand in the San Pablo Bay upland area for irrigation service.

Future Water Supply and Service.—Based upon the foregoing description of conditions in the several areas in the upper bay uplands, it may be concluded that the ultimate intensive agricultural development of these lands will require the importation of irrigation supplies, to supplement available local water resources which are feasible of development, for the entire area with the possible exception of Napa Valley. The necessary irrigation supplies could be adequately and feasibly furnished from the lower Sacramento and San Joaquin rivers. This appears to be not only the nearest source of supply but also the cheapest available. The required supplies could be obtained by pumping the same through conduits extending from a barrier lake or extending from controlled fresh-water channels of the delta. The comparative merits and cost of serving the ultimate water requirements of the upper bay uplands from this source by two alternate plans, with and without a barrier, are presented in Chapter IV.

CHAPTER IV

ECONOMIC CONSIDERATIONS OF SALT WATER BARRIER

The final considerations of a salt water barrier must be directed to the determination of its necessity and desirability in supplying present and ultimate water requirements and facilitating immediate future and ultimate full potential development of the upper San Francisco Bay and Sacramento-San Joaquin Delta regions; and as a unit of the State Water Plan in the consummation of the most practicable conservation and utilization of the state's water resources. The proposed State Water Plan, which is described in detail in another report,* is shown on Plate V, "Major Units of State Plan for Development of Water Resources of California." The portion of the State Plan particularly related to a salt water barrier involves the proposed plan for exportation of surplus water from the delta by the San Joaquin River pumping system, and the furnishing of supplies to the delta and upper San Francisco Bay region.

The data and discussions presented in Chapter III show that imported water supplies will be required, both in the immediate future and ultimately, for industrial, municipal and agricultural developments of the upper San Francisco Bay region. The nearest and most logical source for these necessary water supplies is the lower Sacramento and San Joaquin rivers. However, in order to make this source of supply available and dependable at all times, the invasion of saline water, which during recent years has occurred annually into the lower delta channels, must be prevented by some adequate means. One method of preventing invasion of saline water would be with a salt water barrier. If necessary supplemental water supplies from mountain storage were provided for the operation of a barrier and the unavoidable losses from a barrier lake, saline invasion would be prevented above the structure, and the barrier lake would provide a source for diversion of fresh-water supplies, if made available. The invasion of saline water also could be controlled without a barrier by stream flow, provided in sufficient amount, by means of supplementary supplies released from mountain storage, to maintain fresh water in the channels of the delta down to the lower end near Antioch. With this alternate method of controlling salinity, not only could ample fresh-water supplies be made available for the delta, but also for the upper bay region. Therefore, the determination of the desirability, necessity and economic justification of a salt water barrier must depend fundamentally upon a consideration of the comparative merits and cost of alternate plans, with and without a barrier, for accomplishing these purposes.

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

ULTIMATE WATER REQUIREMENTS AND SUPPLY FOR UPPER SAN FRANCISCO BAY AND DELTA REGIONS

The ultimate water requirements of the upper San Francisco Bay and delta regions are based upon studies of the predicted character and magnitude of industrial, municipal and agricultural developments in the upper bay region and the estimated rates of water demand for each purpose, and detailed experimental data of consumptive use of water in the delta.

Upper San Francisco Bay Region.

The ultimate water requirements of the upper San Francisco Bay region are closely allied with those of the San Francisco Bay basin as a whole, which have been presented in a previous report.* In order to estimate the ultimate water requirements, a study was made of the probable future utilization of the entire basin. It was found that out of a total gross area of about 4000 square miles in the entire basin, about 1500 square miles, or approximately 1,000,000 acres, comprising major valleys and areas bordering the bay, probably could be expected to be intensely developed in the future. This area was classified as urban, suburban, industrial and rural.

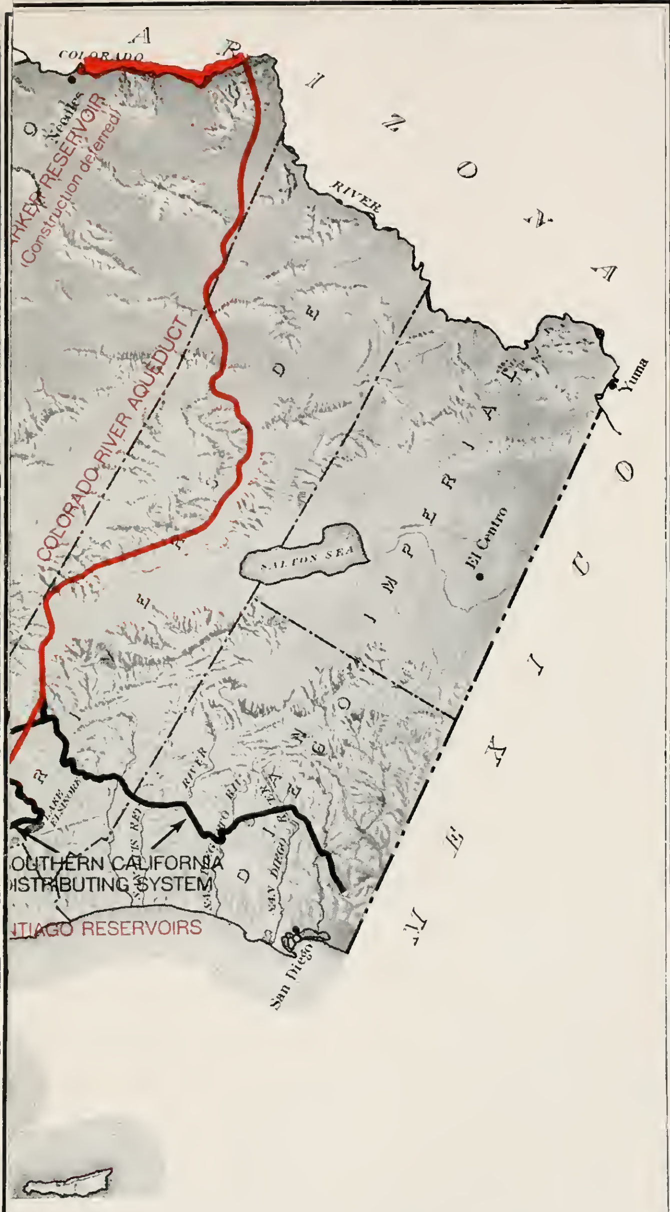
Water requirements for any particular area vary not only in amount with the use to which the water is put and in monthly demand, but also with the point at which the water is measured. The geographic position of the source of supply in relation to point of use, methods of conveyance, the extent of the area to be supplied and the opportunity afforded for reuse of water controlled by topographic, geographic and geologic conditions are factors that have an important bearing on water requirements.

For these reasons some variation in treatment of the problem of requirement and supply for different areas has been necessary. The variation in treatment has in turn necessitated the use of different terms defined as follows:

1. "Gross allowance" designates the amount of water diverted at source of supply.
2. "Net allowance" designates the amount of water actually delivered to the area served.
3. "Consumptive use" designates the amount of water actually consumed through evaporation, transpiration by plant growth and other processes.
4. "Net use" designates the sum of the consumptive use from artificial supplies and irrecoverable losses.

The ultimate water requirements were computed on the basis of the predicted utilization and estimated use of water per unit of area for each type of development. In metropolitan areas, the water requirements are approximately in direct proportion to the density of population. Statistics on amount of water used, population and areas in the cities of California and of the United States, indicate that the water requirements for urban and suburban areas, expressed in feet depth per annum, range from an average of about one foot for a population

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.



MAJOR UNITS OF STATE PLAN

FOR

DEVELOPMENT OF WATER RESOURCES

OF

CALIFORNIA

MAJOR UNITS OF STATE PLAN FOR DEVELOPMENT OF WATER RESOURCES OF CALIFORNIA density of ten persons per acre to about four and one-half feet for forty persons per acre. The future water requirements of urban and suburban areas have been estimated on the basis of predicted density of population in the several districts of the bay region.

The water requirements of industrial districts have been estimated on the basis of available data on use of water per unit of area for present industrial districts in the bay region and other cities of California and the United States. Industrial water requirements vary widely, depending upon the type of industry and intensity of development. The data obtained during this investigation on industrial water use in the upper bay region were given particular weight in estimating the unit water requirements for the ultimate predicted industrial district. The amounts used in estimating the industrial water requirements vary from two to five feet in depth per annum in the various areas of the bay region. Inasmuch as the water supplied for urban, suburban and industrial use is generally conveyed in pipe lines, conveyance losses are small and hence the gross allowance for these purposes is approximately equal to the net allowance.

For the rural or agricultural areas of the basin, the ultimate water requirements have been estimated on the basis of the best data available as to the amount of water required for irrigation. The net allowances were estimated for the assumed irrigable areas, and range from 1.25 feet in depth per season for the Santa Clara Valley and the valleys north of San Pablo Bay to two feet in depth per season for the Livermore Valley and the areas north and south of Suisun Bay. The gross allowance is based upon the net allowance with the addition to the latter of estimated conveyance losses in serving the several areas.

On this basis, the ultimate water requirements of the upper San Francisco Bay basin were estimated at 1,735,000 acre-feet annually. This annual gross allowance for the entire basin is equivalent to 1.7 feet depth over the gross area of intensive development, or a uniform demand of about 1550 million gallons per day or 2400 second-feet.

A portion of these ultimate water requirements could be obtained by development of local water resources of the San Francisco Bay basin. The local drainage area above the valleys and plains comprises over 2200 square miles. The total mean seasonal run-off from local sources for the 40-year period 1889–1929 is estimated at 824,400 acre-feet; for the 20-year period 1909–1929, 633,600 acre-feet; for the ten-year period 1919–1929, 526,100 acre-feet; and for the five-year period 1924–1929, 599,800 acre-feet. Thus, if it were possible to develop the entire amount of more dependable mean run-off, as shown by the last ten-year period, the local water resources would supply only about 30 per cent of the ultimate water requirements of the San Francisco Bay basin. However, under the most favorable conditions, only a part of this mean run-off could be fully developed. Its utilization would require construction and operation of all surface reservoirs capable of economic development and utilization of underground storage where available. Many of the more favorable reservoir sites within the basin have already been constructed. There are further possibilities of additional storage development, notably on the tributary streams of the Santa Clara Valley, on Lagunitas Creek in Marin County, and on tributaries of the Napa River in Napa County. The present developments of local water sup-

density of ten persons per acre to about four and one-half feet for forty persons per acre. The future water requirements of urban and suburban areas have been estimated on the basis of predicted density of population in the several districts of the bay region.

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Based upon present knowledge of possibilities of additional storage reservoirs capable of economic development, it is estimated that an additional water supply from the local water resources of the basin could be made available to the amount of 150 million gallons per day, or 168,000 acre-feet per year. Thus it appears that the total amount of local water supplies available and capable of economic development in the San Francisco Bay basin would amount to about 390 million gallons per day, or 437,000 acre-feet per year, or only about 25 per cent of the total ultimate water requirements of the basin.

This deficit of 1160 million gallons per day, or 1,298,000 acre-feet per year, must be taken care of by importation from outside sources. Two projects for the importation of supplies from outside sources now are partially completed or under construction for this purpose. These comprise the San Francisco water supply project to bring water from the Hetch Hetchy watershed of the Tuolumne River, which will furnish a supply when completed of 400 million gallons per day; and the project of the East Bay Municipal Utility District to bring water from the Mokelumne River watershed, and which, when fully completed, will supply 200 million gallons per day. After these supplies are brought in, there still would remain a deficit of 560 million gallons per day, or 626,000 acre-feet per year, in supplying the ultimate water requirements of the basin.

The bulk of this deficit applies to the upper San Francisco Bay region. After the Hetch Hetchy and the entire Mokelumne River supplies are brought in and the additional local supplies of the lower bay counties, chiefly in Santa Clara, Alameda and Marin, are fully developed, the ultimate water requirements of the lower San Francisco Bay region evidently would be amply provided. As previously stated, there are some possibilities of additional storage development for increasing local supplies in the upper bay region, notably in Napa County. However, the upper bay region must evidently depend for its full ultimate water requirements upon the importation of water supplies from the most suitable outside sources available. The nearest and most logical source for these additional supplies appears to be the delta channels of the lower Sacramento and San Joaquin rivers. The studies of water supply, yield and demand, with the proposed units of the ultimate State Water Plan operating, and with stream flow as during the period 1919 to 1928, demonstrate that ample water supplies would have been available for full ultimate requirements of the two valleys and the Sacramento-San Joaquin Delta, and, in addition, for the greater part of the 626,000 acre-feet ultimately required for the San Francisco Bay region. With the units as proposed operating, a supply of 403,000 acre-feet per season would have been available in the delta channels for the upper San Francisco Bay region, with a maximum seasonal deficiency in a year similar to 1924 of 35 per cent in only that portion of this supply for irrigation. The remaining 223,000 acre-feet per year also could be obtained from this source by additional storage developments on the tributaries of the Sacramento River; or, with the same units, but allowing a small deficiency in the Sacramento Valley supply in a critical year. As an alternate, this amount of water might also be obtained by developments on the Eel River. The question as to which source ultimately should be used, necessarily would involve chiefly the cost of the two alternate sources of supply. However, the studies show that all of the additional water supplies ultimately required for the upper San Francisco Bay region, could be furnished from feasible developments on the Sacramento and San Joaquin rivers, and the supplies made available therefrom in the delta channels near the area to be served.

Sacramento-San Joaquin Delta.

The ultimate water requirements of the Sacramento-San Joaquin Delta are based upon measurements of consumptive use of water by crops, vegetation, and evaporation in the delta. The results of these measurements, conducted over a period of six years, are presented in another report.* Practically all lands in the delta are now reclaimed and largely utilized for crop production. Conditions in the delta are peculiar in that the consumption of water by crops, natural vegetation, and evaporation from the open water in the delta is only partially subject to control. Natural seepage into the islands from the adjacent channels contributes a material portion of the water consumed by crops and vegetation within levees on a large part of the delta lands. However, irrigation supplies are artificially diverted for practically all crops grown, and irrigation is essential for the more flexible and more rapid regulation of the moisture requirements of crops. The consumption of water by natural vegetation along the banks of the channels and on unreclaimed islands and along the interior drains and ponds is a continuous process throughout the entire growing season of these plants. Tules and cat-tails consume large quantities of water at rates amounting to about three to five times as much as those of various crops. Finally, evaporation from open water surfaces is a substantial consumer of water, the consumption going on continuously throughout the year but having its greatest rate during the summer months.

The present estimated consumptive use in the delta varies from 400 second-feet (in mid-winter) to 3700 second-feet (in mid-summer). This includes water consumed by crops, natural vegetation and evaporation. The estimated total annual consumption amounts to about 1,250,000 acre-feet, or over 2.5 acre-feet per acre on the gross area. It is believed that the ultimate water requirements of the delta will approximate the present rates and total amounts of consumptive use.

The stream flow entering the delta during the summer months has been insufficient in five years of the period 1920 to 1929 to take care of the full consumptive needs of the delta. The maximum deficiency occurred in the latter part of the season 1923–24, the driest of record

*Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

during this period, when a total shortage of 277,000 acre-feet occurred during the months of June, July and August, 1924. The maximum monthly shortage in this year amounted to 127,000 acre-feet in July. The shortage in 1920 totaled 225,000 acre-feet, with a maximum monthly shortage of 151,000 acre-feet in August. A shortage, totaling 140,000 acre-feet, with a maximum monthly shortage of 80,000 acre-feet, occurred in 1926. Small shortages also occurred in 1928 and 1929. In the remainder of the years during this period, sufficient water flowed into the delta in all months to take care of the consumptive needs.

The operation of the proposed units of the State Water Plan for both the initial and ultimate developments would fully take care of all water shortages in the delta. Moreover, additional supplies could be furnished to insure the protection of the delta from saline invasion so that fresh water would be available in the channels at all times, free from any harmful saline pollution.

CONTROL OF SALINITY

The utilization of water supplies now or hereafter made available in the lower Sacramento and San Joaquin rivers for the delta and upper bay regions requires some means of controlling the invasion of saline water from the bay so that a dependable fresh-water supply may be obtained at all times from this source. The control of salinity may be obtained either with or without a barrier. The amount of water required for control and the amount and value of supplemental water supplies required to be furnished from mountain storage are important factors in the consideration of the comparative merits of these two alternate methods of salinity control.

Control of Salinity With a Salt Water Barrier.

There has been a somewhat prevalent idea that a physical barrier, in itself, would positively prevent invasion of saline water above the structure. If a barrier could be built and operated as a water-tight dam, there would be no question of its positive effectiveness for this purpose. However, as described in Chapter II, a barrier must be provided with navigation locks for passage of vessels and a large number of flood gates to pass the floods discharged by the Sacramento and San Joaquin rivers. Therefore the structure would not be water-tight but would permit the entrance of salt water during the operation of the usual or standard type of navigation locks and by leakage around both lock gates and flood gates. Moreover, contrary to what has been popularly supposed, a barrier would not create a storage reservoir in which large amounts of water could be impounded for utilization as necessity demanded. There would also be considerable loss of water from a barrier lake by evaporation and transpiration from marginal vegetation. These elements in the method of salinity control with a barrier are of substantial importance in the consideration of its merits, as they affect the amount of water required for control with a barrier, and the amount of supplemental water required from mountain storage.

Barrier Lake Storage.—The level at which the water could be held in a barrier lake is limited, both as to its maximum and minimum elevation. The maximum elevation which could be continuously held for any substantial period of time is controlled by the height which the levees in the delta could safely withstand. The minimum elevation is controlled partly by the necessity of maintaining required navigation depths in the upper bay and delta channels, including especially the new Stockton ship canal; partly by the necessity of preventing the drying-out and cracking of delta levees; and partly by the necessity of holding a barrier-lake level as high as possible to prevent infiltration of salt water and to obtain effective operating conditions for flushing out salt water which may enter a barrier lake.

Plate III graphically presents the mean, maximum and minimum levels of the tide from the Golden Gate to the upper reaches of the delta. These tidal levels have been compiled from data obtained by automatic tide gage records during 1929 and 1930 and represent, especially for the delta channels, the mean of conditions during the period of low stream flow from July to November, inclusive. They, therefore, represent the more normal conditions of fluctuating water level in the various portions of the tidal basin, except during brief periods of flood flows in the winter season. The levees in the lower Sacramento River and San Joaquin River deltas, which are mostly in peat formation, must be especially considered in fixing the allowable maximum and minimum continuous barrier-lake levels. The mean high tide level in these portions of the delta ranges from about two and one-half to three feet above mean sea level. Representatives in the delta best informed as to the conditions therein and the probable effect of a continuous water level held at various heights, have stated that the levees could not safely withstand a water level over any long period at a higher elevation than the mean high tide. It is therefore concluded that the maximum allowable continuous barrier-lake level would be limited to an elevation of about three feet above mean sea level.

Navigation channels are generally planned on the basis of providing certain fixed depths of water below mean lower low water. This is somewhat lower than the elevation of mean low tide as shown on Plate III. The elevation of mean low tide in the upper San Joaquin River from Venice Island to Stockton is approximately at mean sea level. Thus from the standpoint of maintaining the minimum depths required for navigation in the upper part of the Stockton Ship Canal, it would appear possible that a barrier lake level might be lowered to approximately mean sea level. However, it is the opinion of the Army Engineers that the navigation interests, especially operators of deep-draft ocean-going vessels, might reasonably expect to have maintained depths of water corresponding to present mean tide level. This requirement in the upper San Joaquin River near Stockton would limit the minimum barrier-lake level to about one and one-half feet above mean sea level. Thus from the standpoint of the navigation interests, a barrier-lake level might be lowered to one and one-half feet above mean sea level.

There is still another consideration which limits the minimum barrier lake level. This again involves the delta levees. It appears that if a barrier-lake level were allowed to drop below present mean tide level in the San Joaquin Delta and were held at such a lower elevation for any considerable period of time, it would cause a drying out and cracking of the levee material above this lower level, especially for the peat levees. Borings were made by the United States Army Engineers in several places in the levees in the San Joaquin River Delta to obtain data on the line of seepage through the levees in relation to the fluctuating water level in the adjacent channels. These investigations revealed that the upper limit of the saturated portion of the levees was about at mean tide level on the channel side, with a downward slope towards the land side. The levee material above this upper limit of saturation was found to be comparatively dry and, when consisting of peat, to contain many cracks dividing the material into irregular blocks. It appears evident that it would be inadvisable to allow the level of a barrier lake to stand at a lower elevation than the present average level for a period of time sufficient to permit the drying out and cracking of greater portions of the levees than now occurs under natural conditions. It might result in serious consequences, due to the greater facility offered during higher flood stages of winter for water to pass through the levees with the resulting greater possibility of failures occurring. The delta levees therefore limit a barrier lake level both as to its maximum and minimum elevations.

From the standpoint of maintaining the most effective conditions for preventing infiltration of salt water and for flushing out salt water which may enter a barrier lake, it would be desirable to maintain a lake level higher than tidal levels below. As shown on Plate III, tidal levels fluctuate from about four feet below to four feet above mean sea level at the Point San Pablo and Dillon Point sites, and from about two feet below to about four feet above mean sea level at the Chipps Island site, with mean or half tide levels of 0.4, 0.5 and 1.1 feet above mean sea level at the Point San Pablo, Dillon Point and Chipps Island sites, respectively. Maximum high tides at these points of two to three feet above those shown on Plate III have occurred. With flood gates extending to a depth of 70 feet below water surface, the level of a barrier lake would have to be about 1.5 feet above the level of salt water below a barrier in order to take care of the difference in specific gravity and equalize the pressure for the full depth of the gates. This is on the assumption of a salinity in the water below a barrier of about 1600 parts of chlorine per 100,000 parts of water. The difference in level between a barrier-lake water surface and the water surface below a barrier therefore would have to be greater than this amount at all times to prevent infiltration of salt water. Salt water entering a barrier lake either by infiltration or by lockage operations would tend to accumulate in the lower depths above a barrier and would have to be flushed out more or less continuously to prevent harmful pollution of the lake waters. Flushing could only be accomplished when the level in a barrier lake was a sufficient height above the tidal level below a barrier to overcome the difference in density between the salt water below and the fresh water above a barrier and provide an additional differential head to discharge the salt water in the quantity required through the flushing outlets. Even if a barrier-lake level were held at three feet above mean sea level, the period of flushing operations would be confined largely to the stages of the tide at or below mean tide level. Any lowering of a barrier-lake level below an elevation of three feet above mean sea level would result in decreasing the effective flushing head and shortening the period of time during which flushing operations could be conducted, and might result in making it impossible to properly flush out salt water accumulations, thus causing a pollution of the lake waters and an interference with their utilization.

Taking into consideration all of the limiting factors controlling the maximum and minimum levels of a barrier lake, it is concluded that it would not be safe to assume a higher maximum lake level than three feet above mean sea level, nor a greater range of fluctuation in usable storage capacity of more than one foot. Because of this limitation in maximum storage level, the height of a barrier structure is controlled by the maximum tidal levels below the structure rather than by the maximum barrier-lake level. After allowing for necessary free-board to take care of wave action, the height of a barrier structure has been fixed in the preliminary plans of Bulletin No. 22 at ten to fifteen feet above mean sea level. The amounts of usable storage capacity in a barrier lake for each of the three typical barrier sites are shown in Table 24. As a matter of interest only, the storage capacity above each site is also shown for a range of three feet.

TABLE 24

USABLE STORAGE CAPACITY IN BARRIER LAKE

(With a maximum lake level of 3 feet above mean sea level)

Barrier site	Storage in acre-feet	
	Assumed usable capacity for range of one foot	Capacity for range of three feet
Chipps Island	45,000	125,000
Dillon Point	75,000	220,000
Point San Pablo	155,000	450,000

Although the total storage capacity in a barrier lake would be relatively large, amounting to about 950,000 acre-feet above Chipps Island site, 1,625,000 acre-feet above Dillon Point site and 3,100,000 acre-feet above Point San Pablo site, the usable storage capacity limited to an assumed possible range of one foot would be relatively small, comprising only about 5 per cent of the total storage capacities. Even assuming an allowable fluctuation of three feet in a barrier lake, the corresponding amounts of storage within this range would still be relatively small, comprising only about 15 per cent of the respective total storage capacities. When it is considered that the seasonal run-off of the Sacramento and San Joaquin rivers into the delta, as estimated for the period 1871 to 1929, averages over 31,000,000 acre-feet and has ranged from a minimum of about 6,000,000 acre-feet to a maximum of about 83,000,000 acre-feet, it is evident that the usable storage capacity of a barrier lake would have but small importance in effecting any great degree of conservation of the tributary run-off. The amount of water which would be made available by the utilization of the limited amount of storage would be so small as to be of little importance for the creation of additional supplies. As will be shown more clearly hereafter, these amounts of water which might be obtained in usable storage capacity would be far from sufficient to take care of even the water demands required for the operation of a barrier and the unavoidable losses of evaporation and transpiration from a barrier lake.

Required Control Flow.—The control of salinity with a salt water barrier would require substantial amounts of fresh water to provide for barrier operation and unavoidable losses from a barrier lake. A large part of the fresh water required is directly due to the necessity of operating locks in a barrier structure for the passage of vessels. Leakage around flood gates and lock gates and operation of fish ladders would require additional amounts of fresh water. The creation of a barrier lake with a large area of water surface and extensive marginal vegetation would result in large evaporation and transpiration losses, which could not be prevented and would have to be supplied as a part of the water requirements for salinity control with a barrier. At the present time, there are large unreclaimed areas in the marshlands of Suisun and San Pablo bays and also large areas of uncultivated lands enclosed in levees growing various kinds of natural vegetation, the consumptive demands of which would have to be supplied from a barrier lake. Even under future complete reclamation and cropping of these marshlands, the extent of marginal vegetation and the amount of transpiration would be considerable. These water requirements for salinity control are of special importance in the period of low summer stream flow, when supplies would have to be released from mountain storage.

The water requirements for the operation of the usual or standard type of locks have been the subject of a special study by the United States Army engineers in their cooperative investigations of a barrier. These studies have involved a series of laboratory experiments, working with models of the barrier locks, to determine the action of salt water entering a barrier lake during lockage operations and the amount of fresh water required to flush out the accumulations of salt water. These experiments were carried out in cooperation with the University of California. It was found that the salt water entering a barrier lake during operation of standard locks would collect at the lower depths immediately above a barrier and, if allowed to accumulate, would gradually displace and pollute a considerable volume of the lake. In order to confine such accumulations of salt water, the existence or provision of an adequate sump immediately above a barrier would be desirable and essential. The only barrier site having a natural depression or sump of any magnitude is that at Dillon Point. The natural conditions at both the Chipps Island and San Pablo sites are much less favorable.

Although salt water entering through standard locks would tend to accumulate at the greater depths immediately above a barrier, the experiments showed that each volume of salt water entering a lake would pollute many times its own volume of fresh water. Moreover, when a lock full of salt water would be discharged into a lake, the difference in density between the salt and fresh waters would result in setting up a considerable velocity which would tend to carry the salt water a substantial distance upstream from the barrier. Hence, unless a sump having not only considerable depth but also considerable length were naturally available or artificially provided above a barrier, the successive discharges of salt water into a lake could not be confined within the desired narrow limits. It would be possible of course to dredge a sump of the proper proportions required, but it would be impossible to maintain such a sump without more or less continuous dredging operations. The experiments showed that, in order to prevent any widespread pollution of a barrier lake, it would be necessary to flush out the salt water at periodical intervals so as to limit the accumulations and prevent a serious extension of pollution.

In addition to these laboratory experiments, studies were made of the results of lockage operations in the Lake Washington Ship Canal at Seattle, where conditions are somewhat similar to those which would occur with a barrier. Considerable data were available for study on the degree and extent of saline pollution which has occurred above these locks. The lake waters have been seriously polluted by saline water as far upstream as Lake Union, four miles above the locks. Serious difficulties have arisen in attempting to prevent this pollution. The available information is of great value in the study of a salt water barrier, as it not only demonstrates that the operation of the ordinary or standard types of locks results in the gradual pollution of a fresh-water lake above, but also shows that large quantities of fresh water are required to prevent such pollution assuming serious magnitude.

As a result of these studies by the United States Army engineers, it was found that, in order to flush out the accumulations of salt water entering a lake, a volume of fresh water would be required amounting to one and one-half times the volume of salt water entering, at the Dillon Point site; two and one-tenth times at the Point San Pablo site; and two and one-half times at the Chipps Island site. The reason for the smaller volume required for flushing at the Dillon Point site is due to the existence of an excellent natural depression or sump immediately above. With this natural large sump available, the salt water could be accumulated safely above a barrier in greater volume and depth than would be possible either at the San Pablo or Chipps Island sites and hence the salt water could be discharged with a correspondingly less quantity of fresh water lost in flushing. These estimates by the Army Engineers compare favorably with the actual results of operations experienced at the Lake Washington Ship Canal, where it has been found that a fresh water flow amounting to about two times the volume of salt water discharged above the locks prevents any serious pollution of Lake Union.

The amount of fresh water required for lockage operations directly depends upon the number and size of vessels passing the locks. Data on water-borne traffic based upon investigations of the Army Engineers have been presented in Chapter III. Based upon the actual counts of present traffic and the estimates of future traffic predicted for twenty-five years hence, the number and size of locks which would be required at each site have been selected by the United States Army Engineers and a study made as to the number of lockages through each size of lock required to handle the present and predicted future traffic. As a matter of detailed consideration in estimating the number of lockages through each size of lock, the traffic distribution on two typical days was used to determine the possible combinations which could be made in locking upstream and downstream vessels. Under practical operating conditions, the actual number of lockages would be somewhat less than the total number of vessels passing a site because of these possible combinations.

Based on these studies the average number of lockages per day and the computed salt-water inflow and fresh-water outflow by lockages through standard locks are shown in Table 25. This table shows for each site the lock dimensions, the average number of lockages per day, both for present traffic and predicted traffic 25 years hence, and the inflow of salt water and the outflow of fresh water in acre-feet per lockage and per day for both present and future traffic. It will be noted in this table that the total number of lockages per day for both present and future traffic is less than the total number of trips for the reason previously stated.

The leakage of water around flood gates and lock gates and the operation of fish ladders in a barrier structure also would result in substantial losses of fresh water. In the practical design and operation of the gates, it appears improbable that provision could be made for making them tight against leakage. When the tidal waters below a barrier are at their lower stages, there would be direct leakage of fresh water from a lake, and during periods of high tide there would be leakage of salt water into a lake which would have to be flushed out. Under these conditions, the United States Army Engineers have estimated the fresh-water requirements for leakage and fish ladders at amounts ranging from about 300 second-feet at the Dillon Point site to about to about 500 second-feet at the Chipps Island site, the latter of which would have a larger number of flood gates and hence an increased amount of leakage.

The unavoidable losses from a barrier lake, including evaporation and transpiration, would be of substantial amount. The estimates of evaporation and transpiration are based upon a special study, the results of which are presented in detail in Appendix C. These unavoidable losses from a barrier lake are especially important during the summer months, when they are at a maximum and when at the same time the stream flow entering the delta and bay is a minimum for the season. During the summer months of June to September, inclusive, evaporation in the San Pablo and Suisun Bay areas is estimated at from about five to eight inches in depth per month. Transpiration losses from natural aquatic vegetation per unit of area are of even greater magnitude than evaporation. For tules and cat-tails during the period June to September, inclusive, the average transpiration is estimated at from 1.2 to 1.5 feet in depth per month. Large areas of such aquatic growths are at present distributed on the marshes and along the shores of the bays and channels in the upper bay region. Even after the fullest possible reclamation development is completed, bordering fringes of tules and cat-tails would continue to grow in a barrier lake. Salt grass and pickleweed now occupy large areas of the marshlands adjacent to Suisun and San Pablo bays. If a barrier were constructed under the present conditions of development, the consumption of water by such vegetation on the islands would have to be supplied from a barrier lake. The amount of transpiration from such plants during the summer months is estimated at from about 0.4 to 0.6 foot in depth per month.

TABLE 25

SALT-WATER INFLOW AND FRESH-WATER OUTFLOW PAST A BARRIER BY LOCKAGE OPERATIONS WITH STANDARD LOCKS

Site	Lock number	Lock dimensions, in feet			Average number of lockages per day		Inflow and outflow, in acre-feet[1]					
							Per lockage		Average total per day			
									Present traffic		Estimated traffic, 25 years hence	
		Length	Width	Depth on sill	Present traffic, 1929	Estimated traffic, 25 years hence	Salt-water inflow	Fresh-water outflow	Salt-water inflow	Fresh-water outflow	Salt-water inflow	Fresh-water outflow
Chipps Island	1	150	45	14	29	29	1.87	2.17	54	63	54	63
	2	300	60	20	16	28	7.48	8.26	120	132	209	231
	3	500	90	20	4		18.70	20.66	75	83		
		500	90	36		17	35.23	37.19			599	632
	4	800	90	40	2	6	62.98	66.12	126	132	378	397
Totals					51	80			375	410	1,240	1,323
Corresponding total number of trips					61	97						
Dillon Point	1	150	45	14	25	34	1.78	2.17	44	54	61	74
	2	300	60	20	18	33	7.23	8.26	130	149	239	273
	3	500	90	20	9		18.08	20.66	163	186		
		500	90	36		19	34.61	37.19			658	707
	4	800	90	40	4	8	61.98	66.12	248	264	496	529
Totals					56	94			585	653	1,454	1,583
Corresponding total number of trips					67	112						
Point San Pablo	1	150	45	14	60	90.0	1.77	2.17	106	130	159	195
	2	300	60	20	35	60.0	7.19	8.26	252	289	431	496
	3	500	120	37	29	60.0	47.38	50.96	1,374	1,478	2,843	3,058
		700	120	37	1	5.0	66.34	71.35	66	71	332	357
	4	1,200	120	41	0	0.1	126.94	135.54	0	0	13	14
Totals					125	215.1			1,798	1,968	3,778	4,120
Corresponding total number of trips					148	255						

[1] The figures for inflow and outflow of water are based on average lifts from mean tide level of +1.1, +0.5 and +0.4 for Chipps Island, Dillon Point and Point San Pablo sites, respectively, to the assumed barrier-lake level above all three sites of 3.0 feet above mean sea level.

If reclamation development were completed and all the marshlands utilized for crop production, the transpiration from such vegetation would of course be eliminated. Evaporation and transpiration would be considerably smaller during the winter, late fall and early spring months. The total estimated amounts of transpiration for present conditions are based upon the application of the estimated rates to the areas of present vegetation as shown on Plate IV, and as summarized in Table 21. The total amounts of evaporation are based upon the application of the estimated rates to the areas of open water determined by the recent hydrographic surveys and maps of Suisun and San Pablo bays made by the United States Army Engineers.

The rates of flow required for control of salinity with a barrier with standard locks are shown in Table 26 for each typical site as an average for the months of July, August and September. The figures are shown in second-feet continuous flow for barrier operation (lockage and flushing, gate leakage and fish ladders) and for unavoidable losses from a barrier lake (evaporation and transpiration). The lockage and flushing requirements for present conditions correspond to present traffic, and for future conditions to predicted traffic 25 years hence, based upon estimates of the United States Army Engineers as previously described.

TABLE 26

REQUIRED RATE OF FLOW DURING SUMMER MONTHS FOR CONTROL OF SALINITY WITH A BARRIER WITH STANDARD LOCKS

Demand	Rate of flow, in second-feet					
	Chipps Island site		Dillon Point site		Point San Pablo site	
	Present conditions	Future conditions	Present conditions	Future conditions	Present conditions	Future conditions
Lockage and flushing	700	2,250	800	1,900	2,900	6,100
Gate leakage and fish ladders	500	500	300	300	350	350
Evaporation and transpiration[1]	100	50	1,200	450	2,300	1,050
Totals	1,300	2,800	2,300	2,650	5,550	7,500

[1] Mean values for months of July, August and September.

Water requirements for leakage and fish ladders, as estimated by the United States Army Engineers, are the same under both present and future conditions. The figures for evaporation and transpiration are the mean for the months of July, August and September. The amounts shown under present conditions include transpiration from all the present vegetation on the upper bay marshlands above each barrier site, while the amounts shown under future conditions are based on the assumption that the marshlands are completely reclaimed and utilized for crop production and include only transpiration from vegetation on permanently unreclaimed marginal areas. Thus, transpiration would be greatly reduced under assumed future conditions, while evaporation would be slightly reduced by the elimination of open-water areas within the marshlands. For both present and future conditions, the figures for evaporation and transpiration include only that portion of a barrier lake and the marshlands below the confluence of the Sacramento and San Joaquin rivers and do not include the consumption of water within the delta.

The estimates of water requirements for lockage and flushing involve elements of uncertainty, especially as regards the number and size of vessels predicted for future traffic 25 years hence, the number and size of locks required to accommodate future traffic and finally the number of lockages through each size of lock. Different predictions might be made as to the number and size of vessels and the number and size of locks, which would materially alter the estimated lockage and flushing requirements. However, it is believed that the estimates of traffic 25 years hence and the lockage and flushing requirements computed therefrom for standard locks, as submitted by the United States Army Engineers and presented in the foregoing tables, afford as reasonable an approximation of future traffic conditions as could be made. Because of the uncertainty in accurately predicting future water-borne traffic for any particular time, the estimates need not be considered as being especially applicable to 25 years hence, but may be considered to represent conditions which would occur at some indefinite time in the future, either more or less than 25 years hence.

In considering a barrier in relation to the State Water Plan, future conditions and requirements are the most important and governing criteria. Although it is impossible to predict how fast water-borne traffic may grow, it appears certain that if the industrial, commercial and agricultural activities of the upper bay and delta regions continue to grow as may be reasonably expected, there doubtless would be a substantial and continuous increase in water-borne commerce. The federal government, with the cooperation of Stockton, now is engaged in constructing the Stockton Ship Canal, which will make it possible for ocean-going vessels to transport cargoes to and from points as far upstream as Stockton. This development in itself may be expected to substantially increase the volume of water-borne traffic past the several barrier sites. For these reasons, it is believed that more importance should be attached to estimates of water requirements for a barrier under future conditions, rather than under present conditions. The volume of traffic predicted for 25 years hence might be reasonably expected to occur not many years after it would be possible to complete the construction of a barrier. Moreover, it might be reasonably expected that water-borne traffic at a more distant future time would be greater than that estimated for 25 years hence and such increases would further increase the water requirements above those estimated for future conditions.

Taking the figures estimated for future conditions as they stand, it will be noted that the total amounts of water required range from 2800 and 2650 second-feet for the Chipps Island and Dillon Point sites, respectively, to 7500 second-feet for the Point San Pablo site. The much greater quantity of water required for the Point San Pablo site is due not only to the greater volume of traffic at the farther downstream point, but also to the much greater barrier-lake area and extent of marginal vegetation. During the winter months (December, January and February), these amounts would be decreased because of smaller evaporation and transpiration to about 2750 second-feet for the Chipps

Island site, 2300 second-feet for the Dillon Point site and 6650 second-feet for the Point San Pablo site.

These water requirements for control of salinity under future conditions with a barrier with the usual or standard type of locks are unreasonably large. If a barrier, entailing a large expenditure, were constructed for the primary purpose of preventing invasion of salt water, it appears obvious that the structure, especially the locks, should be so designed as to prevent, if possible, the entrance of salt water into a barrier lake.

Required Control Flow with Salt-clearing Locks.—It is reasonable to assume from the studies of salt-clearing locks, presented in Chapter II, that navigation locks could be designed with salt-clearing devices provided, which would be practical in operation and which would be effective in preventing entrance of salt water into a barrier lake and in substantially reducing losses of fresh water. Based upon the assumed practical and effective operation of salt-clearing devices, estimates have been made and are presented in Table 27 of the

TABLE 27

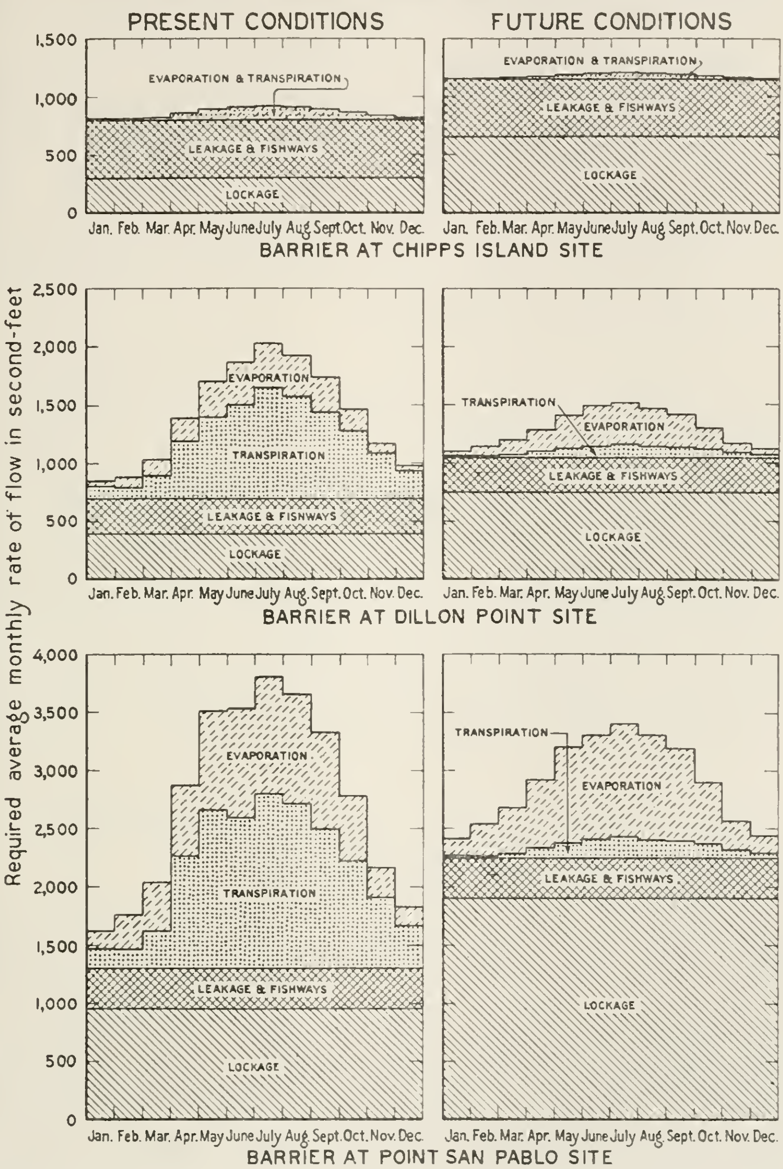
REQUIRED RATE OF FLOW DURING SUMMER MONTHS FOR CONTROL OF SALINITY WITH A BARRIER WITH SALT-CLEARING LOCKS

Demand	Rate of flow, in second-feet					
	Chipps Island site		Dillon Point site		Point San Pablo site	
	Present conditions	Future conditions	Present conditions	Future conditions	Present conditions	Future conditions
Lockage	300	650	400	750	950	1,900
Gate leakage and fish ladders	500	500	300	300	350	350
Evaporation and transpiration[1]	100	50	1,200	450	2,300	1,050
Totals	900	1,200	1,900	1,500	3,600	3,300

[1] Mean values for months of July, August and September.

water requirements for control of salinity with a barrier with salt-clearing locks. The table has been compiled in parallel to Table 26, the only changes in the figures being in the amounts of water estimated for lockage. The water requirements for each month are graphically shown on Plate VI, "Water Requirements for Control of Salinity with a Barrier with Salt-Clearing Locks." The same size of locks and number of lockages for both present and future traffic are used as in Table 25. The water requirements for lockage, based upon the methods of operation of salt-clearing locks described in Chapter II, have been estimated on the assumption that fresh water would be lost in amounts ranging from 77 per cent for the smallest lock to 39 per cent for the largest lock of the total lock volume for both upstream and downstream lockage. On upstream lockage, these amounts of fresh water have been assumed as required to completely eliminate the salt water originally present in the lock. On downstream lockage, it is assumed that these amounts could not be recovered and pumped back to a barrier lake, but would be lost downstream. It is assumed that no salt water would enter a lake through lockage operations and hence no water would be required for flushing as far as lockage operations are concerned. Such amounts of salt water as would infiltrate into a barrier lake around the

PLATE VI



WATER REQUIREMENTS
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floodgates and lock gates would have to be flushed out and the water requirements for this operation are included in the amounts for gate leakage. The water requirements for gate leakage and fish ladders and evaporation and transpiration are identical to those in Table 26.

Here again, the important figures are those for future, rather than for present conditions. The water requirements for control of salinity under future conditions with a barrier utilizing salt-clearing locks are estimated for the summer months at 1200 second-feet for Chipps Island site, 1500 second-feet for Dillon Point site and 3300 second-feet for Point San Pablo site, or a very substantial reduction from the requirements with standard locks. During the winter months (December, January and February), these requirements would be reduced to about 1150, 1100 and 2450 second-feet for the Chipps Island, Dillon Point and Point San Pablo sites, respectively.

It is believed that these estimates of water requirements for control of salinity with locks equipped with salt-clearing devices are reasonable and in conformity with the operating results which should be attained if the navigation locks in a barrier were properly designed. It may be assumed that these estimates represent the minimum amounts of water which would be required for control of salinity with a barrier under both present and future conditions. The actual details of design and operation of locks might be considerably different, such as, for example, a design with multiple-compartment locks as has been suggested by C. E. Grunsky. However, it is not believed that water requirements for lockage could be reduced below those estimated for salt-clearing locks by any different design of locks, practical in operation and feasible in cost. The attainment of these results would require additional expenditures, both in capital cost of construction of such locks and in the annual operating cost of a barrier. The estimated amounts of increased capital and annual costs have been presented in Chapter II. The studies show, however, that if the reduced quantities of water indicated could be effected by construction and operation of this type of lock, the value of the water saved would be greater than the additional cost.

The water requirements for control of salinity with a barrier with salt-clearing locks, as shown in Table 27 and Plate VI, have been adopted as the basis for the following estimates of required supplementary water supply and for the final economic studies. The discussion previously presented in regard to the element of uncertainty in these estimates as to magnitude and character of future water-borne traffic, apply with equal force to the estimates of water requirements with a barrier with salt-clearing locks. The assumed magnitude and character of water-borne traffic upon which the estimates of water requirements for lockage for future conditions are based, are believed to be as fair an approximation of future traffic conditions as could be made. As previously noted, however, it might be reasonably expected that the volume and character of water-borne traffic at a more distant future time would be greater than that assumed in the estimates and the water requirements might be still greater than those estimated for future conditions.

Control of Salinity by Stream Flow Without a Barrier.

The alternate plan for control of saline invasion by means of stream flow without a barrier is based upon an intensive study of the variation and control of salinity in the upper bay and delta. The results of the investigation are presented in detail in another report.* It is concluded that the invasion of saline water into the delta could be positively prevented and salinity controlled at the lower end of the delta by provision of a fresh-water supply sufficient to maintain a flow in the two rivers of not less than 3300 second-feet past Antioch into Suisun Bay. With such a control at the mouth of the rivers, the consumptive needs of the delta would be fully served and a source of diversion of a fresh-water supply of equivalent dependability and quality to that which could be provided in a barrier lake would be available in the channels of the delta and not far distant from the upper bay area.

The control of salinity as proposed by means of stream flow does not rest upon theory, but is supported by the actual observed occurrence of natural control which has been effected by stream flow actually available during the past ten years. It offers not only a positive and dependable means of controlling salinity, but also a method that would be feasible and economical of consummation. Under the proposed plan of control, with the major reservoir units of the State Water Plan operating to provide the required water supplies for this purpose and all other needs in the Great Central Valley, delta and upper bay region, saline conditions in the upper bay channels would be improved over those which have occurred during the last ten to thirteen years and would tend to approach the equivalent of conditions which naturally occurred prior to the extensive development of irrigation, storage and reclamation works in the Sacramento and San Joaquin valleys.

Total Water Requirements for Control of Salinity.

The total monthly water requirements for control of salinity with and without a barrier are shown in Table 28. Those for a barrier are based upon the use of salt-clearing locks. The requirements for a barrier are also graphically shown on Plate VI, which illustrates for each barrier site not only the total water required each month, but also the portion of the total for lockage, gate leakage and fish ladders, evaporation and transpiration.

As shown by Table 28, the amount of water required for control of salinity without a barrier is greater than the amounts required with a barrier at any site, except in certain months for Point San Pablo site, where a greater amount would be required from May to September, inclusive, under present conditions and from June to August, inclusive, under assumed future conditions. The variation in monthly amounts of water required with a barrier directly reflect the variation in amounts of evaporation and transpiration. These reach their maximum during the summer months, but materially decrease during the winter months. However, as previously pointed out, the important period of water requirements for salinity control, either with or without a

*Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

barrier, is during the summer months, when the available stream flow entering the delta and bay is small in amount and generally insufficient to take care of these control requirements. The deficiencies in meeting these requirements from the available stream flow must therefore be supplied from mountain storage reservoirs during the period of deficiency. During the winter months there is usually an abundance of water flowing into the delta and bay and hence the requirements for salinity control would be more than taken care of.

TABLE 28

MONTHLY WATER REQUIREMENTS FOR CONTROL OF SALINITY WITH AND WITHOUT A BARRIER

Month	Water requirements without a barrier, in acre-feet	Water requirements with a barrier, in acre-feet[1]					
		Chipps Island site		Dillon Point site		Point San Pablo site	
		Present conditions	Future conditions	Present conditions	Future conditions	Present conditions	Future conditions
January	203,000	50,000	71,000	52,000	68,000	100,000	148,000
February	184,000	45,000	64,000	49,000	64,000	98,000	141,000
March	203,000	51,000	71,000	64,000	74,000	125,000	165,000
April	196,000	51,000	70,000	83,000	77,000	171,000	174,000
May	203,000	55,000	73,000	105,000	87,000	216,000	197,000
June	196,000	54,000	71,000	111,000	89,000	210,000	197,000
July	203,000	57,000	74,000	125,000	93,000	234,000	209,000
August	203,000	56,000	73,000	119,000	90,000	225,000	204,000
September	196,000	53,000	71,000	104,000	85,000	198,000	190,000
October	203,000	53,000	72,000	90,000	80,000	171,000	179,000
November	196,000	50,000	69,000	69,000	70,000	129,000	153,000
December	203,000	51,000	71,000	60,000	69,000	112,000	150,000
Totals	2,389,000	626,000	850,000	1,031,000	946,000	1,989,000	2,107,000

[1] Barrier water requirements based on use of salt-clearing locks.

Stream Flow Available for Salinity Control.

During the period 1920 to 1929, inclusive, stream gaging stations immediately above the delta were maintained on the Sacramento and San Joaquin rivers and their tributaries. Based upon measurements at these stations, the stream flow into the delta has been compiled during this period. These records are presented in detail in Bulletin No. 27 and will not be repeated here. In addition to these records of inflow, experimental data have been available as previously described for closely estimating the consumption of water in the delta. Based upon the records of inflow and the estimated consumptive use in the delta, the monthly flow into Suisun Bay has been estimated for the ten-year period and is shown in Table 29. It will be noted that, during several of the last ten years, notably in the dry years of 1920, 1924 and 1926, there was no stream flow into Suisun Bay during several of the summer months. During five of the last ten years, namely, 1921, 1922, 1923, 1925 and 1927, some water flowed into Suisun Bay during each month of the year. During those months and years in which there was no flow into Suisun Bay, there was insufficient flow into the delta to take care of even the consumptive needs therein, in accord with the monthly demand for water. The amounts of such shortages have been discussed previously.

Water supplies in addition to those from the Sacramento and San Joaquin River systems would be available from local streams entering

TABLE 29

STREAM FLOW INTO SUISUN BAY DURING PERIOD 1920 TO 1929

Month	Stream flow, in acre-feet										
	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	Mean
January	573,000	5,473,000	1,477,000	2,531,000	593,000	1,064 000	715,000	2,478,000	1,520,000	779,000	1,720,000
February	622,000	4,677,000	3,475,000	1,451,000	1,226,000	5,604,000	4,570,000	7,152,000	2,576,000	1,355,000	3,271,000
March	1,670,000	4,514,000	3,415,000	1,368,000	539,000	2,547,000	1,756,000	4,782,000	5,354,000	1,106,000	2,705,000
April	2,257,000	3,063,000	3,622,000	3,143,000	517,000	3,890,000	3,947,000	4,846,000	5,060,000	943,000	3,129,000
May	2,232,000	3,327,000	5,904,000	2,698,000	195,000	3,320,000	1,230,000	3,237,000	1,886,000	1,104,000	2,513,000
June	896,000	2,212,000	4,417,000	1,328,000	0	1,274,000	219,000	2,071,000	457,000	541,000	1,342,000
July	0	335,000	770,000	508,000	0	237,000	0	387,000	89,000	8,000	233,000
August	0	41,000	85,000	91,000	0	6,000	0	78,000	0	0	30,000
September	10,000	117,000	156,000	247,000	25,000	176,000	151,000	230,000	202,000	166,000	148,000
October	420,000	333,000	461,000	534,000	285,000	432,000	372,000	474,000	398,000	333,000	404,000
November	1,962,000	474,000	759,000	453,000	743,000	551,000	1,212,000	1,350,000	612,000	388,000	850,000
December	4,099,000	1,251,000	2,758,000	519,000	1,052,000	793,000	2,803,000	1,274,000	734,000	2,299,000	1,758,000
Totals	14,741,000	25,817,000	27,299,000	14,871,000	5,175,000	19,894,000	16,975,000	28,359,000	18,888,000	9,022,000	18,103,000

a barrier lake during the winter months, which would increase the available supply somewhat. However, these local streams generally dry up in the summer months and hence would not increase the available supply in a barrier lake during the summer period. Such additional supplies in the winter months would be of no benefit because the supplies from the Sacramento and San Joaquin rivers during those months would be far more than ample to take care of the salinity control requirements. For this reason no attempt has been made to estimate the amount of such local supplies which would be confined to the winter months only.

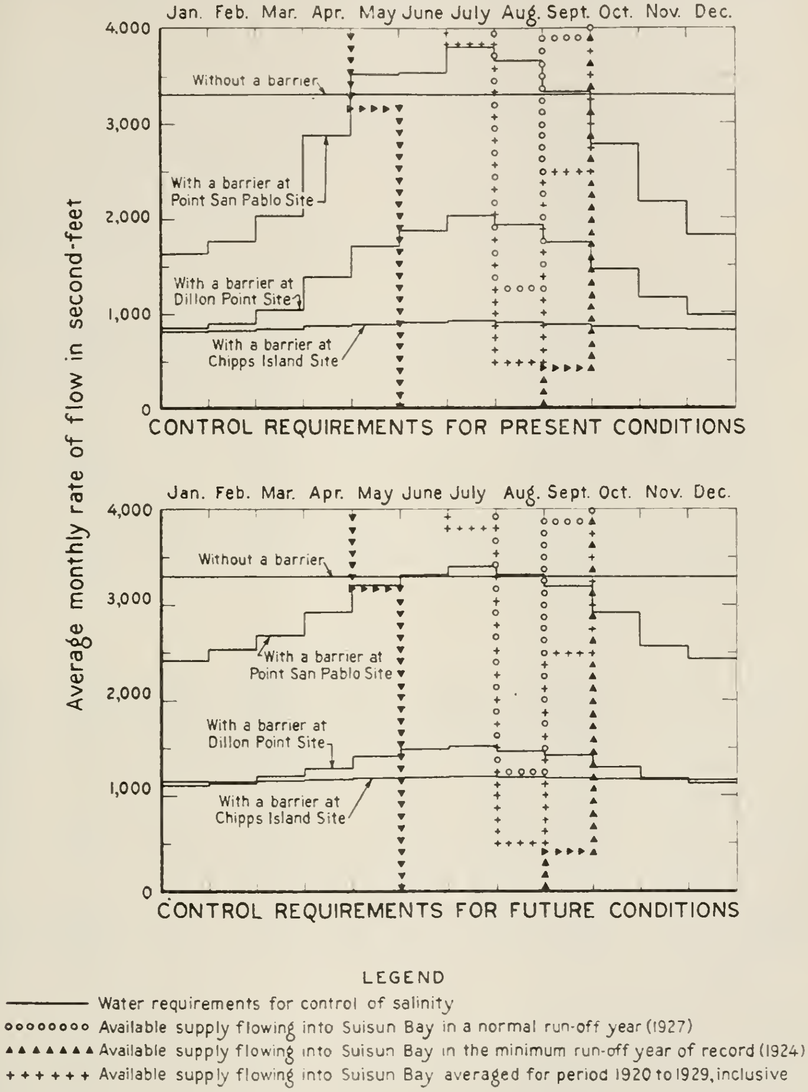
The comparative amounts of available stream flow and water requirements for salinity control with and without a barrier are graphically illustrated on Plate VII, "Relation of Available Water Supply to Water Requirements for Control of Salinity With and Without a Barrier." The diagrams on this plate show the available stream flow into Suisun Bay, during the period of low stream flow, for the minimum and maximum years and the mean of all years during the period 1920 to 1929, inclusive; and the water requirements for salinity control with a barrier with salt-clearing locks under both present and assumed future conditions, and for control by stream flow without a barrier.

Supplemental Water Supply Required for Control of Salinity

The maintenance of the required flow for control of salinity either with or without a barrier would necessitate the furnishing of additional water supplies released from mountain storage to supplement the stream flow such as has been available during the last ten years. These additional supplemental supplies would be required during the summer months of low stream flow. Based upon the control requirements as shown in Table 28, and stream flow available during the period 1920 to 1929 as shown in Table 29, the amounts of supplemental water supply required for control of salinity with and without a barrier have been estimated and are shown in Table 30. Figures are shown for each month of deficiency each year, and the total for each year. The supplemental supplies required for control of salinity with a barrier are shown for both present and future conditions, using salt-clearing locks. In computing the amounts of supplemental supply with a barrier, the usable storage capacities for each barrier site were credited as an additional water supply reducing the amount of supplemental supply which would be required otherwise. The amounts of supplemental water supply required with a barrier under future conditions are of chief importance as compared to the amounts required without a barrier, inasmuch as they are based upon the conditions which may be reasonably expected to occur soon after a barrier could be constructed and put into operation. The figures for present conditions are therefore of interest only as a comparison with the more important and significant figures for future conditions.

The required supplemental supplies have been computed for each month as the difference between monthly stream flow and monthly demand, or the average rate of flow and rate of demand for the month. Actually, however, the stream flow in certain months may be so distributed in a general rise or fall that it would be greater than the demand for part of the month and less than the demand for the remaining part of the month, but with an average flow only slightly

PLATE VII



RELATION OF

AVAILABLE WATER SUPPLY

TO

WATER REQUIREMENTS FOR CONTROL OF SALINITY

WITH AND WITHOUT A BARRIER

greater or less than the average demand. On account of such distribution of flow, the supplemental supply both with and without a barrier would be greater than that computed using total monthly flow or

TABLE 30

SUPPLEMENTAL WATER SUPPLY FOR CONTROL OF SALINITY WITH AND WITHOUT A BARRIER

Month and year	Supplemental supply required without a barrier, in acre-feet	Supplemental supply required with a barrier, in acre-feet[1]					
		Chipps Island site		Dillon Point site		Point San Pablo site	
		Present conditions	Future conditions	Present conditions	Future conditions	Present conditions	Future conditions
1920—							
July	203,000	12,000	29,000	50,000	18,000	79,000	54,000
August	203,000	56,000	73,000	119,000	90,000	225,000	204,000
September	186,000	43,000	61,000	94,000	75,000	188,000	180,000
Total annual	592,000	111,000	163,000	263,000	183,000	492,000	438,000
1921—							
August	162,000	0	0	3,000	0	29,000	8,000
September	79,000	0	0	0	0	81,000	73,000
Total annual	241,000	0	0	3,000	0	110,000	81,000
1922—							
August	118,000	0	0	0	0	0	0
September	40,000	0	0	0	0	27,000	0
Total annual	158,000	0	0	0	0	27,000	0
1923—							
August	112,000	0	0	0	0	0	0
1924—							
May	7,000	0	0	0	0	0	0
June	196,000	9,000	26,000	36,000	14,000	75,000	43,000
July	203,000	57,000	74,000	125,000	93,000	234,000	209,000
August	203,000	56,000	73,000	119,000	90,000	225,000	204,000
September	171,000	28,000	46,000	79,000	60,000	173,000	165,000
Total annual	780,000	150,000	219,000	359,000	257,000	707,000	621,000
1925—							
August	197,000	5,000	22,000	38,000	9,000	64,000	43,000
September	20,000	0	0	0	0	22,000	14,000
Total annual	217,000	5,000	22,000	38,000	9,000	86,000	57,000
1926—							
July	203,000	12,000	29,000	50,000	18,000	79,000	54,000
August	203,000	56,000	73,000	119,000	90,000	225,000	204,000
September	44,000	0	0	0	0	46,000	38,000
Total annual	450,000	68,000	102,000	169,000	108,000	350,000	296,000
1927—							
August	125,000	0	0	0	0	0	0
1928—							
July	114,000	0	0	0	0	0	0
August	203,000	11,000	28,000	80,000	19,000	215,000	169,000
Total annual	317,000	11,000	28,000	80,000	19,000	215,000	169,000
1929—							
July	195,000	4,000	21,000	42,000	10,000	71,000	46,000
August	203,000	56,000	73,000	119,000	90,000	225,000	204,000
September	30,000	0	0	0	0	32,000	24,000
Total annual	428,000	60,000	94,000	161,000	100,000	328,000	274,000
Average annual	342,000	40,500	62,800	107,300	67,600	231,500	193,600
Maximum annual	780,000	150,000	219,000	359,000	257,000	707,000	621,000
Minimum annual	112,000	0	0	0	0	0	0

[1]Barrier water requirements based upon use of salt-clearing locks.

average flow during the month. Taking this factor into account, the annual average, maximum and minimum amount of supplemental supply required for control of salinity without a barrier have been computed as 384,000, 850,000 and 149,000 acre-feet respectively. These more accurate figures have been used in Bulletin No. 27 and in Bulletin No. 25. Increases of the same proportion would be obtained for the supplemental supply required with a barrier if the more accurate distribution of stream flow were used. However, for the purpose of this study, the amounts computed from average monthly flow are used since consideration is directed chiefly to the difference in amounts of supplemental supply required with and without a barrier and these differences would be practically the same if the more detailed distribution of stream flow were used.

The amounts of supplemental water supply required for salinity control with a barrier with salt-clearing locks are less than those required for control without a barrier. The differences in required supplemental water supply have been computed and are presented in Table 31 for each year from 1920 to 1929, inclusive.

TABLE 31

DIFFERENCE IN ANNUAL AMOUNT OF SUPPLEMENTAL WATER SUPPLY FOR CONTROL OF SALINITY WITH AND WITHOUT A BARRIER

(With barrier equipped with salt-clearing locks)

Year	Difference in supplemental water supply, in acre-feet					
	Chipps Island site		Dillon Point site		Point San Pablo site	
	Present conditions	Future conditions	Present conditions	Future conditions	Present conditions	Future conditions
1920	481,000	429,000	329,000	409,000	100,000	154,000
1921	241,000	241,000	238,000	241,000	131,000	160,000
1922	158,000	158,000	158,000	158,000	131,000	158,000
1923	112,000	112,000	112,000	112,000	112,000	112,000
1924	630,000	561,000	421,000	523,000	73,000	159,000
1925	212,000	195,000	179,000	208,000	131,000	160,000
1926	382,000	348,000	281,000	342,000	100,000	154,000
1927	125,000	125,000	125,000	125,000	125,000	125,000
1928	306,000	289,000	237,000	298,000	102,000	148,000
1929	368,000	334,000	267,000	328,000	100,000	154,000
Average for period	301,500	279,200	234,700	274,400	110,500	148,400
Maximum for period	630,000	561,000	421,000	523,000	131,000	160,000
Minimum for period	112,000	112,000	112,000	112,000	73,000	112,000

The differences shown in Table 31 represent the indicated amounts of saving in supplemental water supply by control of salinity with a barrier, as compared to the amounts required for control without a barrier. The maximum indicated saving in supplemental water supply which would result from the use of a barrier under future conditions amounts to 561,000 acre-feet per year for the Chipps Island site, 523,000 acre-feet for the Dillon Point site and 160,000 acre-feet for the Point San Pablo site. Under present water-borne traffic and present conditions of vegetation and development in the upper bay marshlands, the indicated maximum saving amounts to 630,000 acre-feet at the Chipps Island site, 421,000 acre-feet at the Dillon Point site and 131,000 acre-feet at Point San Pablo site. However, these figures for present conditions with a barrier should not be considered as significant, inasmuch as the volume of water-borne traffic may be expected to grow and approach the volume predicted for 25 years hence in a few years after a barrier could be constructed and put into operation. Whether or not the complete reclamation and utilization of the upper bay marshlands would be effected in the same length of time as the predicted growth in water-borne traffic is questionable. The assumption that the development and utilization of these lands would be complete in estimating the future unavoidable losses by evaporation and transpiration from a barrier lake is in favor of control with a barrier as compared to that without a barrier.

If the standard type of locks were used in a barrier structure, the indicated maximum saving in supplemental water supply with a barrier would be reduced under future conditions to annual amounts of 172,000 acre-feet for Chipps Island site and 240,000 acre-feet for Dillon Point site. For Point San Pablo site, a much greater supplemental supply than that required without a barrier, amounting to 1,262,000 acre-feet per year, would be required.

Detailed studies have been carried out under both the proposed initial and ultimate developments of the State Water Plan, with a schedule of operation providing for the amounts of water for salinity control by stream flow without a barrier. The details of these studies are presented in other reports.* Under the initial plan of operation and development of the State Water Plan, Kennett reservoir, on the upper Sacramento River, would be constructed with a capacity of 2,940,000 acre-feet and operated to supplement the flow from unregulated streams and from return irrigation water, to control floods, generate a large block of hydroelectric power, maintain a navigable depth of five to six feet in the Sacramento River from Sacramento to Chico Landing, supply irrigation demands in the Sacramento Valley above Sacramento without deficiency up to 6000 second-feet maximum draft in July, furnish a complete supply without deficiency for the consumptive demands in the Sacramento-San Joaquin Delta, make available a water supply in the delta to serve. without deficiency, the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County, make available a supply, without deficiency, of 896,000 acre-feet for crop lands in San Joaquin Valley now being served from the San Joaquin River above the mouth of the Merced River, and finally furnish a supply of not less than 3300 second-feet past Antioch into Suisun Bay for controlling salinity to the lower end of the delta without a barrier. Under the ultimate development and operation of the State Water Plan, 24 major reservoirs would be constructed with an aggregate capacity of 17,817,000 acre-feet and operated to supply the ultimate water requirements of the Sacramento and San Joaquin valleys and the upper San Francisco Bay region, and in addition furnish a water supply flowing past Antioch into Suisun Bay of not less than 3300 second-feet for control of salinity without a barrier. The results of the studies of water supply, yield and demand show conclusively that in addition to supplying the full water requirements for the initial and ultimate development of the Sacramento and

* Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930. Bulletin No. 26, "Sacramento River Basin," Division of Water Resources, 1931.

San Joaquin valleys, the Sacramento-San Joaquin Delta and upper bay region, ample water supplies would be available for providing positive control of salinity at the lower end of the delta without a barrier. If water supplies were needed in addition to those developed by the proposed major reservoir units of the State Water Plan, studies show that regulated supplies could be substantially increased by construction of other available reservoirs in the Sacramento Basin and by development and diversion of supplies from the Eel River. Therefore, the indicated saving in supplemental supply with a barrier would not be needed to furnish all initial and ultimate requirements of the Great Central Valley, delta and upper bay region.

Value of Supplemental Water Supply.—Inasmuch as the above studies indicate that less amounts of supplemental water supply for salinity control would be required with a barrier than without a barrier, it is of interest to consider the value of such supplies. This may be best measured by a consideration of the costs of reservoir supplies developed in the State Water Plan in the Sacramento Valley from which supplemental water supplies would have to be furnished. The annual cost per acre-foot of water supplies developed in the major reservoirs in the Sacramento Valley ranges from $1 for the Kennett reservoir to $3.33 for the Oroville reservoir with a weighted average annual cost for all reservoirs of about $2. Therefore, the annual value of the indicated amounts of water saved in controlling salinity with a barrier may be estimated at $2 per acre-foot. On this basis, the estimated values of water saved are shown in Table 32.

TABLE 32

INDICATED VALUE OF ANNUAL AMOUNT OF SUPPLEMENTAL WATER SUPPLY SAVED BY CONTROLLING SALINITY WITH A BARRIER UNDER FUTURE CONDITIONS

(With barrier equipped with salt-clearing locks)

Barrier site	Minimum annual saving	Average annual saving	Maximum annual saving
Chipps Island	$224,000	$558,000	$1,122,000
Dillon Point	224,000	549,000	1,046,000
Point San Pablo	224,000	297,000	320,000

The above estimates of the value of water saved by controlling salinity with a barrier should be considered only as indicative and at the best an approximation of the actual saving that might be realized under future operating conditions. The various elements on which these estimates are based, especially as to amount of future water-borne traffic and the extent of development of the upper bay marshlands, are uncertain. However, it is evident that the control of the salinity by a barrier at either an upper or intermediate site might save a substantial amount of water, while at a lower site below San Pablo Bay the amount of water that might be saved would be relatively small. In order to obtain such saving in water as might be effected with a barrier with salt-clearing locks, capital expenditures of $43,500,000, $54,000,000 and $82,000,000 and annual expenditures of $3,600,000, $4,300,000 and $6,300,000 for a barrier at Chipps Island, Dillon Point and Point San

Pablo sites, respectively, would be involved. Therefore, from the standpoint alone of indicated water savings, the annual cost per acre-foot of the maximum indicated amounts of water saved would be in excess of $6, $8 and $39 for the Chipps Island, Dillon Point and Point San Pablo sites, respectively, as compared to an average annual cost of $2 per acre-foot for developing equal amounts of water in mountain storage reservoirs. The water that might be saved in controlling salinity with a barrier instead of by stream flow without a barrier, although of substantial amount, could be furnished from mountain storage reservoirs over and above the supplies required for ultimate development of the Great Central Valley, delta and the upper San Francisco Bay region at a fraction of the cost a barrier would entail; and would not be needed to furnish a full supply for all purposes.

Comparative Merits of Alternate Methods for Control of Salinity.

The primary purpose of controlling the invasion of salinity into the upper bay and delta is twofold: first, to protect the water supply and lands of the delta from saline invasion; and second, to provide a dependable source of fresh-water supply in the lower Sacramento and San Joaquin rivers for industrial, municipal and agricultural uses in the upper San Francisco Bay region, which would be unaffected and unlimited by any possibility of saline pollution. This twofold objective of salinity control could be attained either with or without a barrier. With either method, the delta would be fully protected from saline invasion. With either method, a source of fresh-water supply free from saline pollution would be provided from which necessary fresh-water supplies, if made available, could be furnished to the delta and upper bay region for all uses. Control of salinity with a barrier at an intermediate or lower location would have the added advantage of bringing the source of supply closer to the area to be served in the upper bay region and thus decreasing the length, average size and cost of conduits required to divert and distribute the supplies for various purposes. Various advantages and disadvantages of a barrier as related to present and future developments and activities of the upper bay region and delta have been previously discussed in Chapter III. The final considerations of comparative costs of the two alternate methods of salinity control, together with the comparative costs of works required for water service and development of the delta and upper bay region, will be presented hereafter.

WATER SERVICE FOR UPPER SAN FRANCISCO BAY REGION

In order to serve the water demands of municipalities, industries and agricultural lands in the upper bay region, conduits would be required to convey the water from the most suitable points of diversion and distribute the same to the several areas and interests. Under either alternate method of salinity control, with or without a barrier, the necessary provisions for main conduits and distribution facilities would be fundamentally the same. The plan of service would in general involve main conduits designed and located to economically and conveniently serve the combined needs of agriculture, municipalities and industries. The only salient difference in the physical features of the conduit systems required under the alternate methods of salinity control with and without a barrier would be in the length and size of conduits. With salinity controlled at the lower end of the delta without a barrier, water would have to be conveyed from suitable diversion points far enough upstream to insure fresh-water supplies at all times. The conduits required to serve the upper bay region would in general be longer and larger in size for the same service areas than with a barrier at any of the three typical sites. However, the conduits with an upper barrier site at Chipps Island would be only slightly shorter than without a barrier.

Preliminary studies have been made of the main conduit units which would be required to serve the ultimate water requirements of the upper bay area, first, with salinity controlled by stream flow without a barrier, and second, with salinity controlled with a barrier at each of the three typical sites chosen for study. The main conduit units required under the first plan, without a barrier, are shown on Plate VIII, "Main Water Service Conduits and Reclamation Works for Ultimate Development of Upper San Francisco Bay Area." This plate shows the general location of two main conduits, one north and one south of the bay, extending from suitable diversion points in the delta channels and located to serve the ultimate needs of the upper bay region on either side of the bay.

The main conduit on the north side, designated the "Solano-Napa County Conduit," would have a point of diversion at the westerly end of Lindsay Slough, above Rio Vista, and extend westerly through the Suisun Valley area and pierce the divide between Suisun and Napa valleys in a tunnel and extend across the Napa River to serve the upper San Pablo Bay area. The total length of this main conduit would be 34 miles. It is designed as an open concrete-lined canal for the greater part of its length, with two pumping plants to lift the water and carry the conduit in a central location, from which the combined needs of the area could be conveniently served. The elevation of the water in the conduit at various points along its route is graphically shown on the hydraulic profile on the upper diagram. The designed capacity of this conduit is based upon the delivery of the necessary imported water supplies for the area north of the bay to take care of the ultimate water requirements as previously presented.

The main conduit on the south side of the bay, designated the "Contra Costa County Conduit," would have a point of diversion at the westerly end of Rock Slough, near Knightsen, and extend in a westerly direction, with the water successively elevated by pumping plants, into the Clayton and Ygnacio valleys. This main conduit is designed also as an open concrete-lined canal with a capacity required for serving the ultimate water requirements on the south side of the bay. The water level in this conduit at various points along its route is graphically shown on the hydraulic profie on the lower diagram. A pipe line is provided from Bay Point to Martinez to serve the local industrial and municipal areas. The Benicia area would be conveniently served by a branch pipe line crossing Carquinez Strait. The pipe line could be extended westerly from Martinez as shown to serve the area along the easterly shore of San Pablo Bay from Oleum to Richmond.

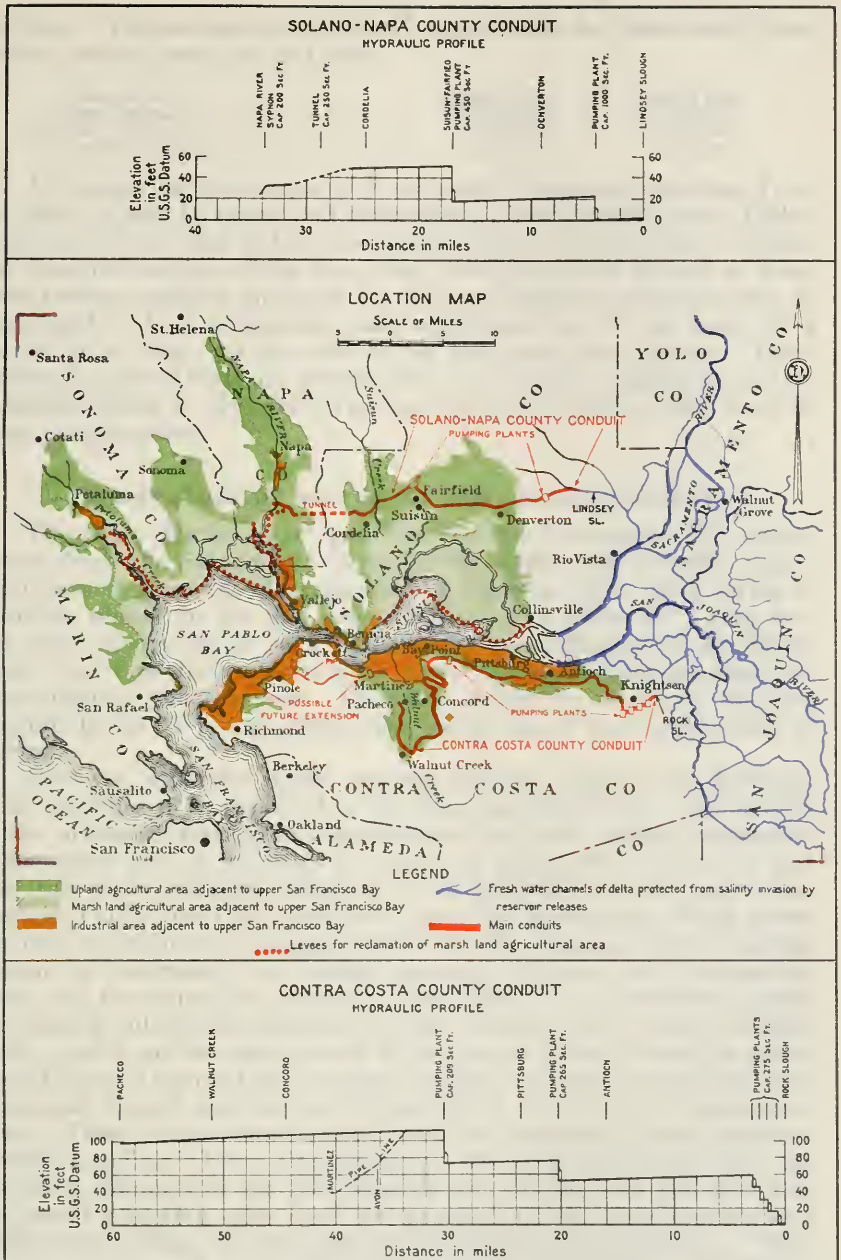
However, there is some question as to whether the last-named area would be best served ultimately from the lower Sacramento River or from an extension of the East Bay Municipal Utility District system.

These main conduits are located with a view to serving the combined needs of agricultural, industrial and municipal developments. The water level would afford considerable pressure to both the present and potential industrial area along both sides of the bay and likewise to the urban and suburban districts. It would also serve considerable areas of agricultural lands by gravity but additional small pumping lifts would be required to serve the areas lying above the conduits. Although these preliminary plans are in no sense to be taken as final, they are deemed to represent a reasonable location and design for main conduits which would be required to serve the upper bay region under the conditions of predicted ultimate demand and development. The general location shown would be about the same if salinity were controlled with a barrier instead of without a barrier. Actual diversion points would be changed and the conduits shortened somewhat and their size decreased over certain portions. In order to obtain the greatest economy in capital cost and annual carrying charges for water distribution, plans should be made for a unified development that would best serve the combined needs of agricultural, industrial and municipal interests. In planning for the future this must be constantly kept in mind and it would be equally true whether or not a barrier were constructed. The needs of all interests could be combined in the consummation of a unified plan of water service that would efficiently and economically serve the immediate future and ultimate developments.

Cost of Main Water Service Conduits.

Preliminary estimates of cost have been prepared for the main service conduits required for furnishing the ultimate water requirements of the upper bay region under the alternate methods of salinity control, with and without a barrier. The estimated cost of service conduits without a barrier is based on the preliminary plans shown on Plate VIII. Unit costs have been used, strictly comparable with those on which the costs of the main conveyance units of the State Water Plan in the San Joaquin Valley are based. The total estimated capital cost of these main conduits, including a liberal allowance for incidentals, contingencies and other overhead expenditures, and interest during construction at 4½ per cent compounded semiannually, totals $10,500,000. The annual cost including interest at 4½ per cent, amortization on a 4 per cent sinking fund basis for 40-year bonds, and depreciation, operation and maintenance, is estimated at $1,400,000. These conduits would deliver 403,000 acre-feet per year at points along the conduits at an average annual cost of $3.50 per acre-foot or about 1.1 cents per thousand gallons.

Preliminary estimates of cost also have been made for main conduit units providing equivalent service from a barrier lake above each of the three typical sites. The designs and cost estimates have been made on an exactly equivalent basis to that for conduits extending from



MAIN WATER SERVICE CONDUITS
AND RECLAMATION WORKS
FOR
ULTIMATE DEVELOPMENT
OF UPPER SAN FRANCISCO BAY AREA

the delta. The estimated capital and annual costs for these main water service conduit units are as follows:

Barrier site	*Capital cost*	*Annual cost*
Chipps Island	$7,700,000	$1,100,000
Dillon Point	5,500,000	900,000
Point San Pablo	4,000,000	700,000

In comparing these costs with the cost of conduits extending from the delta, it will be noted that those from a barrier lake above Dillon Point and Point San Pablo sites would entail a substantially smaller cost than the conduits from the delta. The reductions in cost of these main service conduits indicated by these preliminary estimates may be considered to be a reasonably close approximation of the value of a barrier in a water service system for the upper bay region. These indicated reduced costs are directly due to a barrier bringing the source of supply closer to the area served and are an advantage that must be given consideration.

IMPORTATION OF WATER TO SAN JOAQUIN VALLEY

The State Water Plan* provides for the importation of surplus waters from the Sacramento River to the upper San Joaquin Valley by diversion from the Sacramento-San Joaquin Delta in a series of pumping plants up the San Joaquin River (see Plate V). If a barrier were constructed at some point below the confluence of the Sacramento and San Joaquin rivers, it would act as a diversion dam for accomplishing this purpose. Diversion would be made up the San Joaquin River by pumps lifting the water out of the barrier lake so created.

However, a barrier is not essential for the transfer and diversion of the supplies to be exported to the San Joaquin Valley. The studies of the present investigation demonstrate that with salinity controlled at the lower end of the delta by means of stream flow without a barrier, the water supplies required to be imported to the upper San Joaquin Valley could be transferred from the Sacramento River across the delta to the lowest pumping unit of the San Joaquin River pumping system by enlarging the channel capacity between the Sacramento River and the upper San Joaquin River delta. The preliminary plans for channel enlargement provide for the construction of a new channel from a point on the Sacramento River below Hood, extending along the old natural channel of Snodgrass Slough to a triple connection with Georgiana Slough and the north and south forks of the Mokelumne River. These latter channels then would be enlarged to some extent to Central Landing. From this point the water would flow through the combined channels of the San Joaquin and Middle and Old rivers to the initial pumping unit near the junction of the San Joaquin and Middle rivers, these channels also being enlarged to some extent. With the construction of this additional channel capacity, there would be no physical impediment to the transfer of surplus waters from the

* Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

Sacramento River across the delta for exportation to the San Joaquin Valley.

COMPARATIVE MERITS OF ALTERNATE PLANS OF DEVELOPMENT WITH AND WITHOUT A BARRIER

The continuation of growth and the realization of the ultimate potentialities of industrial, agricultural and municipal developments in the upper San Francisco Bay region are dependent upon the furnishing of ample and dependable fresh-water supplies for all these developments. The available local water resources capable of feasible development have been shown to be inadequate for the most part to take care of the ultimate water requirements of the upper bay region. Even at the present time, shortages exist in available local water supplies meeting the present needs. This is particularly true for the industrial and agricultural development in the upper portion of Contra Costa County, immediately south of Suisun Bay, covering the entire area from Martinez to the westerly end of the delta. In addition to this problem of immediate shortage, the cost of water for industrial and municipal purposes is relatively high and a cheaper supply would be desirable. Additional fresh-water supplies, therefore, must be imported into the upper bay region, for both present and future demands, from the most suitable and economical source available.

The nearest and the most logical source of fresh-water supplies required to be imported is the lower Sacramento and San Joaquin rivers. This source of supply already is being used to some extent to meet the needs of the upper bay region. The city of Antioch obtains its supply from the lower San Joaquin River and a public utility serving a large part of upper Contra Costa County also is obtaining a considerable portion of its water supply by means of a recently completed development with a point of diversion near Mallard Slough, about two miles below the city of Pittsburg. In addition, the industries in the Antioch-Pittsburg area obtain a large part of their fresh-water requirements from the river with independent private diversion works. The precedent for the utilization of the lower Sacramento and San Joaquin rivers as a source of fresh-water supply for the upper bay region, therefore, has been established. The period of availability, and hence dependability, of water supplies now or hereafter made available in the lower Sacramento and San Joaquin rivers is limited by the invasion of saline water into the upper bay and lower delta channels, which takes place each year during the period of low stream flow, resulting in the waters becoming too saline for fresh-water uses. Therefore, in order to make this source of supply dependable and available at all times for the fresh-water needs of the upper bay region, the invasion of salinity must be controlled by some suitable method to the extent of positively protecting the supply furnished at suitable points of diversion. With the invasion of salinity controlled by some suitable means, it has been demonstrated that ample fresh-water supplies from the Sacramento and San Joaquin rivers could be made available at suitable nearby diversion points for conveyance to the upper bay region to take care of all present and ultimate water demands of industries, municipalities and agricultural lands. The essential element involved in obtaining a dependable fresh-water supply from the lower Sacramento and San Joaquin rivers is therefore a control of saline invasion in order to positively protect this source of fresh-water supply. As previously demonstrated, this essential requirement could be attained either with or without a barrier.

The true answer to the important question as to the necessity and desirability of a barrier is to be found from a consideration of the comparative cost of alternate plans of development, with and without a barrier, of equivalent scope in accomplishments and service. Certain objectives are necessary and desirable of accomplishment. These are chiefly: first, control of salinity for the protection of the delta lands and water supply; second, the protection from saline invasion of fresh-water supplies furnished from the Sacramento and San Joaquin rivers in the lower channels thereof for the upper bay region; third, the exportation of water from the Sacramento-San Joaquin Delta to the upper San Joaquin Valley; fourth, the provision of necessary works and facilities for agricultural development of the marshlands adjacent to Suisun and San Pablo bays; and fifth, the facilitation of immediate future and ultimate potential developments of industries, municipalities and agricultural lands in the upper bay area. In order to determine the best plan of accomplishing these objectives, the logical procedure from both an engineering and economic standpoint involves a consideration of the comparative cost of alternate plans of development which would attain these objectives. For this investigation there is involved a comparison of the capital and annual costs of required physical works for two alternate plans, one with a barrier and one without a barrier, and also the benefits or detriments which are peculiarly attached to either plan.

Required Physical Works for Alternate Plans of Development.

The physical works for the two alternate plans of development, with and without a barrier, have been previously described. In both plans, conduits would be required to convey and distribute the fresh-water supplies from the most suitable diversion points. In the plan of development without a barrier, it has been shown in Chapter III that it would be desirable and probably necessary to construct levees for the purpose of cutting off and protecting the marshlands adjacent to Suisun and San Pablo bays from the saline waters of the bay. Preliminary plans for the location of the levees which it is assumed would be required for this purpose are shown on Plate VIII. Their construction would have the advantage of enabling the carrying out of a unified development of the entire marsh area inside these levees, with the smallest possible length of levee required to be maintained and the possibility of more economical drainage operations through central pumping plants. Ample fresh-water supplies could be provided and water levels could be controlled and maintained in the channels interspersing the marshlands at the level found most suitable for the combined needs of drainage and irrigation. In addition to the levee systems assumed as required for the marshlands in the plan of development without a barrier, the physical works also include the channel enlargements required in the delta for the exportation of water to the San Joaquin Valley.

If a barrier were constructed below the bay marshlands, it is possible that they could be fully developed and brought into complete agricultural utilization without the construction of the levee systems assumed as required without a barrier. However, even with a barrier, it might prove desirable to construct such levees in order to obtain therefrom the advantages above enumerated and more efficiently carry out the development work required. It has been pointed out previously that a high barrier-lake level would increase the difficulty and expense of drainage and leaching operations which must be carried out to put these lands into suitable condition for crop production. However, for the alternate plan of development with a barrier, it has been assumed that the levee systems would not be required for the marshlands lying above a barrier. Levee systems are included only for the marshlands lying below a particular barrier site. For a barrier at San Pablo site, no levee systems are included in the cost estimates because all marshlands are above this site. It is evident that these assumptions are in favor of a barrier inasmuch as it is quite possible that the difficulties encountered in effectively removing the salt from the marshlands and draining the same with a high barrier-lake level might lead to the necessity of constructing such levees. Moreover, if such levees were not constructed to cut off marshlands in a barrier lake, it doubtless would prove necessary to carry out extensive work of strengthening and raising the present levee system in order to obtain a degree of protection comparable with that provided by the levees assumed as a part of the plan of development without a barrier.

The physical works for a plan of development with a barrier include sewage and industrial waste disposal works, as described in Chapter III, which would be required to protect a barrier lake from serious pollution. These disposal works would not be required in the plan of development without a barrier inasmuch as the present methods of disposal assisted by the flushing and diluting action of tidal currents and flow would be satisfactory for an indefinite time in the future. In any event, if it should become necessary to improve the present facilities at some time in the future the cost of such improvements would be but a small fraction of the cost of disposal works required with a barrier in order to maintain a barrier lake fresh for all purposes.

Comparative Costs of Alternate Plans of Development.

Based upon the foregoing descriptions of physical works required for the two alternate plans of development, with and without a barrier, estimates of capital and annual cost are presented in Tables 33 and 34, respectively. Four estimates are presented, comprising one for the plan without a barrier and one for each of the three typical barrier sites for a plan with a barrier. The estimates of capital cost include only the amounts estimated for the physical units of each alternate plan. Those for a barrier are for standard locks and do not include the additional costs of salt-clearing locks. The estimates of annual cost include interest, amortization, depreciation, operation, and maintenance of the physical units and, in addition, the annual value of direct tangible benefits or detriments which might accrue from the construction and operation of a barrier but which would not be involved in any way with the alternate plan without a barrier.

TABLE 33

CAPITAL COST OF MAJOR PHYSICAL WORKS FOR ALTERNATE PLANS OF DEVELOPMENT OF UPPER SAN FRANCISCO BAY REGION, WITH AND WITHOUT A BARRIER

Item	Cost without a barrier	Cost with a barrier		
		Chipps Island site	Dillon Point site	Point San Pablo site
Salt water barrier[1]		$40,000,000	$50,000,000	$75,000,000
Sewage disposal works		1,000,000	3,800,000	6,800,000
Conduits for upper bay region	$10,500,000	7,700,000	5,500,000	4,000,000
Levees for upper bay marshlands	3,800,000	3,400,000	1,800,000	
Sacramento-San Joaquin Delta cross channel	4,000,000			
Totals	$18,300,000	$52,100,000	$61,100,000	$85,800,000

[1] Capital costs based upon use of standard locks and do not include additional costs of salt-clearing locks. (See Tables 2 and 4.)

It is unquestionable that there would be substantial benefits accruing to many interests by the consummation of either plan of development, with or without a barrier. A large saving would be obtained in cost of water provided under the plans of service for the industries, municipalities and agricultural lands. Substantial increases in value of industrial, urban and agricultural lands undoubtedly would be realized. The value of lands in the delta probably would be increased and the cost of expensive litigation eliminated. Large benefits would accrue from any stimulation of industrial, agricultural and municipal development in the upper bay region. The northern bay counties, the metropolitan areas of the east bay and San Francisco, the state, and even the nation, would be benefitted by the increased development and substantial growth in products and greater prosperity in the upper bay region.

Estimates might be made of all of these benefits, but, for the most part, they could be considered only as approximations. However, all of these benefits enumerated above would be common to either of the alternate plans of development with and without a barrier. Both alternate plans would be fundamentally equivalent in their scope and accomplishments. Therefore, even if it were possible to make closely approximate estimates of these various benefit values, it is entirely unnecessary in the present investigation of the economic aspects of a barrier to evaluate these benefits which would be common to either alternate plan.

The chief tangible benefit directly attached to a barrier at Dillon Point and Point San Pablo sites which would not be realized under a plan of development without a barrier is the estimated value of possible savings in annual cost of piling in industrial water front structures. Industrial water front structures above Chipps Island site would be benefited equally under either plan and hence the indicated saving for structures above Chipps Island site has been deducted from the total savings for structures above Dillon Point and Point San Pablo sites. The benefit value to industrial water front structures with a barrier is estimated as double the amount of computed saving in annual cost for piling in present structures, assuming a replacement of all timber piling by untreated timber piling. In addition, the value of the amounts of supplemental water supply which might be saved by controlling salinity with a barrier is included as a benefit in the estimates of annual cost.

The value of supplemental water supply saved is computed for the maximum annual amount, less the annual cost of salt-clearing devices. For Chipps Island and Dillon Point sites, this results in a positive benefit or saving, while for Point San Pablo site, the value of water saved is less than the estimated annual cost of salt-clearing devices. The tangible detriments chargeable directly to a barrier include delays to navigation, and increased drainage pumping and levee maintenance cost in the delta and bay marshlands. The evaluated amounts of these detriments, as estimated in Chapter III, have been charged as additional costs in the alternate plan with a barrier for each site.

TABLE 34

ANNUAL COST OF ALTERNATE PLANS OF DEVELOPMENT OF UPPER SAN FRANCISCO BAY REGION, WITH AND WITHOUT A BARRIER

Item	Annual cost without a barrier	Annual cost with a barrier		
		Chipps Island site	Dillon Point site	Point San Pablo site
Physical works				
Salt water barrier		[1] $3,300,000	[1] $3,900,000	[1] $5,600,000
Sewage disposal works		100,000	400,000	780,000
Conduits for upper bay region	$1,400,000	1,100,000	900,000	700,000
Levees for upper bay marshlands	380,000	340,000	170,000	
Sacramento-San Joaquin Delta cross channel	300,000			
Total annual cost of physical works	$2,080,000	$4,840,000	$5,370,000	$7,080,000
Detriments or losses				
Increased drainage and levee maintenance costs in delta		$220,000	$220,000	$220,000
Increased drainage and levee maintenance cost in upper bay marshlands		10,000	70,000	130,000
Delays to navigation		270,000	310,000	700,000
Total annual value of detriments or losses		$500,000	$600,000	$1,050,000
Benefits or savings				
Waterfront structures			$160,000	$470,000
Decreased supplemental water supply required for control of salinity		[2] $820,000	[2] 690,000	[2] —340,000
Total annual value of benefits or savings		$820,000	$850,000	$130,000
Net annual cost	$2,080,000	$4,520,000	$5,120,000	$8,000,000

[1] Do not include additional annual costs of salt-clearing locks.
[2] Savings based upon value of maximum annual amount of supplemental water supply saved by a barrier, less the annual cost of salt-clearing locks. (See Tables 4 and 32.)

The studies of the fishing industry indicate that a barrier might be detrimental to the same with a possibility of some substantial loss. Moreover, a barrier might entail an additional detriment by reason of increased navigation channel maintenance due to changes in tidal currents, especially for the Golden Gate bar and the upper bay channels. However, this might be partially equalized by the benefits to shipping interests from the elimination of tidal currents and fluctuations and the creation of a fresh-water anchorage above a barrier. Because of uncertainty, no estimates of these latter benefits or detriments have been included in the estimates of annual cost.

The estimates in Tables 33 and 34 show that the fundamental requirements and needs for the development of the upper bay region could be provided for at a much smaller capital and annual cost under the plan of development without a barrier. The capital cost of physical works without a barrier including main service conduits, levee systems for the marshlands of Suisun and San Pablo bays, and channel enlargements in the delta is estimated at $18,300,000. Compared to this, the capital cost of physical works for the alternate plan ranges from $52,100,000 with a barrier at the Chipps Island site to $85,800,000 with a barrier at the Point San Pablo site, not including the additional costs of salt-clearing locks.

The capital cost of mountain storage reservoirs required to furnish the supplemental water supplies for salinity control have not been included in the capital costs of physical works for either alternate plan of development. Inasmuch as these reservoirs would be operated to supply water for several other purposes, the allocation of a definite portion of their capital cost to salinity control would be complicated and it was considered too uncertain to attempt an estimate for this study. However, the annual values of the indicated amounts of supplemental water supply saved by controlling salinity with a barrier have been included as benefit values in the estimates of comparative annual costs.

The estimates of annual cost which take into account the evaluation of benefits and detriments peculiar to a barrier are even more significant from a comparative standpoint. For the plan of development without a barrier, the annual cost is estimated at $2,080,000, while in the alternate plan, the estimated annual costs range from $4,520,000 with a barrier at the Chipps Island site to $8,000,000 with a barrier at the Point San Pablo site. The annual costs of physical works alone, excluding the estimated value of benefits and detriments which might be questioned, are of about the same relative magnitude.

Based upon the studies and cost estimates of the two alternate plans of salinity control, water service and development for the upper bay region, it is evident that a plan of development without a barrier could be consummated for a capital and annual cost less than half of that involved in a plan with a barrier at any of the typical sites considered. Therefore, the conclusion is unavoidable that a salt water barrier would not be necessary or economically justified as a unit in the State Water Plan.

The most feasible and economical plan of serving the present and future water requirements of the upper bay region would be by the proposed conduits diverting water from the controlled fresh-water channels of the delta in a plan similar to that shown on Plate VIII. This plan would have the additional advantage of being flexible and capable of progressive development with minimum expenditures. At no stage of the development would the large expenditure for a barrier be required. Initial conduit units could be constructed with relatively small capital expenditures to take care of the immediate water demands in the area. These initial units could be later enlarged and extended as future demands increased and additional conduit units could be built as required.

The proposed immediate development of the State Water Plan provides for such an initial conduit unit to take care of the immediate pressing needs of the present developed industries and agricultural lands along the south side of Suisun Bay in upper Contra Costa County, and in the Benicia area. This initial conduit would have a capacity at its head of 120 second-feet or sufficient to take care of the entire fresh-water demands of the industries from Antioch to Martinez and Benicia for a period of ten years or more in the future. It would also provide an adequate irrigation supply for over 10,000 acres of developed agricultural lands in need of an irrigation supply in the area between Knightsen and Antioch south of the San Joaquin River and in the Ygnacio and Clayton valleys. The location of this conduit would be along the same line as shown for the Contra Costa County conduit on Plate VIII. It is estimated that this initial unit could be constructed for a capital cost of $2,500,000 with an annual cost including interest, amortization, depreciation, operation and maintenance of $300,000. If the total supply provided of 43,500 acre-feet per annum were utilized, the cost of water delivered at points along the conduit would be $6.90 per acre-foot or about 2.1 cents per thousand gallons. This would give about as cheap a supply to the industries as the present average cost in the Pittsburg-Antioch area for boiler and process purposes, which is the lowest average cost in the upper bay region. When the demand arises for additional water supplies in Solano County, it would be feasible to provide a similar initial conduit unit on the north side of the bay in the approximate location shown on Plate VIII.

With the fresh-water requirements for both present and ultimate industrial, municipal and agricultural demands adequately provided for under the proposed plan of service from the controlled fresh-water channels of the lower Sacramento and San Joaquin rivers, it may be safely assumed that the growth and prosperity of the upper bay region, in so far as water supply affects the same, would be assured.

APPENDIX A

INDUSTRIAL SURVEY

of

UPPER SAN FRANCISCO BAY AREA

With Special Reference to a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

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CHAPTER VI

LIST OF PLATES

LETTER OF TRANSMITTAL

MR. EDWARD HYATT,
State Engineer,
Sacramento, California.

DEAR SIR: The committee appointed by you to make a study of the industrial development of the upper San Francisco Bay area in relation to a salt water barrier begs leave to submit the report hereto attached.

The committee bases its findings upon an industrial survey prepared by Professor George W. Dowrie, of the Graduate School of Business of Stanford University. Mr. Dowrie has devoted six months of intensive study to this subject. He was assisted by Mr. Oscar A. Anderson, a graduate fellow at Stanford University. Mr. Dowrie has availed himself of the cooperation of your staff and has had access to all the data in your office. He has made free use of the replies to the comprehensive questionnaire which your office sent out to the industries of the area. He has also had recourse to other public documents and has collected independently a large mass of valuable material through interviews and correspondence. Power and water companies, research departments of various organizations, industrial executives, manufacturers of cooling equipment, industrial engineers, representatives of government agencies, and numerous other persons who were in a position to throw light upon the problem have cooperated most generously.

The committee has been in close touch with the progress of the study at every stage. Frequent meetings have been held at which the plan of the study and its progress were subjected to careful scrutiny. An exceptionally comprehensive mass of data has been brought together and embodied in this report, which the committee transmits to you with its full approval.

Briefly summarized, the conclusions of the committee are as follows:

We find that the upper San Francisco Bay area affords a most attractive location for industries which require relatively large tracts of land, low cost of transportation, proximity to population centers, and the comparative isolation of a country site. The south shore of Suisun Bay contains, at present, the cheapest solid ground near to deep water in the whole bay region.

In respect to labor supply, power, transportation, accessibility to markets and raw materials, the upper bay region has exceptional advantages of which representatives of the industries now located in the area are well aware. The industrial growth of the area indicates that these advantages are of a substantial character.

Study of such comparable data as were available shows that the rate of growth measured in number of employees, in the size of pay rolls, and in the values created by manufacturing industries has for many years been greater in this region than in the state as a whole, and decidedly greater than the trend for the United States.

The only important disadvantage of the area, as set forth by representatives of the industries located there, has been the encroachment of salt water during the season when the two rivers have too small a flow to repel the salinity invasion.

We do not find that the cost of securing fresh water necessary to carry on industrial processes is a major factor in the budgets of typical industries of the territory. However, to the extent that this cost creates a burden on any important industries in the area, it represents an economic handicap. In addition to this, the salinity consciousness, which has been permitted to develop, has created a certain psychological handicap which it is highly desirable to dispel.

Building a barrier below the confluence of the Sacramento and San Joaquin rivers, and thus creating a fresh-water lake, would doubtless remove both the economic and the psychological effects of the encroachment of salt water. Such a lake would be an attraction to heavy users of fresh water. If, however, the cost of building and maintaining the barrier should result in an unduly heavy tax rate upon property located in the territory, the burdens might well outweigh the advantages and result in a net loss. The influences which lead industries to locate in a particular spot are many and complex. If Suisun Bay could be turned into a fresh-water lake at a cost which could reasonably be borne, it would probably tend to stimulate somewhat the industrial growth of the area, but it is not to be expected that there would be any stampede of industries to locate on the shores of the lake. Competing locations would naturally offer counter attractions and would probably match any water rates that might result from the construction of a barrier.

After a careful study of all available data, it appears to the committee that the present generation would have to assume a rather heavy burden for building and maintaining a barrier and that the gains realized in the reduction of water costs would only partially compensate for the expenditures which it would be necessary to make. The committee, therefore, is of the opinion that attention should be focused upon the real needs of the area and upon means of meeting them.

The industries of the upper bay area have definite water problems which need to be solved, and it is entirely appropriate that the cooperation of public authorities should be enlisted in helping to solve these problems. However, their solution does not seem, at present, to justify so elaborate and costly a remedy as a salt water barrier.

The committee recommends, therefore, that serious attention be given to adequate measures for removing the causes of salinity consciousness from which the upper bay area is suffering and for furnishing an adequate supply of fresh water in the most economical way which competent engineers can devise.

Respectfully submitted.

Willard E. Hotchkiss

Dean of Graduate School of Business,
Stanford University, Chairman.

Henry F. Grady

Dean of College of Commerce,
University of California.

[illegible]

Consulting Engineer, San Francisco.

San Francisco, California,
November 19, 1930.

ORGANIZATION

This report was prepared by

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CHAPTER I

THE ECONOMICS OF PLANT LOCATION

Growth and Migration of Industries.

The kinds of factories and business establishments which may be obtained by a given region are of three main types: (1) new home industries; (2) branch plants; (3) industries which have moved bodily. Most of the new industries which rise in an economic region are of the first type; next in order come the branch plants; last come the enterprises which move as a whole.

Some of the factors which lead to the establishment of new factories in a given region are as follows: (1) migration of population, which causes factories to follow people wherever they go; (2) new sources of fuel, power and water, making it profitable to carry on manufacturing at certain localities when motive power is available at attractive rates; (3) new sources of labor; (4) new raw material centers; (5) shifting of markets due to new inventions and demands; (6) development of distribution centers served by land or water transportation, or both.

Industry is sensitive to new developments which have business implications. If new developments bring new opportunities, or if changing conditions call for new industrial adaptations, business enterprises endeavor to take advantage. Modern business is governed largely by the inexorable facts of cost accounting. When unnecessary waste and expense are present, this fact stands out like the proverbial sore thumb. When excessive expense is due to the fact that the location is no longer satisfactory, the industry moves, or puts up branch plants—if it can. The migration of cotton mills to the southern states is partially a result of reading the warnings of cold-blooded cost accounting. This is true also of branch steel plants which have been established in the South Chicago-Gary district. The same may be said of rubber, furniture, automobile and other industries which have come to the Pacific coast in order to be at the seat of a rapidly growing market.

Plant Location as a Problem of Industrial Engineering.

Originally the method of plant location was largely a matter of chance. Many factories were enticed to go to certain communities through the activities of booster clubs which had held out the bait of free sites, tax exemption and other special inducements. This vogue is passing. Appeals are coming to be made upon sound economic grounds. An advertising slogan used by one rapidly growing region is that industries come "Without benefit of bonus." Too often, the results under the old appeal were unhappy, both from the standpoint of the factory and that of the community. A sick business, operating under the handicap of an illogical plant site, is not an asset to any community.

Sometimes an industry is found in a region where transportation facilities are unfavorable, power costs high, and where other disadvantages are present. The reason for its being there, in many cases, is that the originator of the product happened to live in that community, and established the industry there. Sometimes an industry has been established at a given site out of consideration for one factor, like power or transportation, without due consideration for other plant location factors which should have been taken into account. At best, the old methods were not particularly scientific; the procedure used was haphazard.

Modern problems of plant location are now commonly solved by specialists. They have a scientific technique by which they can arrive at logical conclusions; their methods in arriving at decisions are impartial; they are not unduly influenced by the arguments of local boosters. A common procedure is to draw up a check list of all the plant-location factors which might be pertinent to the success of the industry concerned. With this done, the various prospective areas and sites are evaluated in the light of these factors. The finding of the most logical plant site involves a process of elimination.

Relative Importance of Location Factors.

The value of one factor as compared with another in choosing a plant location depends upon the industry involved and especially upon the particular company in question. The problem of plant location must always be one for individual case study; a sweeping generalization which attempted to rate the relative importance of location factors in a given type of industry would be a misleading guide for a particular firm with specific problems of its own. The men's clothing industry, for example, is often classed as an industry requiring a city site, because the important market is in the city itself; the class of labor needed may be conveniently secured, and the factory site needed is not large, since clothing manufacture is a multistory type of industry. These criteria may be applicable in a general way but are not to be depended upon for particular cases. Some of the most successful men's clothing plants are located in suburban and even rural districts. The exceptions made to the city-location theory are so many that it would be useless to make out a general rating scheme, showing the relative importance of location factors in a single industry, like men's clothing manufacture. This principle holds true for other industries as well.

However, it may not be amiss to show how an individual expert on plant location may rate the factors for a given factory in a given line of industry. Mr. W. L. Wotherspoon,* in discussing the investigation which led to the selection of a site for a refinery and rolling mill for monel metal showed how he finally rated the several plant-location factors, but like many other writers on the subject, warned against sweeping generalizations.

Factor	*Relative weight in per cent*
1. Fuels	33
2. Labor	25
3. Living conditions	10
4. Power	10
5. Supplies	6
6. Climate	5
7. Transportation	5
8. Building costs	2
9. Taxes and laws	2
10. Site (cost and quality)	1
11. Water supply	1

* Proceedings of American Society of Mechanical Engineers, December, 1922.

The weighting scheme shows that for the particular factory in question the factor of fuel was thirty-three times as important as such factors as water supply or site-cost and quality, and that such a factor as power was twice as important as the factor of climate. However, these weightings would not necessarily apply in the case of another metal industry, or even another monel metal mill, which had its own peculiar problems in competition and trade development to face.

A recent industrial survey,* covering sixteen thousand firms in the United States and Canada, shows that the rankings given to location factors vary widely with the section in which the industry in question happens to be located, and, of course, with the type of product manufactured. For example, the summing up of the rankings leaves water supply entirely out of the list of sixteen factors of which mention was made the oftenest, but if all of the participating industries had been heavy users of fresh water, or had all been located in a part of the country where abundant fresh water is not easily procured, water supply would undoubtedly have had a prominent place in the list. This does not mean that in such cases water cost necessarily looms large in the sum total of manufacturing costs, but it does mean that water-using industries can not function normally if they do not have water of suitable quality and in sufficient quantity. In the lists of important location factors given by seven writers † on the subject, selected at random, water is included in all but one case.

A list of items, however, which is ranked on the basis of the number of times it was mentioned in reply to a questionnaire is not wholly without merit, for it does tend to reveal the phases of the subject that are causing the greatest concern. In the survey to which we have just referred the conspicuous place given to markets throughout the replies is indicative of the fact that nowadays disposing of his output is the manufacturer's chief concern. Such a state of affairs augurs well for the development of industries on the Pacific coast for the purpose of serving this important consuming area to better advantage.

In simple plant location problems, there is often a paramount factor which determines the general nature of the site to be selected. Thus, the item of cheap and abundant power is of major importance for abrasive manufacturing. Niagara Falls has become important as a center of production for carborundum and other abrasives, because of cheap electricity. In the case of bulky, moderate-priced products, such as furniture, the plant site must be near as possible to the market served. Canning factories are influenced in their location by the perishability of the raw materials. These examples show how a given factor may be of major importance to one type of industry and of secondary importance to another.

As a general thing, the importance of a given factor is relative to: (1) the nature of the business enterprise concerned, (2) the plus or minus values of the other factors which are peculiar to the region or site being considered. The interplay of considerations from these two points of view calls for an evaluating process that is anything but

* Cooperative survey made by the Civic Development Committee of the National Electric Light Association and the Policyholders' Service Bureau of the Metropolitan Life Insurance Company (1927).

† A. G. Anderson, W. M. Booth, H. S. Colburn, E. B. Powell, G. C. Smith, A. P. Wood and W. L. Wotherspoon.

simple. It is the algebraic sum of combined factors resulting in a minimum of costs that determines the locus point which is suitable for a plant site. The iron and steel industry * is a good example of the way circumstances alter cases in matters of plant location. Considering the diverse factors of (1) market, (2) ore, (3) fuel, which must be reconciled, the following practices are to be noted:

Distribution of Factors (Material, fuel, market)	*Location of Industry*
(a) Ore producing, coal producing and market areas approximately coincide.	Industry develops within the common area. Example: Birmingham district, Alabama.
(b) Ore and coal areas are adjacent or coincide; no important local market.	Industry develops close to or within the common area. Example: Sydney, Nova Scotia; Pueblo district, Colorado.
(c) Market area coincides with coal area and ore area is accessible.	Ore is drawn to the common territory. Example: Pittsburgh district. ore from Lake Superior district.
(d) Market area coincides with ore area and coal area is separate.	Coal is drawn to the common area: Steel industry of Italy, obtaining Welsh or Westphalian coal.
(e) Market lies between coal fields and ore fields with no great distance from route between them.	Industry locates within or close to the market area. Examples: South Chicago-Gary industries using Minnesota ore and West Virginia coal.
(f) Coal area lies between the ore fields and market region.	Industry develops in or near the coal fields. Example: Steel industry in Saar coal field, Germany.
(g) Ore area lies between the coal fields and market region.	Industry develops in or near ore fields. Examples: Steel industries at Lake Superior ports, Duluth and Sault Ste. Marie, serving markets of Canada and northwestern United States.

The table suggests how the problem of plant location is affected by the varying combinations of plant-location factors.

Accessibility Versus Proximity.

The ideal in plant location is to have a site that is near the market, and at the source of raw material, fuel, power, water and labor supply. But, as seen in the case of the steel industry, it is not often possible to have all desirable factors centered at one place. This circumstance makes the factor of transportation important. In cane-sugar refining, for example, it is desirable to have a convenient source of raw material, but with cheap oceanic transportation there is no urgent necessity for having proximity of materials. In fact such an enterprise as the California and Hawaiian Sugar Corporation, Limited, which receives its raw sugar from Hawaii, can receive and ship more cheaply at its San Francisco Bay location than it could if located in Hawaii itself. Where good water transportation is to be had, the importance of proximity becomes lessened; in a practical situation it is accessibility, through proper transportation media, that counts.

The difference between accessibility and proximity is to be seen in fresh vegetable and egg marketing. Once the production of vegetables, fruit and eggs required nearness to market, but climatic advantages,

* For details, see the study, "Location Factors in the Iron and Steel Industry," by Richard Hartshorne, pp. 241–252, *Economic Geography*, Vol. IV, No. 3, July, 1928.

fast transportation, and modern refrigeration methods enable distant producers to compete successfully with other producers who are a thousand or even several thousand miles closer to a given market.

Again, the hardwoods of the Orient and the glass-making sand of Belgium are more accessible to various manufacturers in the United States than similar materials found in certain part of the United States itself. Conversely, distant markets may be more accessible, through water transportation, than nearer ones which can not be reached by cheap transportation.

Planned Modification of Factors.

In one sense, man is a creature of his environment, but in another sense he is a maker of it. Industries no longer settle where shipping, transportation and harbor facilities happen to exist. Railroads are now made to come where industries choose to locate, and if harbors are needed they are often built in case a natural one does not already exist. Similarly, if the water factor is not favorable in certain industrial areas while the other factors are, the water is brought to those areas, although the distance may be relatively great.

A cardinal difference between the old New England industrial area and the modern Piedmont-Carolina area is that in the former case industries settled where power happened to be, while in the latter case power is transported to the place where the industries, because of other factors, find it advantageous to locate.

Invention of single purpose machinery, for which operators can be readily trained, makes it unnecessary for plants to locate where there is an abundance of skilled mechanics. In Russia, unskilled urban laborers and even peasants now help to make Ford cars.

The perfection of a new type of manufacturing process emancipated the porcelain-products industry from the requirement of locating where a certain type of skilled labor was to be found. By the acceptance of a new production technique, the porcelain goods manufacturer can choose a plant location independent of the old skilled labor requirement.

All of which means that plant location requires consideration not only of natural advantages, but of those that may be created through new technical processes. When once a site has been selected, buildings constructed, machinery installed, and a corps of employees trained, the die is cast. To avoid mistakes in location, it is necessary to view today's problems in the light of tomorrow's possibilities.

From the General to the Specific in Plant Site Selection.

The necessity for caution has led to circumspect approaches not only in the consideration of technical processes and transportation possibilities, but also in the consideration of regional environments. The question of a specific plant site is determined in view of preliminary questions about the general region considered. In determining upon a site for the new Western Electric Company cable plant, which was to take care of Eastern, Southern and Pacific distribution, the first broad consideration was a choice between a middle western and an Atlantic seaboard location. Each region had its disadvantages, but calculation proved that a seaboard location would have the greater advantages. In turn, a New Jersey location was found to be advantageous over alternative choices in other parts of the Atlantic coast, Finally, there came the task of choosing between specific sites on a New Jersey water front. By a process of elimination and progression from the general to the particular, the actual site wanted was found at Kearny, New Jersey. The net saving secured, over the original "home-site" in the middle west, amounted to $275,000 per year.*

The circumspect process of going from the general to the particular in selecting plant sites has tended to draw attention to the relative advantages of broad regions, such as the South, the Pacific coast area, the Atlantic coast region, and the Middle West section. On a lesser scale, the localities within regions and areas are considered comparatively.

The Quest for Cooperative Benefits.

Intensity of modern competition has had the parodoxical effect of stimulating cooperative endeavor. The recent regional planning movement for the benefit of community and industry represents an endeavor to temper the wastes of individual effort by the economy of a unified program.

Another manifestation of the desire to secure the benefits of cooperation is to be seen in the development of comprehensively planned "manufacturing districts," offering transportation, power, water supply and other joint services to the several factories. The Central Manufacturing District in Chicago, with its Junction Railway, is a case in point; this single belt line gives all producers within the district a very convenient contact with thirty-nine railways without the disadvantages of delays, worries and costs that would result in dealing with many railways single-handed. The belt-line service is only one of many benefits received. The Bush Terminal of New York also operates on the cooperative benefit principle. As an illustration, manufacturers at the Bush Terminal obtained electric current for light and power at 3.3 cents per kilowatt-hour when other manufacturers paid 7.5 cents per kilowatt-hour. Similarly, insurance rates, freight handling costs and many other items of expense were particularly favorable to the companies enjoying mutual services. Other examples of planned "manufacturing districts" are to be found in such places as Los Angeles, Minneapolis, St. Paul and Kansas City.

A still further indication of desire for associational advantages is to be seen in the rapid development of "metropolitan districts" in which satellite industrial communities tend to develop and cluster about established cities. With a suburban location, a manufacturer may enjoy first-class banking facilities, the services of well-stocked supply houses, the advice of consulting engineers, the benefits of competing railroads, and many other advantages of a city. On the other hand. there are not the disadvantages in the way of an expensive and cramped site, traffic congestion, or expensive water charges. Furthermore, a comprehensive "metropolitan district" offers special inducements to industries which serve as a complement to major industries already established, which tends to give the district as a whole a well-balanced character.

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* See "Plant-location Factors of Western Electric Co., Kearny Works," by C. C. Spurling, page 697, *Mechanical Engineering*, Vol. XLIX, No. 6, June. 1927.

All these trends—regional planning, carefully designed manufacturing districts, and more or less spontaneously developed metropolitan districts—reflect the modern desire to capitalize the benefits of cooperation and mutual services.

Intangible Factors of Plant Location.

After tangible factors of plant location have been considered, there still remain the relatively intangible factors. In the last analysis, it is the intangible element that is often the deciding factor which determines whether an industry shall be established in this region or that, in one locality or another. This accounts for surprises when a given community believes it has advantages greater than those of another community and is disappointed to have the prospective industry locate at the other place.

Among the more intangible factors to be considered is that of community and regional morale. With a region divided against itself there is less appeal to prospective industries than that made by a region which is an integrated unit. An integrated region is one that does large-scale planning of a nature that assures the greatest possible present and future economies in industrial operation.

Future economy, especially, is something to ponder in choosing a location. An industry that comes into an area without benefit of comprehensive planning in that area may soon become the victim of unforeseen costs, due to snarled conditions in water supply, transportation, and the like, which wise planning might have forestalled. The problem of regional development is not unlike the problem of municipal development; where comprehensive municipal planning is absent, there is sure to be congestion, confusion and unnecessary expense. Other things being equal, that region or locality is the most promising which has the least criss-crossing of purposes, the least need for overlapping of expenditures for mutual service needs, and the most comprehensively developed natural resources. For such reasons, various writers call attention to "community attitude" as one of the intangible factors to consider in deciding upon a plant location; right attitude is regarded as a form of industry insurance. The United States Census calls attention to momentum as an important factor to consider in plant location. This is another way of saying success breeds success. Risks are good if a community rates well in both tangible and intangible factors, and if the ball has already started rolling in the community's industrial development.

East to West Movement of Industry.

Both cultural and economic progress seem to move from east to west. Western Europe derived her ideas and products from the east, and the American colonies, in their turn, depended upon western Europe for the satisfaction of their cultural wants and for all but the most elementary of their material needs. In like manner, the western states of America have been dependent upon the eastern half of the country for manufactured products and for economic and social leadership.

A study of industrial trends reveals the extent to which the dependence of the west upon the east for manufactured products is lessening. Physical barriers to the industrial development of the west are being removed through developments in chemistry and engineering, But little progress has been made in removing psychological obstructions which impede the migration of certain industries. Textile manufacturing is an outstanding case in point. Since there is no well-developed center of textile production, experienced manufacturers hesitate to enter the Pacific coast field. Although there appears to be no logical reason why textile mills should not be established on the Pacific coast, as well as in New England and the southeast, capital is hesitant about establishing lone mills in new and unproved territory.

California's growth in the field of heavy industry now affords special opportunities to complementary industries which utilize light forms of labor found as a surplus in heavy industry centers. Because of a plentiful supply of natural gas and oil, and comprehensive electrical developments, the cost of power is relatively low. Furthermore, the mild climate of the Pacific coast reduces plant construction and heating costs.

Taken as a whole, the Pacific coast also has an advantage over the east in respect to proximity to the principal textile raw materials; wool, silk and cotton. Most American wool is produced in the western states and most of the imported wool comes from Australia and New Zealand. Much of the latter passes through California ports to be cleaned and manufactured in the east, after which a part of the finished product is shipped west again. Similarly, the western states are nearest to the source of supply for silk, which is obtained from Japan and China, but the material is transported through western ports to the silk mills of New Jersey and Pennsylvania, the eastern mills having to pay millions of dollars in express, insurance and interest for these land shipments. In respect to cotton, California is adjacent to Arizona and Lower California, which obtain excellent results in cotton growing. Yet, like wool, this raw material goes east to be manufactured into textiles, and a considerable part of the finished product is sent back for western consumption or passes through the west on its way to the Orient. The location of the national style center in the east still constitutes a serious impediment to the development of the textile industry in the west, but among American cities, Hollywood is coming to be recognized as second to New York in its influence upon style trends.

The situation is similar to that which formerly existed in the automobile tire industry, in which the west depended upon the eastern manufactured product. But, with the early inertia overcome in getting plants established in the west, California has now become the second largest tire manufacturing center in the world, providing for western consumption and exportation to the Orient. With psychological difficulties removed, there is no logical reason why other new industries should not be established in the west on an extensive scale.

Western Momentum Under Way.—An index of the momentum of development being experienced by the Pacific states is to be seen in population figures. In the last decade, the geographical group consisting of California, Oregon and Washington, with an increase of 46.4 per cent, proved to be the fastest growing division in the entire United States.

Of the Pacific states, California has had, by far, the most rapid development. The number of inhabitants reported for 1930: viz, 5,642,282, represents a gain of 64.6 per cent over its population of 1920. In fact, 2,215,421 of the Pacific coast's gain of 2,584,741 was made by California, the growth of the Los Angeles area having been especially marked. This exceeds the rate of growth of every other state in the Union. This growth of the west is naturally developing a large consuming area for western products.

The response on the part of business interests to this shift in population is seen in the data on western industrial development. A study of the United States Census of Manufacturers shows that the number of manufacturing establishments in the United States showed an increase of 14.3 per cent from 1914 to 1927. During the same time, the number of manufacturing establishments in California showed an increase of 58.2 per cent—a rate of growth four times that for the United States as a whole. Similarly, for the same period, the value of manufactured products for the United States as a whole increased 121 per cent; while the manufactured products of California increased 280 per cent in value, representing a rate that was 2.3 times that of the nation as a whole. Equally significant is the fact that "Value added to manufacture" showed an increase of 185 per cent for the United States as a whole, during the period from 1914 to 1927, but the increase in California was 334 per cent.

In 1927, the products of industry in the State of California had a value of approximately 2,600 million dollars, of which 1,088 million was added by manufacture. This exceeds the sum of: (1) the value of all crops produced in California in 1927, 479.8 millions; (2) the value of the output of fisheries, 10 millions; (3) the value of all mineral production, 459.6 millions (including metals, stone, natural gas, crude petroleum, clays, salt, sand, etc.), and (4) the value of the output of the forests of California, estimated at 60 millions.*

During its early stage of development, an economic region is concerned principally with the extraction or production of raw materials. The west is still an important source for the products of mines, forests, farms and fisheries, but California, particularly, is fast passing into the industrial stage of its development. Economically speaking, California is approaching its adulthood.

One of the great trade assets of the Pacific coast is its favorable location for Oriental trade. While it is true that Pacific coast trade with Europe has grown faster than that of the United States as a whole, during the past decade, it is probable that Pacific coast trade with Asia and Australasia will greatly exceed European trade in the future.†

For the United States as a whole, the physical volume of foreign trade has increased by about one-half since pre-war days, while the foreign commerce of the Pacific coast has about trebled. The foreign trade of the San Francisco bay region is comparatively well balanced and diversified. Only one item, raw silk, is as high as 15 per cent of the total volume. Three-fourths of the import trade of Seattle consists of raw silk, which raises its import figures to twice the amount of its

* The figure for forest products was obtained from the Forest Handbook of California for 1930. The other data are from the United States Statistical Abstract for 1929.

† Unless otherwise specified, data on foreign trade have been assembled by Dean H. F. Grady, from reports of the Chief of Engineers, United States Army, and from the statistical statements of the San Francisco customs district.

exports. Portland, on the other hand, exports six times as much as it imports, because its principal articles of foreign trade are the lumber, wheat and apples grown in that region. Four-fifths of the water-borne commerce of Los Angeles is petroleum and most of the remainder consists of lumber from the Pacific northwest. Aside from petroleum, flour, lumber and canned goods, the products of Pacific coast mills and factories as yet constitute a relatively insignificant part of our foreign exports. These same mills and factories still fall far short of supplying the large consuming areas about them with manufactured products, so it is not surprising to find that they have little to sell abroad.

As for the possibilities for building up a substantial foreign outlet for coast industries other than the four types mentioned above, political and economic developments in the Far East have a large part to play. The constant turmoil in China, the anti-foreign goods movement in India, the progress of Japan in supplying her own wants are all unfavorable factors so far as expanding our market is concerned. And yet, in spite of them, Pacific trade has increased year by year with respect both to volume and variety of products.

The populations of India and China, particularly, are so huge that an average purchase of one additional dollar's worth of foreign products, per capita, would increase foreign trade by some three-quarters of a billion dollars. Undoubtedly both nations will eventually be industrialized, but in the meantime, with every slight step upward in their very low standards of living, they afford an enormous potential outlet for industrial products. China's present situation surely offers no encouragement to the California exporter, but examples of other nations have shown that when once sufficiently able leadership is found, things right themselves surprisingly fast.

The share of the Oriental market which the Pacific coast states will receive depends upon the ability of manufacturers in this area to compete with those from other industrial areas. If the other location factors, plus skill in management, are sufficiently favorable, the situation of the California industries on the shores of the Pacific should enable them to hold a substantial share of Oriental trade.

However, since foreign trade is only a small percentage of the whole, the chief urge for industrial development for some time to come will be the Pacific coast population that can advantageously be supplied with commodities manufactured in Pacific coast factories and mills.

CHAPTER II

THE ECONOMICS OF PLANT LOCATION APPLIED TO THE SAN FRANCISCO BAY REGION

The territory surrounding San Francisco Bay, including its two upper arms—San Pablo and Suisun bays—and the navigable portions of the Sacramento and San Joaquin rivers, in many respects constitutes an economic unit. There exists a strong interdependence among the several areas which constitute this region. Its important common interests and problems call for a well-articulated regional program rather than for displays of local rivalry.

San Francisco is the financial capital of the region and the location of the executive officers of most of the large enterprises operating within its boundaries. San Francisco, Oakland, Sacramento and Stockton are the principal wholesale and retail distributing centers of the area, and the whole area looks to them for the more highly specialized types of personal service.

The Labor Situation.

The bay region as a whole, with its population of considerably over a million, is well supplied with industrial workers. Wage rates, however, are relatively high, as will be seen from the data which follow. On the other hand, it would be necessary to have comparable data concerning relative efficiency of labor before assuming that higher money wages result in higher labor cost.

According to a United States Department of Labor Survey * as of July 1, 1929, the average hourly entrance wage rates in cents, for common labor, were as follows for industries of the type which prevail in this region:

Industry	*United States*	*New England*	*Middle Atlantic*	*East-North-Central*	*West-North-Central*	*South Atlantic*	*East-South-Central*	*Pacific*
Iron, steel	42.5	41.8	41.8	43.6	36.8	35.4	28.5	48.6
Leather	42.2	50.0	44.2	43.4	---	34.6	33.7	52.6
Paper	44.0	47.4	41.6	44.4	39.2	36.4	27.1	43.3
Petroleum	45.7	---	46.3	51.4	50.0	40.3	32.5	57.4
Cement	37.8	---	42.5	38.0	35.7	---	31.0	47.2
Foundries	39.8	39.6	42.0	43.5	40.3	27.5	32.6	51.4
Meat packing	42.0	44.8	41.9	42.0	42.1	40.0	---	41.9
Average for 13 industries surveyed	43.7	48.0	46.4	48.4	41.8	30.2	26.8	47.9

A comparison of average weekly pay envelopes in identical industries for the same week of April, 1929, taken from the same source of information, shows the relationship between regions as it exists when the pay of more highly skilled factory workers is averaged in with the type covered by the preceding table.

East-North-Central	$32.15
Pacific	28.40
Middle Atlantic	27.50
New England	25.30
South Atlantic	20.15

* Monthly Labor Review, October, 1929, p. 172.

It will be noted that while wage scales on the Pacific coast are higher than the average for the country, they are lower in both instances than the prevailing rates in the great industrial area comprised in the east–north–central states.*

Transportation.

The area is served directly by the main lines of three transcontinental railroad systems, the Western Pacific, the Southern Pacific and the Santa Fe. The Northwestern Pacific serves the territory north from Sausalito to Eureka. Not all parts of the bay area have equally good facilities and equally prompt service, but a common rate schedule applies over the whole bay region. Some important parts of the area have lacked the stimulus which competing rail lines afford, but the Interstate Commerce Commission seems disposed to sanction the entrance of competing lines wherever the situation seems to warrant.

The bay area, in common with the rest of California, has an unusually complete network of improved motor highways. The opportunity thus afforded for the use of trucks has made possible delivery direct to the purchaser, or, if rail or water shipping is necessary, delivery is made by truck to the point of shipment.

The whole of the United States is so thoroughly covered with main lines of railroad that no section possesses any great advantage over another in that respect. Rail hauls, however, compared with water shipments, are expensive and, in the case of articles which have large bulk and weight in proportion to their value, railway charges can soon become prohibitive. It is for this reason that the greatest economic development tends to occur where water transportation is available.

In addition to its foreign, intercoastal and coast-wise commerce, the bay area has a large volume of local traffic along its own shores and on the two important rivers and the smaller streams tributary to it.

The following data, compiled by Dean H. F. Grady,† show in approximate figures the relative importance of the water-borne commerce of the port of San Francisco from the standpoint of destination:

To foreign countries	$1,500,000 daily average
To Hawaii	250,000 daily average
To Atlantic Coast of United States	330,000 daily average
Coastwise	2,800,000 daily average
Local	2,000,000 daily average

In his annual report for 1929, the Chief of Engineers, United States Army, gives the total water-borne commerce of the four leading Pacific coast ports as follows:

	Short tons	*Rank among U. S. ports*	*Value*	*Rank among U. S. ports*
San Francisco	41,019,000	2d	$2,257,747,000	2d
Los Angeles	25,696,000	4th	956,702,000	4th
Seattle	8,907,000	11th	773,747,000	7th
Portland	9,165,000	10th	343,220,000	13th

Much is said about the advantage of plant location on deep water where ocean "freighters" can come directly to the company's dock, but relatively few concerns in the San Francisco Bay area have any

* In this group are Illinois, Indiana, Ohio, Michigan and Wisconsin.

† See footnote on page 171.

such volume of shipments to or from points on a given steamship route as to warrant a call for an ocean vessel. Even the very smallest of enterprises, however, finds it profitable to utilize the smaller bay and river craft in bringing in raw materials and sending out their finished products. Ocean steamship lines are keenly competitive, and whenever a sufficient volume of merchandise is forthcoming from any point in the bay area on a sufficiently deep channel there will be no lack of such service.

Foreign Commerce.

We have already indicated in the preceding chapter the volume of commerce of the San Francisco customs district. The following table shows the principal items of export and import, arranged in order of total value.*

Exports	*Imports*
Canned and dried fruits	Raw silk
Refined mineral oils	Green coffee
Barley	Copra
Raw cotton	Burlap
Automobiles	Chinese wood, nut, or tung oil
Canned fish	Raw sugar
Canned milk	Coconut oil
Asphalt	Tea
Redwood lumber	Print paper
Cigarettes	Tin
Canned vegetables	Bananas
Rice	Crab meat
Flour	

The port of San Francisco ships relatively little for other areas. Nine-tenths of the volume of products imported are consumed in northern and central California, and the same proportion of exports are produced there. As noted in the preceding chapter, an examination of products imported and exported indicates how little California has developed general manufactures such as constitute the list of exports from major eastern ports, and likewise how few manufactures are received from foreign countries by water.

The following are the best foreign customers of this shipping area, according to the data for 1929:*

United Kingdom	39 million dollars
Japan	24 million dollars
Philippines	16 million dollars
Canada	7.6 million dollars
Australia	27 million dollars
China	16 million dollars
New Zealand	8.4 million dollars

The remaining amount, 74 million dollars, was distributed among the other countries of the world. It can be readily seen that the Orient and Australasia constitute an important part of the foreign market for the San Francisco Bay region.

That adequate competition exists for the business which the bay region offers is evidenced by the following statement of the shipping facilities afforded on the routes indicated.†

* Annual (1929) Statistical Statement of Customs District of San Francisco.
† 1930 issue, Year Book of "San Francisco Business," p. 69.

To Australasia	8 lines
Around the world	5 lines
To the Orient and Hawaii	15 lines
To Europe	17 lines
To Central and South America	13 lines
Intercoastal	21 lines
Coastwise	22 lines

Fuel and Power.

Fuel oil is supplied by barge from the four large refineries in the upper bay. A slight advantage in cost is had by the upper bay industries because of the shorter haul. The price of fuel oil per barrel in this area compares with prices elsewhere as follows: *

San Francisco Bay	$0.89
Portland and Seattle	1.10
Los Angeles (El Segundo)	0.85
St. Louis	1.26
Chicago	$1.36–1.40
Detroit	1.57
Pittsburgh	1.68–1.73
New York	1.15
Boston	1.15

At 89 cents per barrel, fuel oil costs 14.7 cents per million British thermal units.

Natural gas from the oil fields is available to the industries of the bay region. A minimum rate of 14 cents per thousand cubic feet is made to industries for that part of the flow of gas which is in excess of domestic and other similar requirements. At this rate the cost would be 12.2 cents per million British thermal units. Natural gas is being made available to certain industrial centers in the east, but comparable cost data can not be had. However, by reducing the prevailing cost of coal to a British thermal unit basis, a comparison of fuel costs may be obtained, although to make gas and coal costs truly comparable an industry would have to add to its coal cost the expense for handling, storage and labor charge for stoking and removing ashes.

The following table shows in British thermal units the cost of coal in certain cities (without the added costs indicated above), the cost of fuel oil in the San Francisco Bay area, and the cost of natural gas in the same area.†

	Cost per million British thermal units		
	for Fuel oil	*for Natural gas*	*for Coal*
San Francisco Bay	14.7 cents	12.2 cents	---
Chicago	22.8 cents	---	14.3 cents
Birmingham	---	---	13.0 cents
Atlanta	---	---	16.0 cents
St. Louis	20.8 cents	---	10.5 cents
Cleveland	---	---	12.2 cents
Buffalo	---	---	13.9 cents
Pittsburgh	28.2 cents	---	9.7 cents
Baltimore	---	---	17.4 cents

Electric power lines serve all parts of the bay region from a common "hookup," and at the same scale of prices. The following table, compiled from charts prepared by the statistical department of the Pacific

* Figures furnished by the Standard Oil Company of California.
† Information regarding gas, coal and power rates furnished by the Pacific Gas and Electric Company.

Gas and Electric Company, indicates how prices of electric current to industrial users compare for different centers:

COST OF ELECTRIC POWER TO INDUSTRIAL USERS

Based on uniform load factor and use of 400 hours per month and with "incidental lighting" making up twenty per cent of the total demand

City or locality	Size of installation or maximum demand		
	100 horsepower (cost in mills)	500 horsepower (cost in mills)	1,000 horsepower (cost in mills)
St. Louis	24.8	24.8	10.0
Detroit	23.2	21.5	13.0
Chicago	17.7	12.7	11.0
Pittsburgh, Pennsylvania	16.6	13.5	9.5
Los Angeles (municipal)	13.6	11.1	8.0
San Francisco	12.8	11.1	9.0
Southern California (outside Los Angeles)	16.6	10.0	9.0

Raw Materials and Markets.

Since these are primarily problems which concern specific industries and do not lend themselves to much generalization, their treatment will be taken up in detail only in connection with the plants in the upper bay area. We need only note here that cheap water transportation has compensated for the great distance by land from certain raw materials, and that the surrounding territory has supplied the rest. Likewise, adequate markets are afforded (1) by the presence in the western states of nearly a tenth of the nation's population, and (2) by the fully developed ocean transportation system which we have already described.

Sites.

The question of the cheapness and quality of industrial sites, like that of markets and raw materials, can best be dealt with in connection with specific areas. The bay with its several arms and tributaries offers a shore line more than four hundred miles in total extent, so that the possibilities for expansion along a water front, so far as mere space is concerned, are practically unlimited. In addition there are in the nine counties within a radius of forty-eight miles from San Francisco many thousands of acres of additional land offering potential industrial sites.

Comparison of the Several Areas in the Bay Region.

Although the chief concern of this study is with the area which borders upon Carquinez Strait and Suisun Bay, a brief comparative survey of the other principal industrial areas in the region will place the study in proper perspective.

Before taking up the several areas in their turn, it will be of interest to note the distribution of the water-borne commerce, in 1929, as an index of present utilization by the bay region of its several shipping points:*

	Short tons	*Value*
San Francisco (City)	14,400,000	$1,613,000,000
Oakland	5,800,000	327,000,000
Richmond	5,800,000	119,000,000
San Pablo Bay	4,700,000	82,000,000
Suisun Bay	4,900,000	64,000,000
Carquinez Strait	9,700,000	228,000,000
Other points	1,800,000	54,000,000

* See footnote on page 171.

West Shore of San Francisco Bay.—San Francisco, proper, has been zoned for light, heavy and unrestricted industry. From Fort Mason to China Basin, however, the whole water front is fully occupied. While some fairly large sites are still available back from the water front, they are attractive to the type of industry which can afford to pay prevailing prices because of certain other peculiarly favorable conditions. Reclamation work * at Islais Creek, authorized by the state, will make available some 280 acres which should sell for $1.50 to $3 per square foot. According to local authorities land at that price is destined for purposes of distribution and multi-story manufacturing plants.†

An extensive area south of Hunter's Point, near to a deep channel in the bay, could be made available for industries at from 50 cents to a dollar per square foot.

The San Francisco city district is second in the state in value of industrial output,‡ but its industries have selected their locations largely because of proximity to the local market. The existence of deep water at San Francisco has fostered industries like coffee, spice and chocolate processing, which derive their products from abroad and distribute them through the channels available in a large urban center.

South San Francisco, already the seat of a number of industrial plants of the heavier type, has ample acreage for large-sized plants at moderate cost. Since it lacks direct access to deep water, a 19,000-foot channel is contemplated, which would tend to increase greatly the value of the sites adjacent to it. South San Francisco, although a separate municipality, is closely connected by rail, street car and highway with San Francisco, and is in the same terminal rate area.

In San Mateo County below South San Francisco, a large area of marsh and of dry land extends back from the bay to the cities and towns built along the Southern Pacific line. Seven thousand acres of dry land are already available for industrial uses. Between South San Francisco and Port San Francisco, just north of Redwood City, further land could be made suitable for industries at from $2,500 to $5,000 per acre. In many cases, a firm foundation would have to be secured through the use of piling.

At Port San Francisco, an area of about 3500 acres, and perhaps 640 acres additional, is available for development. An engineer's report states that "the first unit will provide 100 acres with 500 lineal feet on thirty feet of water." Clay and shale underlie this land at a depth of 30 to 40 feet. At Redwood City, definite plans are under way for a deep water barge canal, together with 2800 feet of docks, cold storage facilities and a turning basin.

Port San Jose, at the extreme lower end of the bay, is still another deep water outlet for the products of the Santa Clara and adjacent valleys which is being given serious consideration.

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* It should be borne in mind in reading this chapter of the report that on substantially all lands which have been filled from dredged materials the costs of foundations will be higher than where the structures are built on natural soil. This added cost has to be weighed against the advantages of having a plant located on deep water.

† These data for the West Bay District furnished by the Industrial Department of the San Francisco Chamber of Commerce and Mr. F. T. Letchfield, Industrial Engineer, San Francisco.

‡ U. S. Census of manufactures, 1927.

The whole territory on the west side of the bay north of San Jose has been served directly by but one railroad line, the Southern Pacific, but access is had across the bay to the other trunk lines, the same rates to outside points applying on both sides of the bay. The examiner for the Interstate Commerce Commission has recommended to the Commission that the Western Pacific be allowed to build a line into San Francisco, crossing the bay near Redwood City. This added line, with the Bayshore Highway and two transbay bridges nearby should add considerably to the attractiveness of the whole San Mateo County industrial area. A deep channel extends down the bay as far as Dumbarton Bridge, but access to it from the industries on the shore would have to be provided by dredging channels.

San Mateo and Santa Clara counties are so admirably adapted for residential purposes that there exists a conflict of interests. Owners of attractive homes and extensive estates resist encroachment of industries. This situation is bound to place a limit on industrial development in these counties.

Fresh water for industrial use in the San Mateo country area can be obtained from private wells or from the municipal supply. Several large industrial wells are in use at South San Francisco, but the constantly increasing drain upon the limited supply of underground water on the Peninsula does not offer much encouragement for additional water supplies from this source.

*East Bay Communities.**—On the east side of the bay, below Alameda, the wide salt marshes lying between the deep water and solid ground make utilization of the land for industrial purposes a matter of the somewhat distant future.

In Alameda and Oakland, land values are high, and in some sections of the former natural foundations are none too good. The typical price of $30,000 to $40.000 for available acreage is high for plants which require a considerable amount of land and find no marked advantage in being situated within an urban district. Oakland, like San Francisco, will probably appeal chiefly to the multi-story type of establishment whose product can absorb a relatively high land cost.

A large interest operating under the name of the Berkeley Waterfront Company, has obtained control of much of the shore line from the Key Route Pier to Richmond, and will undoubtedly develop industrial sites for the types of industry which require large acreage and, at the same time, should be located relatively close to large centers of population, and be readily accessible to deep water facilities.

At Richmond, additional high class industrial property is being made available along a channel thirty-two feet in depth. Attractive sites thus will be provided for terminals and manufacturing plants requiring deep water transportation facilities.

A large potential industrial area exists between Point San Pablo and Pinole Point. This would require bulkheading and filling, and would only be made available to take care of special types of plants requiring large areas free from obstruction, easy accessibility to deep water, and good labor supply.

* Information on the East Bay situation was obtained from Mr. F. D. Parr of the Parr Terminal Company, San Francisco.

Some wells are in use in the plants of east bay industries, but the new east bay municipal supply from the Mokelumne River is the principal source of fresh water.

The Upper Bay.—Stockton * has recently assumed a new importance as a potential industrial area. A twenty-six-foot channel which is now under construction through the upper part of Suisun Bay and the San Joaquin River will enable ocean vessels to dock at the Stockton terminals. As a result, the considerable tonnage of grain, canned fruits and vegetables, dried fruits, and some manufactured products which heretofore has had to be shipped by rail or river to a San Francisco Bay port from the central valley area can be loaded on vessels at Stockton. In like manner, inbound shipments of lumber, wood pulp, and general merchandise can be brought directly to Stockton. The present industries, for the most part, are the type which serve the local area (farm machinery, containers, boats) or process its products (canneries). Ample fresh water can be had in the river, with little trouble from salinity at that distance from the Golden Gate—about ninety miles. The city is served by all three transcontinental lines. Much land is available for industries, but that which is best located is low-lying and would have to be protected by levees.† Industrial growth in the near future, as at present, will be devoted largely to serving the surrounding territory and processing its products.

Sacramento‡ is some twelve miles farther from the ocean than Stockton. Sacramento also serves the great central valleys. It is located on two of the transcontinental lines and connects with the third at Stockton. It has a ten-foot river channel to Suisun Bay.§ The water in the river at Sacramento is soft and free from salinity. Abundant industrial land is available, although, as in the case of Stockton, the best situated land would have to be protected from inundation. Flour mills, fruit and vegetable canneries and a large can factory constitute the principal industries. The rest are mostly of the smaller local variety. A ship canal to Sacramento has been under consideration for a long time, but now that the Stockton project has become a reality, the facilities of that port should, for some time to come, prove adequate to serve the territory tributary to both cities. There is no immediate likelihood of a considerable influx of industries which are not closely related to the local area.

The following data, from the Market Data Handbook of the United States Department of Commerce, 1929, show the status of manufacturing in the several cities of the bay region in 1927:

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* Document 554, House of Representatives, 68th Congress, 1st Session, "San Joaquin River and Stockton Channel, California," 1925.

† C. E. Grunsky, Report on Sacramento Deep Water Ship Canal, 1925, p. 61.

‡ C. E. Grunsky, Report on Sacramento Deep Water Ship Canal, 1925, esp. pp. 1–61.

§ The old nine-foot channel is in process of being deepened to ten feet.

	Number of plants	Number of wage earners	Thousands of dollars			
			Wages	Cost of materials	Value added	Value of product
San Francisco	2,092	41,909	$61,134	$237,642	$192,086	$429,728
Oakland-Berkeley-Richmond	866	23,235	35,031	167,549	94,227	261,776
Sacramento	197	6,359	8,377	25,210	17,759	42,969
Stockton	131	3,001	4,240	13,178	10,718	23,895
Upper Bay [1]	58	14,450	22,000	215,000	70,000	285,000

[1]Data include all major basic industries below Antioch and above Richmond approximately 80 per cent being from replies to State Engineer's questionnaire, 15 per cent from Byron Times, 12th Development Edition, and 5 per cent estimated.

From Point Pinole to Antioch on the south shore of Carquinez Strait and Suisun Bay, and at Vallejo and Benicia on the north shore, are located the group of industries which are the special concern of this study. Here inexpensive land is nearer to deep water than at any other point in the bay region. Large tracts have been available away from centers of population where fumes from industrial processes and the hazards of explosive manufacture create a minimum of concern, although this situation is changing with the growth of the upper bay communities. No handicap of city-street rights of way, or building restrictions hampers the laying out of the plant.

From Crockett to Martinez there is little land readily available between the hills, the railway lines and the water. To the east of Martinez, a stretch of lowland has been purchased for reclamation in the general neighborhood of Point Edith.

From this proposed development to Antioch, a considerable acreage of solid land is still available—the typical price is about $7,000 an acre for water front property and about $2,000 for that a half a mile or so farther back.* The Stockton deepwater project will add to the attractiveness of this area for industrial purposes.

At Pittsburg, particularly, wells have been used to supply fresh water when the water in the river becomes brackish. Other industries supplement their own river supplies with the filtered and treated river supply of the California Water Service Company.

The Southern Pacific and Santa Fe railroads traverse the Contra Costa side of the bay, and the Western Pacific, through its ownership and use of the Sacramento Northern, provides the shipping services of a third transcontinental system. The north shore of Suisun Bay and the strait is served by the Southern Pacific and the Western Pacific. The Mare Island Navy Yard at Vallejo, the government arsenal at Benicia, and some private industrial enterprises in these two cities constitute the present development. Port Sacramento, between Vallejo and Benicia, is being projected as a further extension of north shore industrial and shipping activity.

Because of the wide area of marsh land and shallow water which prevails along the north shore of Suisun Bay, it will probably not be developed industrially for some years to come.

The types of industry which exist in the upper bay area have proceeded to build up their own labor force with a favorable turnover rate and comparative freedom from disturbances. The typical wage of

* Data obtained from a company specializing in upper bay industrial sites.

unskilled male labor seems to be 50 cents an hour. Italians, Portuguese, Mexicans, with some American laborers, furnish the common labor supply. Skilled labor averages from 75 cents to a dollar or more an hour.*

The upper bay is, on the whole, better adapted to making products intended for distribution by steamer and rail over a wide area, than providing the populations of the large urban centers with the things they consume directly. However, so populous a region with so great a number and variety of industries, commercial firms and farms, offers no mean outlet for the products of an industrial district, even though the more basic type of industry predominates.

Markets and Raw Material Sources of Upper Bay Industries.

Few of the raw materials used by upper bay producers, aside from the products handled by canneries, originate within the area. The presence of many of them in California and other western states and the easy accessibility of the rest, because of low water transportation costs, has prevented the raw material factor from becoming an impediment to the industrial growth of the upper bay area.

Raw Material Sources.—Specifically, according to the statements received from the industries themselves, the problem of securing raw materials for the several types of industry in the upper bay is met as follows:

Oil refineries:
1. By pipe lines from San Joaquin Valley.
2. By oil steamers from southern California.

Lumber products:
Rail and steamer, or combination of the two, from Oregon, Washington and California.

Cane sugar refinery:
Steamer from plantations in Hawaiian Islands.

Steel mills:
1. Local scrap.
2. Pig iron from Utah.
3. Eastern and foreign water-borne shipments.

Rubber mills:
Rubber—Straits Settlements; Cotton—southern California and San Joaquin Valley.

Chemical companies, including sprays, insecticides, etc.:
California, Japan, Washington, Texas, Belgium.

Canneries—Vegetable and fruit:
Nearby ranches.

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* Data with respect to the upper bay area have been obtained almost wholly from a questionnaire prepared and sent to the industries of the area by the office of the State Engineer. A brief summary of the contents, given at the end of this report, evidences the comprehensiveness and painstaking character of this search for pertinent facts concerning the industrial situation and water problems of the area. For some six months after the questionnaires were placed in the hands of the industries, much "follow-up" work had to be done by the State Engineer's staff, in order that the fullest possible information might be secured. Short of a prohibitively expensive plant-by-plant investigation by a staff of experts, the data are probably the most complete and reliable that could be obtained.

Canneries—Fish:
San Joaquin and Sacramento rivers and upper bay, and trawlers from Pacific Ocean.

Explosives:
Chile, Texas, Pacific coast states.

Ship yards:
Pacific coast and eastern United States.

Dairy products:
Nearby ranches.

Asphalt products:
Largely California, some from Trinidad, the Orient and eastern United States.

Brick works:
Clay at site.

Beverages:
Local mineral springs.

Grain cleaning, warehousing, etc.:
Local valleys.

Mills—Flour and feed:
California—mostly. Some from Washington, Oregon, Idaho and the east.

Sand, gravel, cements, etc.:
Local river and bay bottoms.

Paper boxes:
1. Paper from east and mills in north.
2. Board from Stockton, Antioch and Washington.
3. Straw, scrap paper and rags from local sources and wood pulp from northern mills.

Tannery:
Western states, Argentina, Mexico.

As has been noted, the above information was obtained from the replies to the questionnaire sent to the several industries by the State Engineer's office. No complaint was made by any of the industries to the effect that they were badly located with respect to raw material supplies.

Markets for Upper Bay Products.—The following statement compiled from the State Engineer's questionnaire shows the market for the products of upper bay industries:

Oil refineries:
North and South America, Europe and the Far East.

Lumber product manufacturers:
Mill work—mostly local. Some wood products sent to east and middle west.

Sugar refinery:
Thirty-five states of the United States.

Steel mill:
Eleven western states and the Orient.

Rubber products mill:
World wide market.

Chemical plants:
Eleven western states, a small amount to the middle west and foreign countries.

Canneries:
The whole world.

Explosive plants:
The Pacific states, South America and the Far East.

Ship yards:
The Pacific coast; United States Navy.

Asphalt product plant:
Eleven western states, Alaska, Mexico, the Orient.

Brick works and other building materials:
The bay region.

Beverage plant:
The bay and delta areas.

Flour and feed mills:
Poultry and stock feeds are for the most part sold locally; the Sonoma, Marin and Napa County chicken ranches comprise a large market. Flour is sold in California and the Orient.

Box Factories:
Local poultry and fruit interests require a large quantity of wooden boxes. Paper boxes have a world-wide market.

Tanneries:
Leather is sold on the coast and in thirty foreign countries.

So far as most points in the west are concerned, and those foreign and eastern markets which can be reached by water, the upper bay region has no difficulty in meeting competition, provided other factors are favorable. Two or three firms, however, which cater to San Francisco and Oakland trade, expressed dissatisfaction with the upper bay as a location for their industries.

Dominant Location Factors in the Upper Bay Area.

The following table indicates the number of times the industries listed the several location factors directly or by implication in replying to the State Engineer's question as to why they chose a location in the upper bay:

1.	Water transportation facilities	63
2.	Rail transportation facilities	53
3.	Good highways	51
4.	Close to the market for a particular product	43
5.	Raw materials at hand or cheaply obtained	34
6.	Existence of a suitable building	15
7.	Satisfactory labor force	10
8.	Near San Francisco and Oakland	10
9.	Ample cheap fresh water at time of locating	10
10.	Comparative isolation	6
11.	Climate	5
12.	Adequate site at low cost	3
13.	Recognized center of the industry	2
14.	Favorable topography	2

When asked to point out the special advantages and disadvantages experienced in their present locations, the various groups stressed the following:

I. Fruit and vegetable canners and pickling works—

Special advantages:
1. Nearness to a perishable raw material.
2. Access by rail, highway, steamer, to foreign, intercoastal and bay markets.

Special disadvantages:
None specified.

II. Lumber and wood products—

Special advantages:
1. Raw material by water at low transportation cost.
2. Large consumption area reached by rail, water, highway.

Special disadvantage:
1. Too long a haul to its two large customer areas, San Francisco and Oakland.

III. Rubber products—

Special advantages:
1. Crude rubber brought to dock from Orient.
2. Fabric from California cotton.

Special disadvantage:
1. Very heavy water user for process. Product adversely affected by salty water pumped from bay during salinity period.

IV. Chemicals—

Special advantages:
1. Raw materials come from Asia and western United States—transported cheaply.
2. Fumes blow away from cities.

Special disadvantages:
1. Only cheap water now available is in the bay and rivers. Cooling apparatus used deteriorates at abnormal rate because of saltiness of its supply during dry season.
2. Certain processes not undertaken because of lack of cheap fresh water supply during salinity period.

V. Oil refineries—

Special advantages:
1. Accessibility of foreign, western and local consuming territory.
2. Head of valley pipe lines.

Special disadvantages:
1. Type of apparatus used wears out faster when cooling water becomes salty.
2. Fresh water bought from public supply systems is too costly.

VI. Fish canners—

Special advantage:

1. Raw material from two rivers and the ocean.

Special disadvantages:

None specified.

VII. Ship building—

Special advantage:

1. Can float vessels directly into deep water.

Special disadvantages:

None specified.

VIII. Creamery—

Special advantage:

1. Adjacent to ranches.

Special disadvantage:

None specified.

IX. Powder plants—

Special advantage:

1. Isolation of sites.

Special disadvantage:

1. Type of cooling apparatus used is destroyed relatively fast because cooling water is salty.

X. Copper smelting and refining—

Special advantages:

1. Ore transported to plant at satisfactory cost.
2. Prevailing winds carry fumes away from cities.

Special disadvantage:

1. When river water used in process becomes salty it injures product.

XI. Paper and fibre products—

Special advantage:

None specified.

Special disadvantage:

None specified.

XII. Iron and steel products—

Special advantage:

1. Large supply of scrap metal in populous area. New iron produced in Utah and transported at satisfactory cost.

Special disadvantage:

1. Obtain present water supply from wells. Dependability for future expanded program, questionable. River water is cheaper and softer, but is salty in dry season and turbid during flood period.

XIII. Cane sugar refining—

Special advantage:

1. Deep water from plantations to plant.

Special disadvantage:

1. Heavy user of water of very low chlorine content. Has obtained such supply at great expense heretofore. (Is now developing a new supply in the hope of obtaining a considerable reduction in water cost.)

Summary of Location Advantages of the San Francisco Bay Region as a Whole.

1. Nearest of the manufacturing areas of the west to the west's geographical population center.
2. Large consuming population within its own limits and in adjacent valleys.
3. Lack of extremes in temperature.
4. Location in extensive fruit and vegetable canning region favorable for canneries, can companies, tin mills, makers of food machinery and implements used in planting and cultivating raw product.
5. Served by a network of railway lines.
6. Motor highway system comprehensive and up-to-date.
7. Ocean steamship lines to forty foreign countries and to eastern, southern and Pacific coast ports of the United States.
8. Labor supply adequate and comparatively free from labor troubles in plants.
9. Power—electric, fuel oil, natural gas—at rates which compare favorably with other industrial areas.
10. Navigation between points in the bay and into Sacramento and San Joaquin rivers.
11. Accessibility to the San Francisco money market, one of the largest in the United States.
12. Numerous plant locations with bay water available for industrial uses.

Obstacles to the Industrial Development of the San Francisco Bay Region.

1. Municipal water supplies are being provided at such great expense that a price of 24 to 30 cents per thousand gallons is exacted in most instances. This, no heavy user of fresh water can afford to pay unless the other location factors are sufficiently favorable to wipe out the handicap.
2. Unlike most important industrial centers of the east and south, the bay region proper,* contains no stream or lake along which an industry can locate and pump an abundant supply of fresh water the year around.
3. Private wells, which furnish an abundant supply of fresh water in some regions, are used by a few industries in the bay region, but this source of fresh water can not be relied upon to any great extent.

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* Excludes locations on the two rivers above the line of salinity encroachment.

Summary of Outstanding Location Advantages Afforded by the Upper San Francisco Bay Area.

1. Availability of large acreage of level sites on solid ground and deep water.
2. Low cost of sites compared with other developed bay areas.
3. Adapted to one-floor type of heavy industry which covers large acreage and whose main markets call for deep water transportation. Will not attract so readily those which can pay large rate for space in a city.
4. Equal availability, with other parts of the region in respect to raw materials from California or neighboring states, or those brought in by way of ocean vessels.
5. Relative isolation for industries that are obnoxious or dangerous to city populations.
6. Four of the largest oil refineries in California are located in this area, which assures a plentiful supply of fuel oil with a negligible transportation cost.
7. Natural gas and electric power are available to industries at as low rates as elsewhere in this region.
8. Labor supply and cost are favorable.
9. Raw material for canneries, such as the asparagus of the delta, the fruit from the two great valleys, and fish from the rivers, is close at hand.

The obstacles noted in the case of the bay region as a whole apply with equal force to the upper bay.

CHAPTER III

WATER AS A PLANT LOCATION FACTOR—IN GENERAL AND IN THE AREAS UNDER SPECIAL CONSIDERATION

Most authorities on plant location include water as a factor to be considered in the establishment of a factory. It is an item that is frequently weighed with such other factors as market, raw materials, labor, transportation, power and fuel.

From an industrial point of view, there are three important aspects of the water situation, viz, its quantity, its quality, and its cost. Some of the industries which find the quantity of water an important item for manufacturing purposes are:

1. Oil refineries
2. Iron and steel industries
3. Meat packing plants
4. Soap and soap compound factories
5. Sugar refineries
6. Tanning establishments
7. Paper manufacturing industries
8. Textile industries
9. Cement mills
10. Explosive manufacturing plants
11. Rubber product industries
12. Plants manufacturing chemicals and allied products
13. Industrial power stations
14. Food canning and preserving industries
15. Dyeing industries
16. Beverage production plants
17. Ice making plants
18. Paint and varnish plants
19. Salt refineries
20. Gelatinous product industries

Cooling and condensing call for especially large quantities of water, either salty or fresh. Fresh water is used also for boiler purposes, for washing, cleaning, filtration processes, boiling or treating products, distillation, steaming, etc.

Quality of water available is of primary importance in many industries. Textile mills demand a great volume of soft water free from iron and sediment. Rayon mills, for example, will not tolerate such elements as iron, magnesium and calcium, which discolor goods or give hardness to the water. To remove undesirable elements in the water usually involves considerable expense and therefore various kinds of textile mills consider softness and purity of water as one of the major considerations of plant location. Suitable water has been one of several factors which have attracted rayon and other mills to the southeastern states. Canneries need a water under a hardness of 170 parts per million, a water that is clean, sanitary and low in organic nitrogen. Power producers, oil refineries and steel plants need (1) a good quality of boiler water, free from sediment and oil, fresh and soft, and (2) large quantities of either salty or fresh water for cooling and condensing.

The Pacific Coast Situation.

The salvation of the Pacific coast states is the oceanic wind which precipitates its moisture for the benefit of the western mountain slopes. If the prevailing wind were from the opposite direction the west coast would be barren indeed. Mountains like the Sierra Nevada, with their long western slopes, serve as a condenser for the precipitation of water from the moist west winds. Properly utilized, the fresh water afforded is ample for a large coastal civilization.

Taken as a whole, the surface waters of the Pacific slope vary greatly in quality. In respect to hardness, the water is softest in the north and hardest in the south. In some parts of California water is relatively hard, but Mokelumne River water, for example, which is the source of the east bay municipal supply in San Francisco-Oakland region, has a hardness of only 40 parts per million, which constitutes a softness that is comparable with water found in such low-average states as Washington, Oregon and New York.

Much of the water used by municipalities, ranches and industries in California is pumped from underground. This extensive practice has led to a serious falling of the water table in many parts of the state. The wise utilization of water resources is becoming a major problem in California. Surface storage is an important means for providing against shortage of water.

The Lower San Francisco Bay Area Situation.

The east and west sides of the lower San Francisco Bay have both had to take steps to forestall water famine. The cities on the east side of the San Francisco Bay have formed the East Bay Municipal Utility District for the purpose of bringing water some ninety miles from the Mokelumne River to reservoirs at Oakland and Berkeley.

San Francisco is incurring the heavy expense of bringing in the Hetch Hetchy water supply from the Tuolumne River.

Smaller towns and various industries about the lower San Francisco Bay are depending largely upon wells and somewhat upon local surface water as a source of supply. Lack of water is retarding the development of desirable residential sites on the foothills in the region. A further exploitation of underground waters and some tying in with the large municipal supply projects will have to be done, if near future needs outside of the large cities are to be met.

The Upper San Francisco Bay Area Situation.

The region about the San Pablo and Suisun bays is much less densely populated than the lower bay area, hence the need for an abundant supply of fresh water has been less urgent. The public water supply companies to be found about the upper bay have thus far been able to get along with local sources of supply and have not as yet been driven to seek distant ones. The water companies, sources of water obtained, annual consumption, and cost of water to large users are as follows:

Organization	Source of water	Annual demand in million gallons	Cost to large users in cents per thousand gallons
Antioch Municipal Water Works	San Joaquin River	212	[1]9.3
Benicia Water Company	Local streams	94	44.0
California Water Service Corporation	Sacramento River and wells	1,105	23.3
Hercules Water Company	Wells and East Bay Municipal supply	94	26.7
Pittsburg Municipal Water Works	Wells	200	16.7
Martinez Municipal Water Works	California Water Service Corporation	213	34.7
Vallejo Municipal Water Works	Creeks in Napa and Solano Counties	570	26.3

[1] Within city limits of Antioch.

It can be seen from a comparison of this table with that on page 212 that the cost of water to large users from public supplies is high compared with prices which prevail in the United States east of the Rockies and in the Pacific northwest. This is partly due to the fact that the water-supply companies have encountered heavy costs, for which customers must pay.

The California Water Service Corporation has spent one and a half million dollars at Clyde in developing a pumping project and reservoir to yield three and a half million gallons a day. An ultimate yield of eight million gallons is being planned. The point of intake is at Mallard Slough. The company sells water to Martinez and Concord and covers the territory from Pinole on the west to Bay Point on the east. What the company will do in its future development program is contingent upon other developments in the region and upon its success in securing the patronage of large users of water. This same method of procuring fresh water for this area is susceptible of much further development.

All told, with respect to water supply, the upper bay region is operating at an economic disadvantage. This is the inevitable result when a single coordinated plan of development is lacking. The following illustrations show the need of careful regional planning with respect to water supply: The California and Hawaiian Sugar Refining Corporation, Limited, has been bringing water to its plant at Crockett by means of barges, which at times must go many miles up-stream to reach a source of fresh-water supply. During recent years, this source has been supplemented from July to December, inclusive, by a Marin County supply taken aboard barges at San Quentin. In an attempt to alleviate its difficulties, wells were also dug in the hope that industrial water could be found, but there was no success. A nine-mile pipe line from San Pablo to Crockett was projected, but the supply was found to be too uncertain. The corporation believes that its water problem has now been solved by a pipe line being constructed to bring water from wells in Napa Valley.

The Hercules Powder Company at one time received its water from Pinole Creek. This source of supply ran out and, as an emergency measure, water had to be secured from Spring Valley in drums. Many wells were drilled also, and a special six-inch pipe was connected to the East Bay Water Company's system, but during the peak of its business the powder company was still hampered by lack of adequate water supply. During the war the supply of munitions from this area was seriously curtailed by the shortage of fresh water. In Solano County, during the war, soldiers had to be rationed as to water because of shortage. At the present time, such of the industries of Contra Costa County as must have a considerable supply of fresh water for boiler and process, depend upon wells and public supplies as a supplementary source when the volume of river flow is at its minimum and the salt encroachment is present.

Salt Water Difficulties.

The encroachment of salt water upon a fresh-water area raises a problem in connection with both domestic and industrial water supply. One reason is that saline water can not be treated and made fresh, in large quantities, without prohibitive expense; it is particularly hard to remove dissolved salt from water.

Even when some new source of fresh-water supply is found, the economic troubles in trying to surmount the water question do not necessarily come to an end. The new supply secured may be more or less temporary in nature, and still newer sources must be sought after the temporary source becomes unsuitable or deficient. Companies which turn from bay water to wells as a recourse in the time of salt water difficulty are often compelled to find new wells as old wells become useless. In their reply to the questionnaire, the representatives of a very large water-consuming industry in the upper bay area stated:

> Depreciation on wells is placed at 10 per cent as the wells get salty in time and have to be abandoned.

Another large user states his case in the following manner:

> Water from our private wells has been used for boiler water during summer seasons until the summer of 1929 when hardness increased to 82 grains per gallon, making it unfit for boiler use. Hardness was approximately 40 grains in 1921.

Another manufacturer, who uses river water for some purposes and well water for others, says:

> We have had three wells turn salt since 1924.

Another manufacturer makes the following statement:

> Since 1924 this company has been without water in summer time with which it was possible to manufacture. In 1924 it cost $5,000 to haul water for ———.* Under present conditions we could not afford to manufacture this article in summer during the last four or five years.

When asked as to what financial loss, if any, they have incurred from the salinity conditions in the upper bay and rivers, several typical industries replied as follows:

> A. Depreciation of plant equipment is double that with fresh water. Have losses due to the eating away of condenser tubes, condenser boxes, piping, and concrete by hot salt water. Salt water after it is heated by condensers and coolers eats away both concrete and steel. This would be reduced 50 per cent by the use of fresh water.
>
> B. Apparatus is designed for the use of salt water.
>
> C. Have been forced to use thicker walls for condensers, which helps to meet the corrosion problem, but cuts down the efficiency of equipment. Many other

* Name of product omitted. Confidential information.

adaptations in equipment are being made. Increased cost of manufactured products and plant operation is 5 per cent. Costs in plant maintenance and depreciation of plant equipment are 300 per cent above normal with fresh water available. Costs in 1929 in excess of costs in 1920 directly chargeable to salt water conditions amounted to $81,000.

D. Financial loss due to increased salinity of river:
Plant operation, $40,000 per year.
Depreciation of plant equipment, $3,600 per year.
Depreciation above normal with fresh water is about 200 per cent.

E. Increased depreciation above normal for various types of equipment is 100 to 400 per cent.

F. As close as we can figure it, the financial loss to this company due to salt water is in excess of $20,000 per year.

G. Depreciation of equipment for condenser and cooling purposes—four times that resulting from fresh water.

H. Mechanical roasters and power house condensers deteriorate very rapidly by reason of salt water.

I. Abnormal cost due to excessive depreciation of plant equipment and added expenses in plant maintenance is 35 per cent above normal.

J. High salinity does not result in abnormal depreciation of condenser and cooling equipment because necessary expenditure for equipment to resist salt water corrosion has been made.

K. Depreciation rate for heated water equipment is 30 per cent above normal.

L. Abnormal depreciation rate of condenser and cooling equipment is $500 per year for this company.

These cases show that the water in the upper bay can be employed for certain industrial uses the year around, but that (1) deterioration is increased if the type of cooling equipment used is not adapted to this most economical source of water, and (2) that a cheaper fresh-water supply should be developed for boiler and process use.

The Relative Importance of Water to the Upper Bay Industries.

The upper bay area, by chance or design, contains an unusually large proportion of heavy water using industries. According to their own statements, they were not attracted to the area, *primarily* by the supply of fresh water which the upper bay afforded during the greater part of the year, but this factor seems to have been given considerable weight by some of them. The canneries, chemical plants, iron and steel mills, oil refineries, powder works, paper company and rubber mill, which dominate the upper bay industrial set-up, all use large amounts of water for process or cooling, or both. In no case does the water cost constitute more than a small fraction of the value of the product.* It might still be true, however, that those industries which have to meet keen competition from plants located on plentiful supplies of fresh water, other manufacturing costs being equal, would find that the water situation in the upper bay would put them under a severe handicap.

None of the industries in the area have moved away because of the water situation, and four new enterprises of considerable size—The Johns-Manville Company, the tinplate mill at the United States Steel Products plants, the Shell Products Company, and the Stockton Brick Company, near Pittsburg—have located there since the salinity condition became troublesome. However, such a complication of factors

* See table on page 208.

is involved in the location of a new plant that one is hardly safe in attributing to salinity conditions the failure of still other enterprises to locate in the upper bay area. Furthermore, a representative from the bay region states that he recently engaged in six weeks of conferences with eastern officials of plants who contemplated establishing Pacific coast branches.† He reports that the industries in question were attracted by the market, labor and transportation facilities of the upper bay district, but were repelled by the cost of fresh water.

Industries are likely to be frightened by the mere fact that municipal water is selling at from 9 to 44 cents per thousand gallons and averaging over 24 cents, that private well supplies are not altogether reliable, and that river water is salty a portion of the year. On the other hand, if a careful investigation were made, it would probably show that all other factors were so favorable in the upper bay, and its water difficulties so far from being unsolvable, that the present unfavorable water situation could be materially discounted.

On its face, the proposal to solve the area's water difficulties by the construction of a salt water barrier would add another attractive location factor to the imposing list which the upper bay district affords, providing that such a project did not bring with it a marked increase in the tax burden of the area. If such an increase did result the barrier might repel rather than attract new plants.

† Statement of Mr. Warren McBryde, Consulting Engineer, San Francisco.

CHAPTER IV

THE INDUSTRIAL SITUATION IN THE UPPER BAY AREA—PRESENT AND PROSPECTIVE

The only official description of the upper bay industrial situation is that published by the Federal Government in the "Market Data Handbook," issued by the United States Department of Commerce. The first, and also the latest number of the handbook (1929), gives the situation for 1927 as follows:

	Number of establishments		
Type of industry	*In Contra Costa County*	*In Solano County*	*Total*
Food and kindred products	29	19	48
Textiles and their products	1	0	1
Paving material	4	0	4
Iron, steel and their products	5	0	5
Machinery	3	1	4
Forest products	8	2	10
Leather and its products	0	1	1
Rubber products	1	0	1
Roofing material	1	0	1
Paper industries	2	0	2
Printing and publishing	15	11	26
Chemicals and allied products	19	2	21
Stone, clay, glass, etc., products	7	1	8
Metal products, except iron and steel	2	1	3
Tobacco products	0	0	0
Musical instruments	0	0	0
Transportation equipment	1	0	1
Railroad repair shops	4	2	6
Totals	102	40	142

Unfortunately the handbook does not separate out the industries of Richmond, which is in Contra Costa County, but in reality belongs to the east bay industrial area, rather than to the upper bay. From the questionnaire sent the industries, however, we are able to present the following tabulation of the *more important* upper bay industries, beginning at Pinole Point and extending on both sides of Carquinez Strait and Suisun Bay eastward to the mouths of the Sacramento and San Joaquin rivers:

Location and type of industry	*Number of industries*
Antioch—	
Fibreboard products	1
Canneries	3
Lumber products	1
Shipbuilding	1
Avon—	
Oil refining	1
Bay Point—	
Lumber products	1
Shipbuilding	1
Chemicals	1
Cement mill	1
Benicia—	
Canneries	1
Arsenal	1
Tannery	1
Chemicals	1
Tractor factory	1
Crockett—	
Grain cleaning, etc.	1
Sugar refining	1
Giant—	
Explosives	1

Location and type of industry	Number of industries
Hercules—	
Explosives	1
Martinez—	
Copper smelting	1
Lumber products	1
Oil refining	1
Pittsburg—	
Fish products	2
Steel products	1
Chemicals	3
Asbestos products	1
Dairy products	1
Wood products	1
Rubber products	1
Brick works	1
Port Costa—	
Brick works	1
Grain cleaning, etc.	1
Oil products	2
Rodeo (Oleum)—	
Oil refining	1
Selby—	
Ore smelting	1
Vallejo—	
Navy yard	1
Flour milling	1
Dairy products	1

If one undertook to describe in a sentence the nature of the industrial activity in the upper bay, he would characterize it as the type which, for one reason or another, operates best outside of congested metropolitan areas and yet finds it highly desirable from the standpoint of either its markets or material sources to have at its command as good shipping facilities as location in a large port city would afford.

The Location History of the Area by Decades.

Not all of the dates when these industries were established are available. Such as were furnished in the questionnaire are the basis for the following location record by decades:

Before 1881		
Arsenal	1	(1850)
Navy yard	1	(1853)
Cannery (fruit)	1	(1870)
Cannery (fish)	1	(1875)
Grain cleaning	1	(1876)
Powder mill	1	(1880)
1881–1890		
Ore smelter	1	
Lumber products	1	
Grain cleaning	1	
Flour mill	1	
1891–1900		
Powder mill	1	
Oil refinery	1	
1901–1910		
Chemical plant	2	
Lumber products	3	
Sugar refinery	1	
Steel mill	1	
Cannery (fruit)	1	
Copper smelter	1	
Rubber mill	1	
Brick works	1	
Beverage factory	1	
1911–1920		
Oil refinery	2	
Chemical plant	1	
Dairy products	1	
Rock products	1	
Lumber products	1	
1921–1930		
Paper products	1	(1927)
Cannery (fruit)	2	(1921) (1928)
Cannery (fish)	1	(1927)
Chemical plant	2	(1923) (1930)
Shipyard	2	(1926) (1928)
Lumber products	1	(1927)
Dairy products	1	(1922)
Asbestos products	1	(1925)
Tin plate mill *	1	(1929)
Brick works	1	(1930)

* Built in connection with then existing steel mill.

It is evident that during each of the decades given, at least one important industry has chosen the upper bay as its location. Viewed from the standpoint of present size of plants and value of output, 1901–1910 seems to have been the "golden era" of industrial establishment in the upper bay.

The decade just coming to a close has been distinguished by three outstanding developments: (1) The Johns-Manville Company established an asbestos products plant (1925); (2) The Steel Corporation (1929) built a tin plate mill in connection with its steel mill; (3) The Shell Products Company is establishing a large chemical plant (1930).

The new tin mill is the first one to be built west of St. Louis. It was erected at a cost of $3,000,000 and its corps of new workers materially increases the steel corporation's labor force at Pittsburg. The fact that 18 per cent of the national output of tin plate was used on the coast prompted this development. All of the raw materials but the tin are produced in Utah. The latter is brought direct by steamer from the Straits Settlements. Making the tin plate near the source of consumption avoids the heavy rust and other damage (10 per cent) incurred in ocean shipments from the east.

The Effect of Salinity on Plant Location.

An effort was made in connection with this study to obtain accurate information as to what industries, if any, have been lost to the upper bay area because of the salinity problem, but results were not satisfactory.* Since no dependable list can be made, one can only report the "hunches" of numerous individuals. The result is that in the case of no industry can it be said without fear of contradiction that it was or was not frightened away from the upper bay because of the salinity problem.

As was pointed out earlier, the tangible location factors, themselves, are many and they are interwoven in complicated fashion. Add to that the intangible personal factor and it is but natural that one finds much difference of opinion as to what led to the location of a given plant in a given place. Even responsible people and the industries themselves frequently find it difficult to single out the ultimate determining element.

Present Growth of the Upper San Francisco Bay Area.

It would be highly desirable to compare the growth of the upper bay area with respect to employees, wages, capital investment, value of output and other items with (1) the United States, (2) with California, and (3) with other local industrial areas.

Unfortunately, there are no census figures for the upper bay area as such. These for the United States and for California are available for 1904, 1909, 1914, 1919, 1923, 1925 and 1927. The 1929 census has been taken but the data will not be compiled for many months; the material in the 1927 census of manufactures did not become available until 1929.

Data obtained by the questionnaire method are never wholly satisfactory. No matter how carefully the questions are framed, different

* Two large industries which chose another location after considering various sites in the San Francisco Bay region have written as follows: Industry A: "The chief factors taken into consideration were adequate supply of satisfactory labor with adequate housing facilities in vicinity of plant site, sufficient power at reasonable rates, and adequate water supply at no cost except cost of pumping. A large ——— factory needs large quantities of fresh, cool water, and being assured of an ample supply underneath its plant with low pumping cost was one of the main factors in selecting the ——— site." Industry B: "The water situation was one of a number of factors which influenced our decision to locate in ———, but it was not necessarily the deciding factor."

interpretations will be placed upon them and will render them incomparable, at least to some extent. In this case some industries did not care to reveal certain facts about their operations, while others did not have the requisite records at hand. Particularly with respect to the capital investment figures and those covering water costs, reservations will have to be made. The replies do, however, represent a sufficient percentage of the whole and probably sufficient comparability to warrant their use in showing trends since 1924.

The following figures indicate the relative change in recent years, in the three areas given:

Value of the product of industries

	In U. S.	*In California*
1919	$62,000,000,000	$1,981,000,000
1921	43,618,000,000	1,758,000,000
1923	60,529,000,000	2,214,000,000
1925	62,668,000,000	2,442,000,000
1927	62,718,000,000	2,593,000,000

In the Upper Bay Area (partial total)[1]

1924	$71,066,000	1927	$84,840,000
1925	80,463,000	1928	91,023,000
1926	84,172,000	1929	90,516,000

[1] Includes only those industries furnishing these data for all six years in State Engineer's questionnaire, being Nos. 1, 2, 8, 11, 15, 19, 21, 23, 25 and 28, as shown in the list of industries at end of this report.

During the past five years the average annual growth in value of products in the upper bay has been approximately 5.5 per cent. From 1923 (the first year given after an acute depression) until 1927 the average annual increase in the value of product for the United States as a whole was slightly less than 1 per cent, and for California 4.3 per cent. It is greatly to be regretted that data do not exist for tracing the trends back over an extended period for all three areas. It is needless to point out that comparisons for such short periods lose much of their value.

Number of employees in industries

Average for the year

	In U. S.	*In California*
1919	8,997,900	243,700
1921	6,944,300	198,300
1923	8,776,600	246,100
1925	8,381,500	249,500
1927	8,349,700	262,800

In the Upper Bay Area (partial total)[1]

1924	8,854	1927	10,048
1925	9,566	1928	10,954
1926	10,324	1929	12,195

[1] Includes only those industries furnishing these data for all six years in State Engineer's questionnaire, being Nos. 1, 2, 8, 10, 11, 14, 15, 19, 20, 21, 23, 28, 31, 32, 33, 35 and 37, as shown in the list of industries at end of this report.

During the years 1924–1929 the average annual increase in workers employed in upper bay industries has been 7.5 per cent. For the

United States as a whole there was a decrease of industrial workers from 1923 to 1927, and for California an increase of not quite 2 per cent.

Growth of payrolls

	In U. S.	*In California*
1919	$10,460,000,000	$305,000,000
1921	8,200,000,000	284,000,000
1923	11,007,000,000	353,000,000
1925	10,727,000,000	350,000,000
1927	10,848,000,000	378,000,000

In the Upper Bay Area (partial total)[1]

1924	$13,993,000	1927	$16,594,000
1925	15,369,000	1928	18,029,000
1926	17,010,000	1929	21,123,000

[1] Includes only those industries furnishing these data for all six years in State Engineer's questionnaire, being Nos. 1, 2, 8, 10, 11, 15, 19, 20, 21, 23, 28, 29, 31, 32, 33, 35 and 37, as shown in the list of industries at the end of this report.

From 1924 to 1929 the average annual increase in the upper bay payroll was slightly more than 10 per cent. For the United States as a whole from 1923 to 1927, there was a decrease during the first biennium and, from 1925 to 1927, an average increase over the preceding biennium of slightly more than 1 per cent, and for California an increase over the four years of 1.8 per cent.

Growth of the capital investment

Since the government does not include this item in its enumerations we shall not be able to make comparisons, but the partial * upper bay figures are:

1924	$26,262,000	1927	$28,930,000
1925	26,453,000	1928	31,928,000
1926	27,876,000	1929	34,851,000

As noted previously, this item is particularly susceptible to wrong interpretation. However, though the totals for the several years may not be dependable, they serve to confirm the impression of steady growth obtained from the other data, showing an average annual growth of over 6 per cent.

While no one knows what the growth might have been under other conditions, the figures we have been able to procure indicate that a healthy expansion has been going on in the upper bay area, at least since 1924. Separate computations of the average annual growth in value of products, number of employees, payroll and capital investment in the area north of San Pablo Bay, including Napa and Petaluma, show rates of growth for these items that are practically identical with those just given for the upper bay area, and furnish some additional confirmation of the steady expansion of industry in the entire area since 1924.

The Prospective Growth of the Upper Bay Area.

Representatives of the industries themselves, when asked to predict their water needs for 1940, placed their total requirement at 44 billion gallons annually, an increase of 54 per cent over present consumption. This, of course, makes no allowance for new industries. If the *plant*

* Includes only those industries furnishing these data for all six years in State Engineer's questionnaire, being Nos. 1, 2, 9, 10, 11, 14, 15, 21, 25, 28, 31 and 33, as shown in the list of industries at the end of this report.

investment increase of existing industries keeps pace with this estimated growth in water requirements, the 82 millions of dollars given for 1929 in the following table will have increased to 127 millions, and assessed valuation, which averages about a third of plant investment, will have increased by approximately 15 millions. But the rates of increase in investment, payrolls, employees and value of product have all been somewhat greater during the past five years than these amounts would indicate. Each decade has witnessed the establishment of important new plants.

If the average annual rate since 1924 continues until 1940, we should have the following picture of the industrial set-up of the upper bay area in 1940:

	Partial totals for 1929 [1]	*Corresponding partial total for 1940*	*Partial totals in estimated per cent of totals for all industries*
(a) Capital investment	$82,346,000	$135,200,000	75
(b) Number of employees	14,100	25,800	88
(c) Payroll	$23,654,000	$ 50,200,000	92
(d) Value of output	$172,111,000	$276,200,000	61

[1] Includes all industries in area that made returns in State Engineers' questionnaire; or, by reference to numbers in list of industries in table at the end of this report:

For (a) Nos. 1, 2, 3, 9, 10, 11, 14, 15, 17, 21, 25, 28, 29, 30, 31, 33, 34, 35, 37 and 38.
For (b) Nos. 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 14, 15, 17, 19, 20, 21, 23, 25, 28 and 30 to 38, inclusive.
For (c) Nos. 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 14, 15, 17, 19, 20, 21, 23, 25 and 28 to 38, inclusive.
For (d) Nos. 1, 2, 3, 6, 7, 8, 9, 10, 11, 14, 15, 17, 19, 21, 23, 25, 28, 29, 30, 31, 34, 35, 36 and 38.

In making these calculations it was assumed that the actual *amount* (not *per cent*) of increase shown the last five years will continue during the eleven years from 1929 to 1940. No one knows what the future has in store with respect to any economic situation. It is a reasonable assumption, however, that, given an adequate low-cost supply of fresh water for boiler, process, and similar needs, the industrial growth of the upper bay area will at least maintain its present rate. In the first place, except for a limited list of industries, confined, for one reason or another, to some particular eastern or foreign locality, the establishments represented by the three hundred thirty odd commodities in the Census of Manufactures *will tend to serve the Pacific coast market from Pacific coast plants.*

The following reasons are offered in justification of this assumption:

I. A recent report on industrial development in the United States and Canada compiled from information received from manufacturers, shows that accessibility of markets is the outstanding location factor in the minds of some sixteen thousand firms.

II. Pipe lines for natural gas and oil and long distance electric transmission lines have all but wiped out differences in power cost in the several market areas.

III. The rapid progress of the science of industrial chemistry has (a) provided new raw materials, (b) made possible the utilization of lower grade and waste products.

IV. Similar progress in the engineering field has eliminated much of the highly skilled labor force which tied industries to certain areas.

V. Improved transportation and new deep waterways have given cheaper access to raw materials.

VI. The west has attracted so heavy a migration of workers from the east, Mexico and the Philippines, that a surplus of labor is available in most fields.

VII. National advertising with its playing up of standard brands has built up a sufficient western demand for the products in question to warrant the establishment of plants on the coast from which a more satisfactory distribution service can be maintained.

VIII. So far as industrial processes are concerned, heat, humidity, and other physical factors have lost their dominating influence over plant location since artificial controls have been devised, hence any unfavorable climatic elements which might be present in a western location would no longer act as a hindrance to the establishment of certain types of industry in this area.

IX. The records show that industries actually are developing faster on the coast than in the United States as a whole. In the period of economic recovery, beginning with 1923 and ending with 1927 (last census available), the average annual rate of growth of industrial output was 0.8 per cent for the United States and 4.3 per cent for California.

X. The following tables procured from the Research Department of the Oakland Chamber of Commerce show how the railroad rate structure with but few exceptions favors distribution of even high-class shipments from the San Francisco Bay region over the sections indicated.

FREIGHT RATE PER 100 POUNDS, FIRST CLASS

Destination	From San Francisco Bay territory	From Ohio territory	From Illinois-Wisconsin territory	From Iowa, Missouri, Arkansas, Louisiana territory	From Indiana-Michigan territory	From Northeast and middle Atlantic territory
Boise	$3.31	$4.80	$4.35	$4.20	$4.57	$5.25
Butte	2.95	4.95½	3.98	3.71	4.77	5.40
Casper	4.20	4.95½	3.98	3.71	4.77	5.40
Denver	3.66	3.70	2.73½	2.46	3.52½	4.15½
Eureka	.84½	6.24½	5.94½	5.79	6.09½	6.39½
Los Angeles	.84½	5.40	5.10	4.95	5.25	5.55
Phoenix	2.67½	4.80	4.35	4.20	4.57½	5.13
Portland	.72	5.40	5.10	4.95	5.25	5.25
Reno	1.13½	4.80	4.35	4.20	4.57½	5.25
Salt Lake City	2.16½	5.31	3.98½	3.71	3.98½	5.37
Santa Fe	3.66	4.31½	3.34½	3.04	4.13½	4.76½
Seattle	1.39½	5.40	5.10	4.95	5.25	5.55

XI. With an anticipated decline in relative importance of the European trade of the United States, and an increase in the growth of trade with the Orient and Australasia, the *time* element involved in supplying the nations on the Pacific from Atlantic coast industries is a factor which works in favor of the establishment of additional branch plants on the Pacific coast. It should be added, of course, that as the trade with Asia and Australia increases, branch plants will begin to be built in that trade area also. In the second place, western state consumption of products of the type produced by upper bay industries is probably well in excess of the average for the country as a whole, and the population of this consuming area is growing faster than the United States as a whole. In addition, the exports of these same products from Pacific coast ports have been increasing even faster than domestic consumption.

Advertising firms and sales managers, in fixing sales quotas for various territories, calculate the percentage of the total output which the users in a given territory are likely to buy. This is done by taking such indicia as population, bank deposits, telephone connections, incomes, etc., and arriving at a resultant percentage of probable consumption, or the sales quota. The latest obtainable quota for the eleven western states is 10.2 per cent. Assuming that substantially this same percentage of the products of heavy users of water is consumed in this western state area, we can ascertain its consumption of this type of products by taking 10.2 per cent of the national consumption (domestic production plus imports less exports).

The following is the list of heavy water-using industries which are at all likely to supply western and export demand from plants located in the upper bay area:

	Consumed in west	*Exported from Pacific coast*
Rubber products	$110,000,000	$4,650,000
Glass	28,200,000	300,000
Iron and steel products	322,000,000	2,020,000
Petroleum products	214,000,000	111,600,000
Asbestos products	4,500,000	260,000
Pipe	9,500,000	400,000
Paint and varnish	52,000,000	800,000
Chemicals	54,800,000	830,000
Soap	28,700,000	230,000
Sugar	70,300,000	100,000
Explosives	7,200,000	1,200,000
Leather	53,700,000	3,640,000
Roofing	12,300,000	630,000
Slaughtering, etc.	305,000,000	650,000
Totals	$1,272,200,000	$127,310,000

Estimated total consumption for 1927, $1,399,510,000.

At the rate of growth in the population of the eleven western states, predicted by population experts, there should be a 35 per cent increase in consumption in 1940. This would raise the item $1,272,200,000 to $1,717,470,000. If the same present trend continues with respect to export trade, the $127,310,000 in exports of products of the listed heavy water users will have increased to $200,000,000 by 1940, making a total demand of $1,917,000,000 in this market, for the products of the industries most likely to locate in the upper bay area. With its very attractive list of location factors, the upper bay area can reasonably be expected to maintain its present rate of increase and receive its share of the additional increment carried by the westward movement of industrial plants. No one is so rash as to think that *all* of this market's demand for the products of heavy water using industries will be supplied within this area, but the estimated consumption figures show what an attractive goal lies before the upper bay industries. Just how much of this estimated maximum volume of business the upper bay area could succeed in securing, no one can foretell. Such intangibles as community spirit and morale, relative skill at industrial salesmanship, and industrial area programs, often more than offset the tangible attractions of an industrial site.

CHAPTER V

THE PROBLEM OF WATER COSTS IN THE UPPER BAY AREA

As we saw in Chapter III, upper bay industries obtain their supplies of water from three principal sources: (1) public supply systems, (2) private wells, (3) the rivers—meaning by the latter also supplies of water pumped from any of the bodies of water which comprise upper San Francisco Bay. In all three cases, water cost figures should include all expense attached to whatever transmission and distribution lines, pumps, storage facilities and treatment are needed. Not only water bills and actual operating costs are involved, but also interest, maintenance and depreciation. In drawing up the questionnaire sent to the industries, great pains were taken to include all of these factors, but exact comparability of data was probably not secured.

Cost as Related to Source.

The cheapest sources of water supply are lakes, streams and wells, in close proximity to the place of use and obtainable either by gravity diversion or by low pumping lifts. Where water supply must be pumped, the cost of water for any given capacity varies directly with the magnitude of pumping lift. As a rough approximation, for every $100 spent to pump a given quantity of water through a head of 10 feet, $2,500 must be spent if the pumping head is 250 feet.

Water from Underground Sources.—For supplies obtained from underground sources there are often other disadvantages which tend to increase the cost above similar supplies obtained from lakes and streams. There is usually a definite limit to the amount of available water in any underground reservoir and an overdraft by excessive pumping frequently results in a lowering of the water table. The variation and increase in pumping head that often occur, result in increased pumping cost. Moreover deep well pumping equipment is generally more expensive and of lower efficiency than surface pumping equipment and these combine to further increase the cost of pumping from underground sources.

Those large upper bay industries which now pump from an underground water supply with low lifts at their plants report costs of two to three cents per thousand gallons, while with less favorable conditions the corresponding cost rises to nearly 25 cents per thousand gallons. Such water is harder than river water and, therefore, usually requires treatment for boiler use. The smaller user of well water naturally has a greater expense per thousand gallons consumed, and his costs are found to range from 11 to 83 cents per thousand gallons. If an abundant underground supply, with a low pumping head, can be found at one's plant, this furnishes an economical solution for his water problem. But as has been pointed out before in this study, the status of the underground water in the San Francisco Bay region does not warrant our looking to that source as the principal dependence of domestic and industrial users.

Water from Public Supply Systems.—Water furnished by existing public supply systems in the upper bay is relatively costly, even at the lower rates quoted to large users. First, no one water company has a sufficient volume of business to enable it to operate at the optimum volume and minimum cost. Second, public water supplies are designed for human consumption and are commonly subjected to such treatment as will make the water sterile and palatable. For many industrial needs raw rater would serve just about as well, hence when industries buy their water from a public system they are paying for unnecessary frills. Third, for a large supply of water, the public company or municipality must resort to a stream. Wells are used by some smaller public systems in the upper bay, but the major company in the area has ceased to rely upon this source. If river water is obtained from above the salinity encroachment area, the cost of a long pipe line is incurred in addition to the usual purification expense. If the water is pumped close at hand, there must be sufficient additional storage, main, and pump capacity to procure and store, during the fresh-water period in winter and spring, a sufficient supply to carry consumers through the dry and saline period of the summer and fall.

It is not surprising then to find the industries reporting total water costs all the way from 11 to 93 cents per thousand gallons for the portion of their supply which they receive from public systems. Except for about a half dozen companies in the area the amounts consumed are small and the relatively high unit costs include the expense of special treatment or equipment, or both.

So far as boiler, drinking, sanitary and other similar needs are concerned, the total volume required is so small in most industries that what seems like a heavy rate per thousand gallons places no substantial burden upon them.

Water for Process Purposes.

The amount and quality of water required for processing varies greatly with the industry. In the case of sugar refining, the large amounts of process water used must be unusually free from salt. The California and Hawaiian Sugar Refining Corporation, Limited, state that they have paid as high as 4 per cent of their cost of manufacture for water, but they estimate that their newly acquired source of supply will reduce their present cost of water by some 30 per cent.

Others, like the rubber and paper industries, require large amounts of process water. The rubber company evaporates river water for process uses and claims a loss in its devulcanizing plant during the high salinity period of 1929, amounting to $2,250 per month.

The sugar company is not disposed to risk the water in a barrier lake for process purposes, being content with the new source of supply of which we have just spoken. Industries in the Pittsburg-Antioch area which use a large quantity of water for processing, pump it from the river, except when the salinity is too great. They must then resort to public or private supplies. The river supply for process purposes is procured by the largest user at 1.5 cents per thousand gallons. A group of moderate-sized river water consumers report somewhat higher costs for process water generally, ranging from slightly more than one cent to over 12 cents per thousand gallons, while one of the smaller users reports his cost in excess of 30 cents. The largest user, to which reference was made above, places its annual loss, because of inability to process with river water all twelve months, at some $1,600—the amount paid for public supply water in excess of the cost of pumping it from the river. This amounts to 0.04 of 1 per cent of the value of this company's annual output and 0.3 of 1 per cent of its annual payroll.

The use for purposes other than cooling and condensing amounts to 425 million gallons per month for all of the upper bay industries included in this study, while the use for cooling and condensing amounts to 1880 million gallons per month. Of the 425 million gallons used for all other purposes, the one industry which was referred to as having suffered a loss of $1,600 a year uses nearly 115 million gallons, or more than one-fourth of the entire amount.

Water for Cooling and Condensing Purposes.

Cooling and condensing water is required in very large quantities in the steel, oil, rubber and sugar industries, some of the wood products and chemical plants and at the navy yard. Unless an industry is particularly well situated with respect to the other factors, industrial engineers consider that it can not afford to pay more than six cents per 1000 gallons for cooling and condensing water. The following table shows what water for this purpose is costing typical large users in the upper bay:

Industry	*Annual consumption, in millions of gallons*	*Cost per thousand gallons, in cents*
A	1,050	1.8
B	1,420	2.6 [1]
C	840	1.1
D	1,020	7.7 [2]
E	490	1.2
F	7,290	0.8

[1] Three per cent of this water from private wells, but has no material effect on unit cost.

[2] In this case 2 per cent of the water is obtained from public supply and has the effect of increasing the average cost about 7 per cent.

Effect of Salinity.—So far as quantity of water and the cost of pumping are concerned it can be seen that industries on the upper bay have a very attractive situation. As we noted in another connection the difficulty lies in the damage caused to cooling equipment by salt water action during the salinity period. There are two ways of eliminating the more rapid deterioration of cooling equipment due to salt water action: (1) By substituting the somewhat more expensive salt-resisting equipment for the present cooling apparatus as fast as the latter needs to be replaced (any extra expense for the new type of equipment ought to be offset to some extent at least by the lower depreciation charge); (2) by providing a supply of fresh water to the industries, in such volume, and at such a price, as would warrant its use for cooling and condensing, either by building a barrier or by importation by means of a conduit from the most practical source.

To evaluate the additional expense of salt-resisting cooling and condensing equipment over similar nonsalt-resisting equipment, four of the larger typical users were interviewed and their estimates of maintenance, depreciation and capital cost for both types of equipment obtained. A wide variation occurred in the answers obtained, due largely to the types of industries selected. All of the industries in the upper bay area were then classified into four groups, one for each of the industries interviewed, in accordance with the similarity in their use of cooling and condenser water. To each of the industries in the same group the rate of increase in capital and annual cost per unit of consumption for the industry interviewed was assumed to apply and, in combination with any industry's total use of cooling and condenser water, gave the total increase in capital and annual cost for the industry. Based on this method of analysis and on the data obtained from these larger typical industries, it is estimated for all industries in the area that the capital cost for cooling equipment designed for salt water conditions would be about $200,000 more than that for equipment designed for fresh-water conditions; and that the annual cost of cooling water under salt-water conditions and with salt-resisting equipment would be about $150,000 more than under fresh-water conditions and with fresh-water equipment.

The above estimated amounts of increased capital and annual cost apply to all of the industries in the entire area above Richmond. For the industries above the Dillon Point site only, the corresponding estimated amounts would be $175,000 as the increased capital cost, and $138,000 as the increased annual cost.

It is believed that the above figures present a reasonably accurate picture of the total value of fresh water for cooling purposes to the entire area. They represent an increase in total capital cost of less than one-fifth of one per cent and an increase per thousand gallons of cooling and condenser water of less than two-thirds of a cent. This estimate of the additional expense of salt-resisting cooling equipment is for a complete change from nonsalt-resisting to salt-resisting equipment for the present salinity conditions; neither of which conditions are generally applicable to the upper bay area. Practically all of the industries have some of each type of equipment, being more nearly on the salt-resisting basis as the industry is further downstream.

To estimate the decrease in cost of cooling and condensing water with fresh water available above a barrier, the following alternate method of analysis is presented. The present costs of cooling water were reduced by the decreased depreciation figures estimated by the industries themselves in the State Engineer's questionnaire for fresh water conditions as against present conditions. This resulted in the estimated amount of $70,000 as the indicated saving, which includes all industries above Richmond in the entire area. For the industries above Dillon Point site only, this corresponding estimated amount of indicated saving would be $43,000. However, the additional reduction in annual charges due to less interest on a smaller capital investment and to lower maintenance cost that could be obtained with fresh water are not included. The previous study for a complete change of equipment indicated that depreciation constituted the major portion of the difference and, therefore, it is thought that the true value of fresh water for cooling and condensing purposes lies somewhere between the two figures of $70,000 and $150,000 for the industries in the entire area above Richmond and $43,000 to $138,000 for the industries above Dillon Point site only.

That the extra cost of using salt water for cooling and condensing purposes over fresh is quite small is substantiated by the following letter received from a concern which uses pure sea water exclusively for these purposes:

> It does not seem to us that there is any additional cost of operation of steam condensing equipment utilizing salt water, as compared with fresh water. The principal source of expense with condensers, is condenser tubes, and there is a very wide variation in the life of tubes of different manufacture.
>
> Admiralty Mixture brass tubes are rather generally used for plants using salt water, and for plants using fresh water about one-half use this same tube, and the other half use Muntz Metal, which latter are about 10 per cent cheaper than Admiralty.
>
> Our experience indicates that the use of salt water in the average life of condenser tubes is about four years. However, we have had variations from six months to twenty-five years. The data which we have. indicates that fresh-water plants obtain about the same life.
>
> Temperature of the condensing water is a very important condition, because the higher the temperature, the larger the surface required in order to obtain the same vacuum, or a larger volume of circulating water must be handled.
>
> With higher temperature fresh water, quite often sludge is formed in the tubes, which offers resistance to the flow of water; reduces the vacuum, and is quite troublesome to remove, sometimes requiring chlorination of the water as a preventive measure. At times fresh water carries incrusting solids which form scale in the condenser tubes, reducing turbine efficiency, and is troublesome to remove.
>
> We are of the opinion that there would be but slight, if any, advantage of locating a steam power plant so as to utilize fresh water for condenser purposes.

A competitor of the above company states in reply to a similar inquiry that:

> The extra cost of using salt water over fresh water of the same temperature for condensing purposes is about 25 cents per million gallons pumped.

Still further evidence that the cost of cooling with salt water may not be much greater than with fresh is presented by a firm which manufactures cooling and condensing equipment and which replied that:

> The increased cost of supplying Admiralty Metal tubes in place of Muntz Metal tubes would amount to about 1½ per cent of the total cost of a condenser, the exact amount depending upon the size of the equipment and its construction.

They were unwilling to estimate the relative deterioration rate with salty and fresh water because it has been their experience that similarly equipped plants in comparable locations have had widely differing rates of deterioration. They attribute much of the mischief done to upper bay equipment to sewage and various contaminations introduced by waste products from industrial plants.

So far as the manufacturing costs of present industries are concerned, therefore. it is a question of letting them continue to bear whatever added expense salt water corrosion occasions or of substituting one of the two alternatives just set forth.

Relative Importance of Water Costs.

Since we have no data covering the relative importance of the various items which go to make up the respective manufacturing costs of upper bay products, we can not say with assurance just how consequential the cost of water really is. The nearest approach we can make is to compare total expenditures for water with such other items as are available, viz, capital investment, payroll and value of output.

The following table has been compiled for 1929, for thirteen outstanding industries which submitted usable data:

RELATIVE IMPORTANCE OF WATER COSTS

Industry	Capital Investment[1]	Value of product[1]	Pay roll[1]	Cost of water (total)			
				Cooling water[1]	Other water[1]	All water[1]	As per cent of value of products
A	$3,068	$2,290	$368	$25.3	$33.0	$58.3	2.5
B	11,300	60,000	1,470	15.6	161.9	177.5	0.3
C	8,866	9,245	4,062	19.2	26.9	46.1	0.5
D	5,731	37,194	2,667	78.1	113.8	191.9	0.5
E	4,070	[2]12,000	1,284	42.0	40.4	82.4	0.7
F	-------------	[2]4,250	570	-------------	21.6	21.6	0.5
G	-------------	3,961	1,323	55.9	63.2	119.1	0.35
H	1,342	1,883	447	9.5	3.8	13.3	0.7
I	2,000	2,870	543	5.9	9.0	14.9	0.5
J	-------------	2,765	343	36.9	3.6	40.5	1.5
K	-------------	[2]2,500	480	5.1	5.3	10.4	0.4
L	454	2,000	320	-------------	3.5	3.5	0.2
M	854	2,696	186	-------------	11.0	11.0	0.4
Totals	-------------	$173,654	-------------	-------------	-------------	$790.5	(mean) 0.45

[1] Values in thousands of dollars.

[2] Items so marked not furnished with the other data sent by the industries to the State Engineer. They are taken from the industrial survey made by the Byron Times, and published in its twelfth annual development edition, page 5.

Present Cost and Consumption of Water for Cooling and Condensing.

The following table for cooling and condensing water shows the present total consumption of water and the maximum, minimum and average cost thereof from public and private supplies, from river, and from all sources combined for the industries in the following areas:

A. Pittsburg-Antioch area above Chipps Island site.

B. Crockett-Pittsburg area—between Dillon Point and Chipps Island sites.

C. Richmond-Crockett area—between Point San Pablo and Dillon Point sites.

PRESENT COST AND CONSUMPTION OF COOLING AND CONDENSING WATER IN UPPER SAN FRANCISCO BAY AREA

Based upon data furnished by the industries

	Area A	Area B	Area C	Total A and B	Total Area
I. From public water supplies—					
a. Total consumption in million gallons per year	----------	18.0	13.2	18.0	31.2
b. Maximum cost in cents per 1000 gallons	----------	33.0	28.0	33.0	33.0
c. Minimum cost in cents per 1000 gallons	----------	33.0	28.0	33.0	28.0
d. Average cost in cents per 1000 gallons	----------	33.0	28.0	33.0	32.0
II. From private sources—					
a. Total consumption in million gallons per year	64.1	----------	----------	64.1	64.1
b. Maximum cost in cents per 1000 gallons	8.8	----------	----------	8.8	8.8
c. Minimum cost in cents per 1000 gallons	2.2	----------	----------	2.2	2.2
d. Average cost in cents per 1000 gallons	4.4	----------	----------	4.4	4.4
III. From river—					
a. Total consumption in million gallons per year	3,769.9	10,097.1	9,609.1	13,867.0	23,476.1
b. Maximum cost in cents per 1000 gallons	39.0	13.4	8.4	39.0	39.0
c. Minimum cost in cents per 1000 gallons	1.1	0.8	0.4	0.8	0.4
d. Average cost in cents per 1000 gallons	2.0	2.0	2.2	2.0	2.1
IV. From combined sources—					
a. Total consumption in million gallons per year	3,834.0	10,115.1	9,622.3	13,949.1	23,571.4
b. Maximum cost in cents per 1000 gallons	39.0	13.4	8.4	39.0	39.0
c. Minimum cost in cents per 1000 gallons	1.1	0.8	0.4	0.8	0.4
d. Average cost in cents per 1000 gallons	2.0	2.1	2.2	2.0	2.1

This table shows a regular small increase in the average cost of water from all sources as the distance downstream and the salinity increase, being 2.0, 2.1 and 2.2 cents per thousand gallons for areas A, B and C, respectively. The relatively low cost shown above for cooling water, the total use of which is over 80 per cent of the entire industrial water consumption, indicates a favorable situation for the industries as regards cooling water. The indicated saving for the entire area above Richmond, as previously estimated, which might be obtained in cost of cooling water supplied by a fresh-water barrier lake, namely between \$70,000 and \$150,000 annually, does not appear to be of great importance.

Present Cost and Consumption of Water for Boiler and Process Purposes.

A similar table of consumption and cost of water for boiler, process and other uses is presented below with identical headings as regards sources and areas.

PRESENT COST AND CONSUMPTION OF BOILER AND PROCESS WATER IN UPPER SAN FRANCISCO BAY AREA

Based upon data furnished by the industries

	Area A	Area B	Area C	Total A and B	Total Area
I. From public water supplies—					
a. Total consumption in million gallons per year	43.3	358.7	777.6	402.0	1,179.6
b. Maximum cost in cents per 1000 gallons	50.0	93.0	60.0	93.0	93.0
c. Minimum cost in cents per 1000 gallons	11.0	29.0	14.0	11.0	11.0
d. Average cost in cents per 1000 gallons	21.0	35.0	38.0	34.0	36.4
II. From private sources—					
a. Total consumption in million gallons per year	891.1	260.6	26.7	1,151.7	1,178.4
b. Maximum cost in cents per 1000 gallons	37.0	24.5	83.0	37.0	83.0
c. Minimum cost in cents per 1000 gallons	2.2	1.8	2.8	1.8	1.8
d. Average cost in cents per 1000 gallons	3.5	23.8	10.9	8.1	8.1
III. From river—					
a. Total consumption in million gallons per year	2,265.7	154.4	324.3	2,420.1	2,744.4
b. Maximum cost in cents per 1000 gallons	4.8	7.2	12.7	7.2	12.7
c. Minimum cost in cents per 1000 gallons	1.1	0.8	6.7	0.8	0.8
d. Average cost in cents per 1000 gallons	1.4	6.8	12.4	1.8	3.0
IV. From combined sources—					
a. Total consumption in million gallons per year	3,200.1	773.7	1,128.6	3,973.8	5,102.4
b. Maximum cost in cents per 1000 gallons	38.2	93.0	59.7	93.0	93.0
c. Minimum cost in cents per 1000 gallons	1.2	2.3	6.6	1.2	1.2
d. Average cost in cents per 1000 gallons	2.3	25.8	29.7	6.9	11.9

Estimated Cost for Present Consumption of Water from a Barrier Lake.

In the course of this study estimates, based upon the data submitted by the industries, have been made as to how much the making of the upper bay area into a fresh-water lake would affect industrial water costs. Too much dependence should not be placed in the completeness and comparability of the results because thoroughly satisfactory figures would have involved a personal investigation at each plant conducted by a staff of experts. The estimated costs for present consumption are shown in the following table:

ESTIMATED COST FOR PRESENT CONSUMPTION OF WATER FROM A BARRIER LAKE

Based upon data furnished by the industries. Costs of water do not include any portion of a barrier cost or any extra expense that might be necessary for treatment or disposal works to obtain fresh water in or from a barrier lake

	Area A	Area B	Area C	Total A and B	Total Area
I. Cooling and condensing water—					
a. Total consumption in million gallons per year	3,834.0	10,115.1	9,622.3	13,949.1	23,571.4
b. Maximum cost in cents per 1000 gallons	35.7	12.9	8.4	35.7	35.7
c. Minimum cost in cents per 1000 gallons	1.0	0.7	0.4	0.7	0.4
d. Average cost in cents per 1000 gallons	1.8	1.7	2.0	1.7	1.8
II. Boiler and process water—					
a. Total consumption in million gallons per year	3,200.1	773.7	1,128.6	3,973.8	5,102.4
b. Maximum cost in cents per 1000 gallons	40.6	13.8	10.1	40.6	40.6
c. Minimum cost in cents per 1000 gallons	1.0	0.8	0.4	0.8	0.4
d. Average cost in cents per 1000 gallons	1.7	3.9	2.9	2.1	2.3

The indicated saving which might be realized for boiler and process water supplied from a fresh-water barrier lake in place of present sources is considerably greater and more important than in the case of cooling water. For all industries submitting usable data the total estimated annual saving in the cost of boiler, process and other water, except cooling and condensing, would be about $500,000. This indicated saving, as estimated from the data furnished by the industries, includes the water supply at present used by the California and Hawaiian Sugar Corporation, which is about to complete a new water supply system to take care of its entire fresh-water requirements for the present and for some years in the future. The figure also includes the indicated savings for all industries in the area above Richmond. For the industries above the Dillon Point site only the corresponding estimate of indicated saving would be about $190,000.

Since salty water is not suited to most of these boiler, process and other uses, the river supply has had to be supplemented by connections with wells and public systems. The marked difference in the figure for Area A and those for B and C is accounted for by: (1) the fact that the public supply is far cheaper at Antioch than elsewhere, (2) the fact that the wells in Area A are the best in the whole region, and (3) the fact that the salinity difficulty is the least in the upper area.

In all of the above estimates of indicated savings in cost of industrial water supplied from a fresh-water barrier lake in place of present sources, it should be noted that no allowance has been made for additional costs which might become necessary either for water treatment or sewage and industrial waste disposal or for expensive water supply intakes. It is assumed that suitable fresh water could be obtained simply by pumping directly from a barrier lake close to the plant location on the bay shore. If expensive treatment and disposal works or water intake works were required, the cost of such works would tend to decrease the indicated savings estimated above.

Comparative Water Rates in Other Localities.

Some cities or water districts make special rates to heavy water-using industries on the theory that even though the rate is so low that it does not cover the cost of the service, the community will be the gainer because of the industrial growth fostered thereby. If the rate is based upon the economy of quantity consumption, such reductions are sound, but when they are so great as to constitute a "sop," the ultimate effects are bad. An industry is in business to make money and should pay its own way. The following table shows the rates charged large industrial users in leading American cities and the minimum quantity to which the minimum rate applies:

COMPARATIVE WATER RATES

City	Per 100 cubic feet	Per 1000 gallons	Minimum quantity to which rate applies
1. Atlanta	$0 09	$0 12	Excess of 20,000 cubic feet per month.
2. Baltimore	08	10⅔	Excess of 1.000,000 feet per year.
3. Chicago	06	068	
4. Cincinnati	12	16	
5. Cleveland	06	08	
6. Detroit	04	05⅓	Over 100,000 cubic feet per year.
7. Los Angeles	07	09⅓	Over 100,000 cubic feet per month.
8. Mobile	------------	10	Rate to largest users.
9. New Orleans	------------	07	Over 100,000 gallons per month.
10. Oakland	209	279	Over 50,000 cubic feet per month.
11. Philadelphia	04	05⅓	Over 1,150,000 cubic feet per year.
12. Pittsburgh, Pennsylvania	------------	14	750,000 gallons or more per year.
13. Portland, Oregon	05	06⅔	Over 120,000 cubic feet per month.
14. San Diego	20	30	
15. San Francisco	216	288	For all over 33,000 cubic feet per month.
16. St Louis	05	06⅔	Over 1,000,000 cubic feet per month.
17. St. Paul	03	04	Over 500,000 cubic feet per month.
18. Seattle	04	05⅓	Over 30,000 cubic feet per month.

Three of the California cities listed are obviously making no material reduction to large consumers, while the fourth, with comparable water costs, has adopted a policy of fostering industrial development by means of attractive water rates to heavy users.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The Background of the Survey.

In the earlier part of this study the foundation was laid for this appraisal of the industrial problems of the upper bay area. An examination was made of the factors which govern industries in the selection of locations for plants. The conclusion was reached that plant location is becoming more a matter of careful independent investigation by the industry and less one merely of community boosting.

Chambers of commerce have an important legitimate role in connection with the location of industries, in the shape of collecting and placing at the disposal of industries reliable information relative to the several location factors, and in cooperating with one another in the formulation of sane and comprehensive plans for regional development.

Rating the importance of location factors, apart from a specific situation, is futile. Important exceptions exist for every generalization one can make. It is noteworthy, however, that the problem of markets seems to cause industrialists the greatest concern at the present time.

Progress in chemistry and engineering has done much to wipe out regional differences with respect to power, raw material, labor, water, and other important elements in plant operation. Hence many of the old bases of territorial specialization have been eliminated.

The census for 1930 shows that during the preceding decade the Pacific states area was the fastest growing part of the United States, California alone having gained 64.6 per cent in population since 1920. This western state market area with some 9 per cent of the country's population consumes over 10 per cent of the national industrial output.

The more rapid growth made by industries in California, compared with the United States as a whole, shows that the scientific progress to which we have just referred is enabling manufacturers to supply this large and rapidly expanding market from western plants. Coupled with the growth of domestic consumption has been the even more rapid expansion of the foreign trade of the Pacific coast ports.

As one studies the industrial problems of the San Francisco Bay region he is impressed with the economic unity and interdependence of its constituent parts. This fact calls for regional planning rather than community rivalry. Factors like labor supply, cost of living, rail and water transportation, power, raw materials and markets are satisfactory for the region as a whole and for each of its several subdivisions.

Industrial sites are available in every part of the bay region, those in the large cities being much more expensive and, therefore, probably better adapted to the multi-story type of plant. The larger industrial tracts vary from solid land to marshy or even water-covered ground. For the latter a considerable outlay will have to be made for reclamation work. Taken as a whole, the region offers almost unlimited room for factories on the extensive water front of the bay and its tributary rivers, and on the land farther back, but with access to water transportation.

Merits of the Upper Bay as an Industrial Area.

The upper San Francisco Bay area affords a most attractive combination of location factors for industries which require relatively large tracts of land, low cost transportation, proximity to large cities and, at the same time, the comparative isolation of a country site. Other parts of the San Francisco Bay region offer comparable advantages, but the south shore of Suisun Bay contains at present one of the cheapest areas of solid ground near to deep water in the whole bay region.

We have found that all of such major factors as labor supply and cost, power supply and cost, transportation (rail, water and highway), accessibility of markets and raw materials, have with very minor exceptions been reported as favorable by the industries of the area. The only consequential disadvantage set forth has been the encroachment of salt water during the season when the two rivers have too small a flow to repel the salinity invasion.

The growth of the industries which have built their plants in the area indicates that the advantages claimed for it are not mere ''paper'' ones. We have seen that such comparable data as were available revealed a rate of growth in value of product, number of employees and size of payrolls greater than that for the state as a whole and markedly more rapid than the trend for the whole United States.

All of this goes to prove that the upper bay is a valuable part of the industrial structure of the Pacific coast and that, if it is suffering from any remediable handicaps, serious consideration should be given to the problem of removing them.

The Water Problem of Upper Bay Industries.

Normally, water does not constitute a large part of the total cost of manufacture. Nevertheless it is just as essential to a water-using industry as are the most costly materials. Cooling and condensing call for large quantities of water. Here coldness is the quality most desired, although freedom from ingredients which cause abnormal deterioration of the cooling equipment makes possible a lower annual cost of cooling water because of the smaller initial outlay for cooling apparatus, decreased depreciation and maintenance, and a smaller consumption of water than is the case where special resisting materials are installed. However, the cost of cooling water is not large and the higher temperatures that would result in a barrier lake might offset the additional cost of salt-resisting equipment.

Upper bay industries obtain some of their cooling water from wells and from public supply systems, but for the most part it is pumped from Suisun Bay, Carquinez Strait or the lower end of the San Joaquin River. For convenience we have referred to all of this supply as river water, and quite properly so, for the water from the two rivers flows through the bay and strait on its way to the sea.

During the dry season, when a minimum of fresh water is being discharged into Suisun Bay from the rivers, the chlorine content of the water in the bay shows a marked increase. Naturally, the less the precipitation in the area drained by the rivers, the greater is the salinity in the bay. At such time those industries which have cooling apparatus designed to use fresh water suffer a loss from its abnormal deterioration.

Plants which have installed salt-resisting equipment have made a heavier initial investment and consume more water, but have reduced the depreciation rate very materially.

That coldness is after all the important quality in a cooling water is evidenced by the fact that great power plants are choosing sites on salt water where veritable rivers of cold salt water can be pumped through the cooling apparatus at a very low cost. One such concern, whose consumption of salt water for cooling is very heavy, reports that, including depreciation, its cooling water cost is but 1.3 cents per thousand gallons. In the upper bay, where the chlorine content is comparatively low, even when conditions are at their worst, the depreciation rate would be smaller.

So far as cooling and condensing use goes, and this constitutes more than 80 per cent of the total water consumption of upper bay industries, there is little justification for undergoing great expense in substituting a year around supply of fresh water. Based upon estimates from data supplied by the industries, it will be recalled that but $70,000 to $150,000 annually would be saved by the change to the fresh water of a barrier lake and that only in case the temperature of the water in the lake is not raised. The continued use of the present water with a more suitable type of equipment appears to be the logical solution of the cooling and condensing problem.

The presence of as great chlorine content as Suisun Bay contains during the period of low water in the rivers, makes the water undesirable at that time for use in boilers and for most of the processing carried on in the area. Salt can not be eliminated from water except at prohibitive expense. While Suisun Bay has never been fresh throughout an entire year, at least so far back as the sugar corporation's records go (1908), salinity encroachment is more serious than before water was diverted from the rivers so extensively for irrigation purposes. Then, too, we have had a cycle of low rainfall since 1917, and this has aggravated the situation.

It will be recalled that the annual indicated saving based upon the data obtained from the industries for water used for boiler, process and miscellaneous purposes would be about $500,000 with fresh water obtained from a barrier lake. It is doubtful if river water would suffice for all of these uses without treatment, and additional expense, which would tend to balance the indicated saving. It is obvious that the problem of a fresh-water supply for the upper bay merits serious attention. The boiler and process costs of industries in the territory west of Pittsburg, which we designated as Areas B and C, judged by published water rates, are completely out of line with those of Los Angeles or Seattle, or with any of the industrial areas in the east. The boiler and process water costs in Area B averaged 25.8 cents from all sources, even when river water was available at a low pumping cost for a part of the year. In Area C the corresponding average of the small group which furnished data was even greater, viz, 30 cents per thousand gallons.

In the case of cooling and condensing water we found the figures furnished for the cost of river water are so low, even under existing conditions, that they do not seem to warrant any considerable outlay for an alternative source of supply. For other uses, the cost should be materially lower than it is at present, particularly for industries situated west of Pittsburg.

Suggested Alternate Sources of Fresh Water.

Two methods have been suggested as a possible means of obtaining fresh water at a smaller cost than that from present sources and facilities:

I. *Importation from Sources Outside Local Area.*—If all of the upper bay region united to obtain its fresh water from a common source, a sufficient volume of consumption would be secured to warrant a large scale domestic and industrial water development. Water can be brought in from one of several adequate sources. Industrial demand for boiler, process and other water, except cooling and condensing, calls for 14 million gallons of fresh water per day, with an estimated consumption by existing industries in 1940 of 23 million gallons per day. If that part of the supply which is now bought from public systems could be furnished to large users at ten cents per thousand gallons with an additional allowance of, say, two cents per thousand for distribution and treatment, the average total cost of water for boiler and process use from combined river, public and private sources would be reduced to 6.3 cents per thousand gallons, inasmuch as industries would still be able to pump their supplies from the river during much of the year. At present, three billion of the five billion gallons used for boilers and processing is taken directly from the river, and the rest, in about equal amounts, from private wells and public supplies. If it be assumed that such a system as the one proposed would be self-supporting, there would be no tax burden to frighten industries away from the upper bay.

II. *Salt Water Barrier Lake.*—A fresh-water lake can be created by constructing a barrier at some site yet to be determined. It is estimated that an annual charge of some four million dollars * would be incurred. The following are some of the alleged gains and losses to upper bay industries from the construction of a barrier.

SOME ALLEGED GAINS

1. A constant and ample supply of fresh water at the cost of pumping it.
2. Cheaper pumping cost and softer water than in the case of a deep well, where well water is to be had.
3. Removal of the present limitations which the water situation has placed upon industrial growth, including the introduction of new processes and products.
4. Prolonged life of cooling equipment.
5. Safer navigation and more dependable depth of water for the ships which serve the industries above the barrier.
6. Larger local market due to the stimulation of the area's growth.
7. Elimination of the destruction of piling by the teredo, a borer which can not live in fresh water.
8. Cleansing of ship bottoms by the destructive action of fresh water upon barnacles.

* Estimate of State Division of Water Resources based upon a capital cost for a barrier of $50,000,000 (including interest during construction), interest at 4½ per cent per annum, amortization for 40-year bonds, depreciation, and operation and maintenance.

SOME ALLEGED LOSSES

1. Heavy increase in the taxes of the beneficiary industries, unless much of the cost is assumed by the state, the federal government, or the two jointly.

2. Imposition of a tax burden upon industries which have no direct interest in a barrier.

3. Possible heavy expense for waste disposal in case the barrier causes Suisun Bay to be fouled from matter which would otherwise be carried out through the straits.

4. The obstruction to navigation due to the locks in the barrier, with resulting increases in freight rates.

5. Possible damage to plant sites from changes in the ground water level.

6. Shoaling of navigable channels when the scouring effect of the present open channel is lost.

7. Possible damage to industries below the barrier site if the salinity of their supply of bay water is considerably increased by the impounding of the fresh river water behind the barrier.

8. Possible destruction of the fishing and fish canning industries, if fish do not use the opened lock gates and the fish ladder for ascending to the rivers. The question is also raised whether the young fry which now descend to the ocean through water of gradually increasing salinity could survive a sudden change from the fresh water behind a barrier to the salty water below.

There are certain intangible losses now occurring that might be eliminated by a barrier lake and thus add benefit values. A typical loss of this character is the potential profit which might be realized from the manufacture of products which can not be profitably produced under present salinity conditions. There is insufficient information available to evaluate such benefits.

Most of the questions raised in these two lists involve a technical knowledge of civil engineering, navigation, icthyology, or sanitation problems. Experts consulted did not agree as to what results could be expected. This much is clear, that some four million dollars * a year must be provided from some source or other if a barrier is to be built.

Estimated Tax Burden.—That the present industries, by themselves, could not bear the burden is clear. Even if all of the taxpayers of the two counties most directly concerned, viz, Contra Costa and Solano, assumed the obligation, a four-million-dollar * annual charge on their assessed valuation of 129 millions (1929) would increase taxes in the two counties by $3.10 per $100 of assessed valuation. The total tax rate in Pittsburg, for example, is now $3.63.

A tax from the two counties named of fifty cents per $100 of assessed valuation, such as has been imposed in the east bay for the new Mokelumne River supply, would raise less than one-sixth of the requisite amount for a barrier.

In order to estimate the *maximum* rate which industries in the upper bay could afford to be taxed for a barrier, the following table

* Estimate of State Division of Water Resources based upon a capital cost for barrier of $50,000,000 (including interest during construction), interest at 4½ per cent per annum, amortization for 40-year bonds, depreciation, and operation and maintenance.

has been compiled, covering those industries for which both assessment and water-cost figures were available:

MAXIMUM TAXABLE RATE FOR INDUSTRIES FOR A BARRIER

I Industry	II Assessed valuation	[1]III Estimated annual savings in water cost	IV Tax rate per $100 which would wipe out III
A	$344,000	$9,100	$2 65
B	173,000	4,900	2 83
C	1,663,000	21,600	1 30
D	83,000	100	12
E	44,000	0	0
F	306,000	900	30
G	5,292,000	159,300	3 01
H	3,754,000	114,600	3 05
I	387,000	4,800	1 24
J	5,483,000	64,800	1 18
K	458,000	22,700	4 96
L	254,000	3,400	1 34
Total or average for industries A to L	$18,241,000	$406,200	$2 23
[2]Total or average for entire area	$23,735,000	$480,000	$2 02
Total or average for industries above Dillon Point site only	$14,202,000	$223,000	$1 57

[1] The figures in Column III are the estimated indicated savings with a fresh water supply available in a barrier lake at the cost of pumping only, in place of the present sources and costs of water.
[2] Includes all large industrial water users except Mare Island Navy Yard.

The total indicated saving for the industries in the entire area corresponds to a tax rate of $2.02 per $100 of assessed valuation. However, for the industries above the Dillon Point site only the total indicated saving corresponds to a tax rate of $1.57 per $100 of assessed valuation. It should be noted that the increase in taxes which is estimated would occur for Contra Costa and Solano counties to take care of the estimated annual charge of a barrier costing $50,000,000 corresponds to a barrier located at or near Dillon Point. A barrier constructed at Point San Pablo, or nearby, would probably cost considerably more, or from $75,000,000 to $90,000,000. The tax rate which would wipe out the indicated estimated saving in water cost as computed for the industries above the Dillon Point site, viz, $1.57, is therefore directly comparable to the estimated increase in taxes, namely $3.10, to take care of the entire annual cost.

Basis of State or Federal Aid.—Appropriations received from the state or federal governments toward meeting the cost of a barrier would have to be put upon one or both of two bases: first, restitution for alleged damages due to changed conditions in the upper bay area which might be partially due to developments carried out on the two river systems under federal and state laws and auspices; second, recognition of a state-wide and nation-wide benefit in keeping with the contribution made to the project's cost.

Final Conclusions.

Accepting the statements made by the representatives of the industries in the area, regarding the losses they are sustaining from the salinity difficulty, the present volume of industrial activity and the total loss alleged are far from being of a magnitude which would warrant so elaborate and costly a remedy as a salt water barrier.

The upper bay industrial area at present may be said to be "salinity conscious." So long as this state of mind prevails, it is bound to serve as an impediment to securing the share of industrial activity which the excellence of the area's attractions warrants. Definite steps should be taken to wipe out both the actual and the psychological handicaps which salt water encroachment has imposed.

A fresh-water industrial lake in a region so endowed with other advantageous location factors would no doubt prove to be an attraction to heavy users of fresh water, but if there were attached to a site along the lake a tax rate which all but wiped out the benefits of the water supply, a barrier might prove to be a boomerang, so far as its drawing power was concerned.

Industries would not rush madly into the upper bay area even when a barrier was provided. Other areas with competing locations would probably match this attraction with counter attractions, such as comparable water-rate reductions. All of which means that the present generation would assume a heavy burden with only partial compensatory gains in the way of some saving in water costs and a stimulated industrial development.

If the entire gain credited to a barrier lake by the industries, viz, \$570,000 to \$650,000 per annum, were treated as the extent of damage done by irrigation, reclamation, power and other projects, this would amount respectively to 14.3 and 16.3 per cent of the estimated total annual burden connected with a barrier.

Regions outside of the upper bay area would tend to be affected as follows by any development which stimulated its industrial growth:

I. *The East Bay.*— As one of the shopping centers for the upper bay district, the cities of the East Bay would benefit by the stimulation of the former's growth. Likewise individuals and firms in the East Bay who render professional and other personal service would benefit from an increased patronage from the upper bay territory. East Bay industries might benefit from being allowed to participate jointly with the upper bay in a project to furnish fresh water to industrial users at a cost considerably less than the 29.1 cents per 1000 gallons charged by the East Bay Municipal Utility District. If a barrier lake were created, a pipeline could be laid to the East Bay city, but as tax payers in the present Municipal Utility District and probable bearers of a part of the cost of a barrier if they enjoyed its benefits, might find that these two offsets made very substantial inroads into the anticipated saving in water costs.

II. *The Remainder of the Bay Region.*—San Francisco, as an important center for shopping, personal, professional and banking service, would also benefit by the stimulation of upper bay growth. Similarly, producers of poultry, eggs, fruit, vegetables and other products and services required by upper bay inhabitants, would profit by the larger market. In somewhat the same fashion producers of products and services needed by the upper bay industries would benefit. These gains are real, but not calculable in dollars and cents.

III. *The Rest of the State and the Nation.*—To the extent that a community profits more from industries located in its midst than it does from those farther removed, any other section of the state or of the United States would receive less direct benefit from the location of an industry in the upper bay than from the same establishment located in its own midst. Indirectly, it does reap a gain from new developments elsewhere which broaden the market for its products and provide it with new sources of supply for the things it consumes. It is not an easy task, however, to "sell" to areas with competing sites the idea of contributing to a project designed to increase the latter's competitive advantage when they have no large volume of business with the upper bay.

The whole matter in a nutshell seems to be that, while the industries of the upper San Francisco Bay have water problems which need to be solved, they do not of themselves, for the present, at least, seem to justify so elaborate and costly a remedy as a salt water barrier. It is recommended, however, that serious attention be given to adequate measures for removing the causes of salinity consciousness in the upper bay area, and for providing an adequate supply of fresh water for industrial purposes in the most economical way which competent engineers can devise.

LIST OF INDUSTRIES IN UPPER BAY AREA

Limited to those with 20 or more employees

Division	Reference number	Name of industry	Location
Area A—Above Chipps Island Site.	1	Antioch Lumber and Mill Company	Antioch
	2	Hickmott Canning Company	Antioch
	3	West Shore Packing Company	Antioch
	4	California Packing Corporation	Antioch
	5	Fibreboard Products Company	Antioch
	6	Fulton Shipbuilding Company	Antioch
	7	National Chemical Company	Pittsburg
	8	Great Western Electro Chemical Company	Pittsburg
	9	Pioneer Rubber Mills	Pittsburg
	10	U. S. Steel Products Corporation	Pittsburg
	11	Redwood Manufacturers Company	Pittsburg
	12	Johns-Manville Company	Pittsburg
	13	F. E. Booth Company	Pittsburg
	14	Northern California Fisheries Association	Pittsburg
	15	Pioneer Dairy Company	Pittsburg
Area B—Above Dillon Point and below Chipps Island sites.	16	General Chemical Company	Bay Point
	17	Coos Bay Lumber Company	Bay Point
	18	Cowell Portland Cement Company	Bay Point
	19	Associated Oil Company	Avon
	20	Mountain Copper Company	Martinez
	21	Shell Oil Company	Martinez
	22	Western Plywood Company	Martinez
	23	Port Costa Brick Company	Port Costa
	24	Associated Pipe Line Company	Port Costa
	25	Port Costa Warehouse Company	Port Costa
	26	Benicia Arsenal	Benicia
	27	Yuba Manufacturing Company	Benicia
	28	California Rex Spray Company	Benicia
	29	G. W. Hume Company	Benicia
Area C—Above Point San Pablo and below Dillon Point sites (exclusive of Richmond and Napa-Petaluma area).	30	Grangers Business Association	Crockett
	31	C. & H. Sugar Refining Corporation, Ltd.	Crockett
	32	American Smelting and Refining Company	Selby
	33	Union Oil Company	Rodeo
	34	Hercules Powder Company	Hercules
	35	Giant Powder Company	Giant
	36	Sperry Flour Company	Vallejo
	37	Mare Island Navy Yard	Vallejo
	38	Maid of California Milk Company	Vallejo
Area D—Napa and Petaluma area.	39	Basalt Rock Company	Napa
	40	Cameron Shirt Company	Napa
	41	Keig Shoe Company	Napa
	42	Napa Fruit Company	Napa
	43	Napa Glove Company	Napa
	44	Napa Milling Company	Napa
	45	Napa County Prune Association	Napa
	46	Sawyer Tanning Company	Napa
	47	Petaluma Cooperative Creamery	Petaluma
	48	Belding Hemingway Company	Petaluma
	49	Camm and Hedges Company	Petaluma
	50	Golden Eagle Milling Company	Petaluma
	51	Coulson and Company	Petaluma
	52	Geo. P. McNear Company	Petaluma
	53	Swift and Company	Petaluma
	54	Western Ice and Refrigerator Company	Petaluma
	55	Petaluma Box Company	Petaluma
	56	Vonsen Company	Petaluma
	57	McNear Brick Company	McNears
	58	Daniel Contracting Company	McNears

SUMMARY OF CONTENTS OF STATE ENGINEER'S QUESTIONNAIRE

A. General and Miscellaneous Information.

Type of industry; Products; Date of location; Reasons; Advantages and disadvantages of site; Sources of raw materials; Markets; Power and fuel used; Period of continuous operation.

B. Description of Transportation Facilities.

Rail; Water; Highway.

C. Labor.

Source; Type; Adequacy of quality and quantity; Cost; Disputes.

D. Water Supply—From Public and Private Systems and the River.

Quality; Quantity; Pumps; Storage; Distribution; Treatment; Value of plant; Present consumption from each source for boiler and process, cooling and condensing, and other uses; Annual cost of water for each source; Estimate of financial loss due to salinity of water; Estimated demand in 1940 for each of the several purposes and sources; Proposed plans of the industry for water supply development; Importance of water to the industry; Desirable cost figure; Additional tax it could afford for satisfactory supply.

E. Domestic Sewage Disposal.

Area and population served; Quantity; Present and proposed methods of disposal; Description of outfall; Present and proposed methods of treatment.

F. Industrial Waste Disposal.

Quantity and type of waste; Description of outfall; Present and proposed plans for disposal and treatment.

G. Reclamation Works.

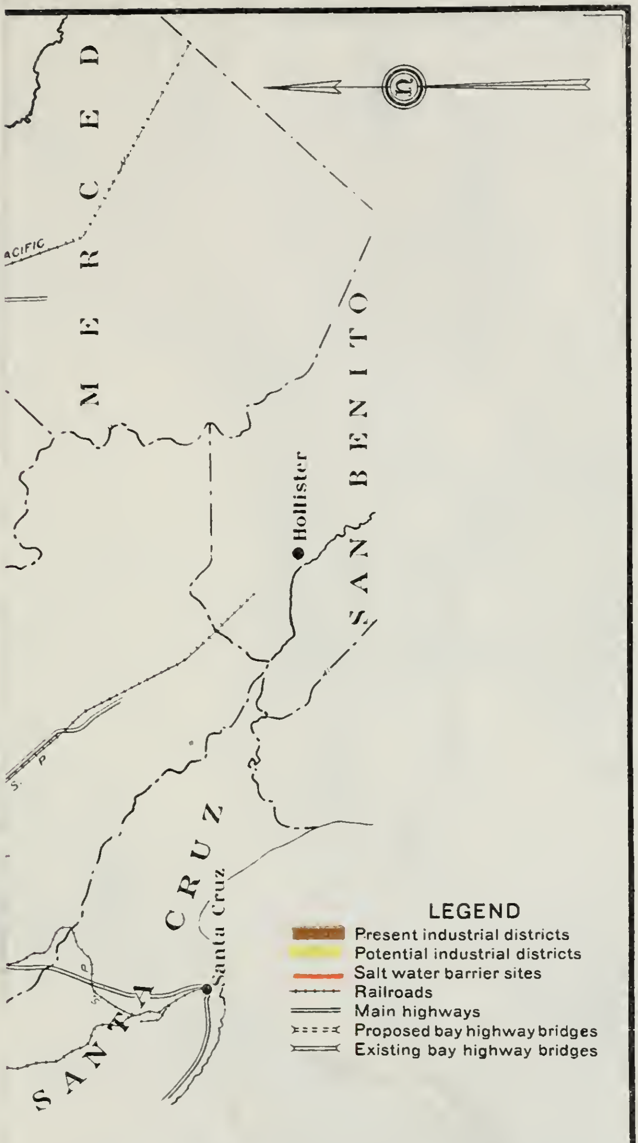
Present and proposed work; Areas involved; Drainage works, their cost and value.

H. Effect of Construction of a Salt Water Barrier.

Up river from the plant; Down river; Benefits and detriments.

I. Statistical Information (for each year from 1906 to 1929, inclusive).

Capital investment; Assessed valuation; Cost of raw material brought in from outside of county; Gross value of sales; Number of employees (average per year); Total pay roll; Annual consumption of boiler and process water, cooling and condenser water and water for other uses, from each of the three sources, viz, public systems, private wells, the river; Annual water cost for each principal source and use; Total value of the water system and total annual maintenance cost for each of the three principal sources of supply; Estimated annual saving if suitable raw river water were available; Actual cost of treating raw river water for each of the types of use.



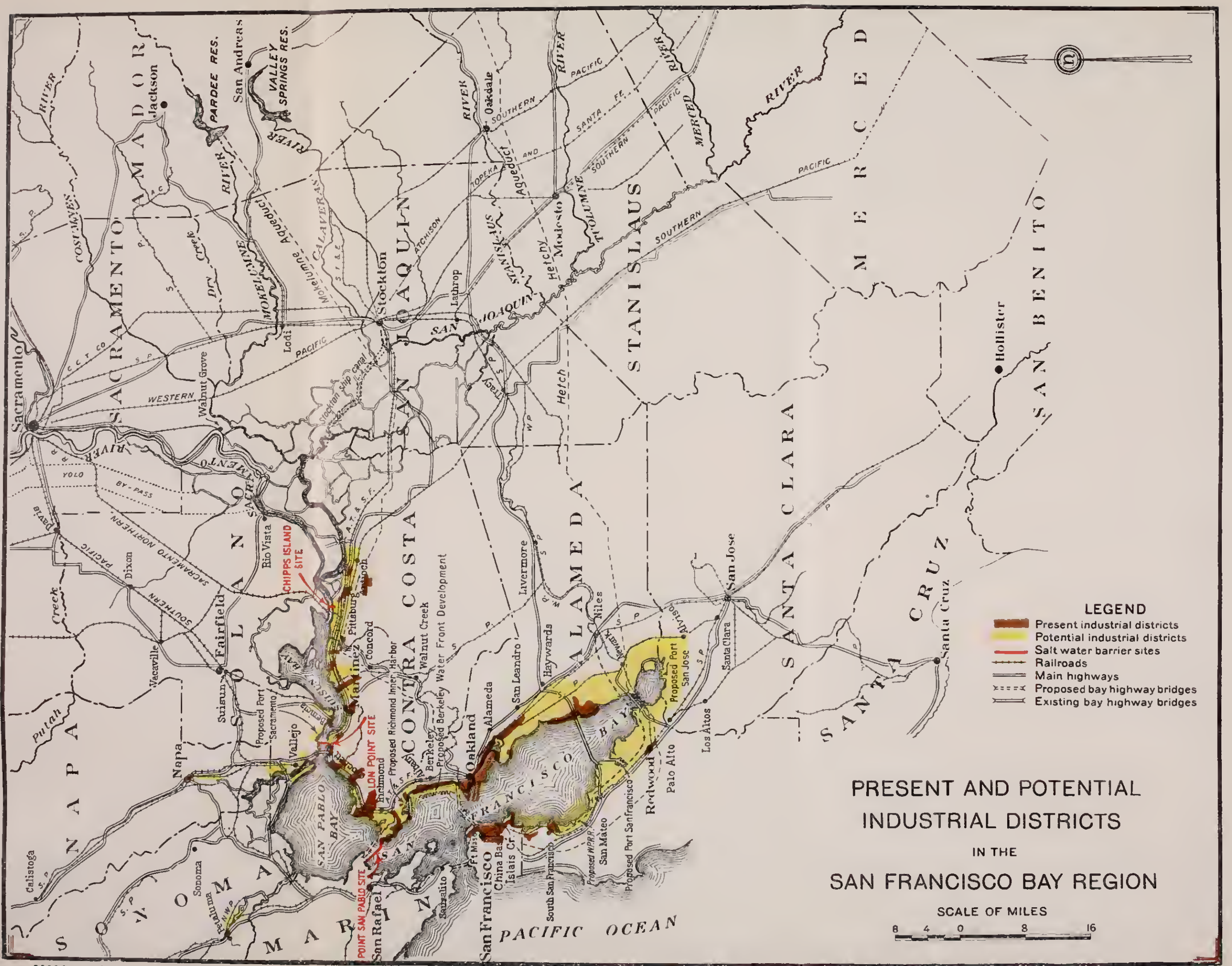
PRESENT AND POTENTIAL INDUSTRIAL DISTRICTS

IN THE

SAN FRANCISCO BAY REGION

SCALE OF MILES

8 4 0 8 16


PRESENT AND POTENTIAL
INDUSTRIAL DISTRICTS
IN THE
SAN FRANCISCO BAY REGION
SCALE OF MILES
8 4 0 8 16
LEGEND
Present industrial districts
Potential industrial districts
Salt water barrier sites
Railroads
Main highways
Proposed bay highway bridges
Existing bay highway bridges
CHIPPS ISLAND SITE
LON POINT SITE
POINT SAN PABLO SITE
PACIFIC OCEAN
SAN FRANCISCO BAY
SAN PABLO BAY
SACRAMENTO
SAN JOAQUIN
CONTRA COSTA
ALAMEDA
SANTA CLARA
SANTA CRUZ
SAN BENITO
STANISLAUS
MERCED
AMADOR
SOLANO
NAPA
SONOMA
MARIN
Sacramento
Stockton
Oakland
San Francisco
San Jose
Modesto
Oakdale
Lodi
Jackson
San Andreas
Hollister
Santa Cruz
Vallejo
Fairfield
Suisun
Napa
Petaluma
Sonoma
Calistoga
San Rafael
Sausalito
Richmond
Berkeley
Albany
Alameda
San Leandro
Haywards
Livermore
Niles
Alviso
Santa Clara
Los Altos
Palo Alto
Redwood
San Mateo
South San Francisco
Martinez
Concord
Pittsburg
Antioch
Benicia
Walnut Creek
Walnut Grove
Rio Vista
Dixon
Davis
Vacaville
Tracy
Lathrop
Proposed Port Sacramento
Proposed Richmond Inner Harbor
Proposed Berkeley Water Front Development
Proposed Port San Jose
Proposed Port Sanfrancisco
Stockton Ship Canal
PARDEE RES.
VALLEY SPRINGS RES.
Hetch Hetchy Aqueduct
Mokelumne Aqueduct
YOLO BY-PASS


PRESENT INDUSTRIES
AND
PRESENT AND POTENTIAL INDUSTRIAL DISTRICTS
IN THE
UPPER SAN FRANCISCO BAY AREA
LEGEND
1 to 58 Present major industries (Numbered as in List of Industries at end of this report)
Present industrial districts
Potential industrial districts
Salt water barrier sites
Railroads
Main highways
Main power lines
Water and Utility District boundaries
County boundaries
City boundaries
SCALE OF MILES
NAPA CO.
SOLANO CO.
SONOMA CO.
MARIN CO.
CONTRA COSTA CO.
SACRAMENTO CO.
Napa
Sonoma
Petaluma
Fairfield
Suisun
Cordelia
Vallejo
Benicia
Selby
Crockett
Oleum
Port Costa
Martinez
Hercules
Pinole
Pt. Pinole
Giant
San Rafael
San Anselmo
Ross
Larkspur
Mill Valley
Corte Madera
Richmond
El Cerrito
Albany
Berkeley
Avon
Bay Point
Clyde
Pittsburg
Antioch
Concord
Walnut Creek
SAN PABLO BAY
SUISUN BAY
CARQUINEZ STRAIT
DILLON POINT SITE
PROPOSED PORT SACRAMENTO
CHIPPS IS. SITE
POINT SAN PABLO SITE
PROPOSED RICHMOND-SAN RAFAEL BRIDGE
PROPOSED RICHMOND INNER HARBOR
MARE ISLAND
GRIZZLY ISLAND
SIMMONS ISLAND
HAMMOND ISLAND
WHEELER ISLAND
RYER IS.
ROE IS.
VAN SICKLE IS.
CHIPPS IS.
BROWNS IS.
WINTER IS.
SACRAMENTO RIVER
SAN JOAQUIN RIVER
NAPA RIVER
Napa Slough
South Slough
Sonoma Creek
Napa Creek
Petaluma Creek
Suisun Slough
Montezuma Slough
CHENERY RES.
SAN PABLO RES.
ANTIOCH CITY RES.
ALPINE RES.
MALLARD SLOUGH PUMPING PLANT
MARIN MUNICIPAL WATER DIST. BOUNDARY
EAST BAY MUNICIPAL UTILITY DISTRICT

APPENDIX B

FEASIBILITY AND SUITABILITY

of Combining a

HIGHWAY CROSSING

With a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

15—80996

TABLE OF CONTENTS

LIST OF PLATES

LETTER OF TRANSMITTAL

Mr. Edward Hyatt,
State Engineer,
Sacramento, California.

Dear Sir: Please refer to your letters of January 3 and February 25 requesting the Division of Highways to undertake a study of the feasibility of using a salt water barrier as a highway crossing.

I am transmitting herewith a report of such a study. A detailed field and office study of the various locations of the salt water barriers, as outlined in the report, were made; tentative routings to meet these crossings were outlined and investigated on the ground. Studies of traffic flow and density were made and comparative estimates of cost of such routings and crossings were prepared.

The report covers the main features and brings out the resulting conclusions of these studies which indicate that the combination of a highway crossing with a salt water barrier is not feasible nor economically warranted.

Very truly yours,

State Highway Engineer.

Sacramento, California,
November 29, 1930.

ORGANIZATION

DIVISION OF HIGHWAYS

C. H. PURCELL .... *State Highway Engineer*

The report covered by this appendix was prepared under the direction of the Division of Highways by

F. J. GRUMM, *Engineer of Surveys and Plans,*

and

T. A. BEDFORD, *Assistant Engineer of Surveys and Plans.*

CHAPTER I

SUMMARY AND CONCLUSIONS

Barrier locations considered for their possibilities as a highway crossing over the Carquinez Strait and upper bay area were:

Chipps Island site on upper Suisun Bay.
Martinez site.
Benicia site.
Dillon Point site.
Vallejo Junction site.
San Pablo site.

Possible Highway Routes.

The following routes have been worked out, utilizing the above sites.

Route A—Chipps Island crossing.

Sacramento to Oakland via Birds Landing, Chipps Island, Lawler Ravine, Walnut Creek and Tunnel road—78 miles.

Route B—Martinez crossing.

Sacramento to Oakland via Fairfield, Army Point, Martinez, Walnut Creek and Tunnel road—83 miles.

Route C—Benicia crossing.

Sacramento to Oakland via Fairfield, Benicia, Franklin Canyon and Richmond—82 miles.

Route D—Dillon Point crossing.

1. Sacramento to Oakland via Fairfield, Suisun Bay, Dillon Point, Franklin Canyon and Richmond—84 miles.
2. Sacramento to Oakland via Fairfield, American Canyon, Dillon Point, Franklin Canyon and Richmond—84.5 miles.

Route E—Vallejo Junction crossing.

Sacramento to Oakland via Fairfield, American Canyon, Vallejo Junction and Richmond—80 miles.

Route F—San Pablo Point site.

Redwood Highway to Richmond—16 miles.

These routes are shown on Plate B-I.

Conclusions.

1. The present Carquinez Bridge is adequate for present traffic and probably will serve for the next fifteen or twenty years without the necessity of enlarging its capacity.

2. The Carquinez Bridge is now far ahead of traffic needs and superior to the highway facilities leading up to the bridge. The development of these facilities offers the least expensive method of serving traffic. They are now a part of the State highway system and should first be developed to their ultimate capacity.

3. Only under exceptional conditions, at preferred locations and with special design could a proposed salt water barrier be utilized advantageously as a basis or support for a highway crossing.

4. The amount which might be contributed from highway funds towards building a barrier, by reason of present facilities and savings effected, is so small in comparison with the total cost of a barrier that it could not be considered a controlling or influencing factor in selecting the site, methods of financing, or time of construction.

5. Traffic requirements preclude the possibility of using a barrier as a low level crossing and, therefore, the resulting design and construction would assume the character and nature of an individual structure which could be more advantageously placed to meet highway requirements.

6. On the San Pablo Strait crossing, provided the franchise granted for construction of the bridge could be canceled or acquired and plans for a barrier altered to provide a high crossing over the locks without draw spans and without materially increasing the cost, it might be possible to work out a cooperative arrangement and plan for the utilization of a barrier as a highway crossing on the basis of a contribution to the extent of three or four per cent of the cost of the barrier; but such participation, based on traffic prediction, would not be warranted until 1955.

CHAPTER II

FEASIBILITY AND SUITABILITY OF A BARRIER AS A HIGHWAY CROSSING

Before considering each individual project in detail, a general discussion on the feasibility and suitability of a salt water barrier as a highway crossing seems expedient.

Reference is made to Bulletin No. 22, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers," by Walker R. Young, Engineer, U. S. Bureau of Reclamation.

The following quotations are made from this report:

"**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 provisions for carrying a railroad and highway." (Page 28.)

"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, as summarized in Table 6–40." (Page 31.)

"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, Benecia or Army Point sites." (Page 32.)

"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." (Page 57.)

"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." (Page 57–58.)

"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, 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." (Page 60.)

Several of the plans for barriers show alternative designs for dams topped with a 20-foot highway alone and with the combined highway and railroad bed having a total width of 64 feet, of which the highway occupies 31 feet. The widths indicated are not considered adequate for main trunk highways, but it seems probable that by revision in design provision can be made for furnishing an adequate width for highway use. This is estimated to be 56 feet as a minimum. The design for embankment or rock and earth filled dams should furnish suitable foundation for a low elevation highway at any desired width. For the low elevation drawbridge of 50-foot clearance, there probably would be no difficulty in founding the approach to the bridge on top of the embankment. While the barrier report contains some sixteen separate estimates of completed barriers on different designs, both with and without highways, no two are sufficiently parallel nor in sufficient detail to permit of deductions as to the increase in costs occasioned by adopting the barrier to highway purposes. However, it is apparent the added cost of the low elevation road would be only a fraction of the cost of a separate highway bridge built on the same location.

The report presents but one design for a high crossing and that is an alternative design for the Dillon Point site. This design provides for a series of concrete piers on 120-foot centers, separated for the lower portion by concrete core walls and for the upper portion by floodgates. These piers carry steel towers supporting the highway and railroad tracks. Around these concrete piers and core walls the rock fill is then placed. This design and location could possibly be utilized by making some sacrifices. There has been insufficient time to check its adequacy and there are several features in connection with it which are open to question. Among these is what effect settlement of the rock fill would have on the concrete piers and core walls carrying the highway structure. The bridge piers would puncture and weaken the embankment and the lateral displacements in the embankment, caused by settlement or uneven ground, would endanger the bridge piers, some of which must be 200 feet or more in height.

Conflict Between Highway and Water Traffic.

For the low elevation road with 50-foot clearance, requiring drawbridges, interruptions in highway traffic would be inevitable. In reality it would not be a conflict for, since the water traffic has the right of way, highway traffic simply would have to wait. As the water traffic increased the highway traffic interruptions would be multiplied, and when highway traffic increased at the same time the highway difficulties again would be multiplied.

The attached tables, copied in part from Bulletin No. 22, depict water traffic conditions as they appeared in 1925. As pointed out in Bulletin No. 22, a substantial increase may be expected in this water traffic from year to year.

TABLE 6-38[1]

OPERATION OF LIFT SPAN TO ACCOMMODATE WATER TRAFFIC AS OBSERVED JULY 6-7, 1925, DILLON POINT[1]

Lockages as in Table 6-29, neglecting vessels not requiring lifting of span bridge at upstream end of locks with 50-foo under-clearance.[1]

Date[1]	Lift span operation[1]		Bridge traffic[1]		Number of boats passed
	Begun	Ended	Waiting, minutes	Moving, minutes[2]	
July 6	6.37 p.m.	6.44 p.m.	7	4	1
July 6	6.48 p.m.	6.55 p.m.	7	15	1
July 6	7.10 p.m.	7.20 p.m.	10	24	1
July 6	7.44 p.m.	7.54 p.m.	10	51	1
July 6 July 6	8.45 p.m.	8.59 p.m.	14	33	2
July 6	9.32 p.m.	9.39 p.m.	7	2	1
July 6 July 6	9.41 p.m.	9.51 p.m.	10	21	2
July 6 July 6	10.12 p.m.	10.24 p.m.	12	105	2
July 7	12.09 a.m.	12.16 a.m.	7	145	1
July 7	2.41 a.m.	2.51 a.m.	10	23	1
July 7	3.14 a.m.	3.24 a.m.	10	8	1
July 7	3.32 a.m.	3.42 a.m.	10	2	1
July 7 July 7 July 7	3.44 a.m.	4.05 a.m.	21	249	3
July 7	8.14 a.m.	8.24 a.m.	10	57	1
July 7	9.21 a.m.	9.28 a.m.	7	49	1
July 7	10.17 a.m.	10.24 a.m.	7	38	1
July 7	11.02 a.m.	11.09 a.m.	7	8	1
July 7	11.17 a.m.	11.24 a.m.	7	28	1
July 7	11.52 a.m.	11.59 a.m.	7	38	1
July 7	12.37 p.m.	12.44 p.m.	7	70	1
July 7	1.54 p.m.	2.04 p.m.	10	25	1
July 7	2.29 p.m.	2.39 p.m.	10	78	1
July 7	3.57 p.m.	4.04 p.m.	7	6	1
July 7	4.10 p.m.	4.20 p.m.	10	75	1
July 7 July 7 July 7	5.35 p.m.	5.52 p.m.	17	102	3
July 7	7.34 p.m.	7.44 p.m.	10	86	1
July 7	9.10 p.m.	9.17 p.m.	7	----------	1

[1] These portions of table taken from Table 6-38 of Bulletin No. 22 of the Division of Water Resources, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."

[2] Time elapsed before next interruption.

TABLE 6-39[1]

OPERATION OF LIFT SPANS TO ACCOMMODATE WATER TRAFFIC AS OBSERVED JULY 6-7, 1925, POINT SAN PABLO[1]

Lockages as in Table 6-32, neglecting vessels not requiring lifting of span bridge at upstream end of locks with 50-foot under-clearance.[1]

Date[1]	Lift span operation[1]				Bridge traffic[1]		Number of boats passed
	60 and 80-foot locks		110-foot locks		Waiting, minutes	Moving, minutes[2]	
	Begun	Ended	Begun	Ended			
July 6 July 6 July 6 July 6	6.17 p.m.	6.29 p.m.	---	---	12	18	4
July 6	6.47 p.m.	6.54 p.m.	---	---	7	33	1
July 6	7.27 p.m.	7.34 p.m.	---	---	7	12	1
July 6 July 6	7.46 p.m.	8.03 p.m.	---	---	17	8	2
July 6	8.11 p.m.	8.18 p.m.	---	---	7	23	1
July 6 July 6 July 6	8.41 p.m.	8.54 p.m.	---	---	18	8	4
July 6	---	---	8.52 p.m.	8.59 p.m.			
July 6 July 6	9.07 p.m.	9.24 p.m.	---	---	17	37	2
July 6	10.01 p.m.	10.11 p.m.	---	---	10	16	1
July 6	10.27 p.m.	10.34 p.m.	---	---	7	310	1
July 7	3.44 a.m.	3.54 a.m.	---	---	10	18	1
July 7	4.12 a.m.	4.22 a.m.	---	---	10	9	1
July 7	4.31 a.m.	4.41 a.m.	---	---	10	3	1
July 7 July 7	4.44 a.m.	5.01 a.m.	---	---	17	6	2
July 7 July 7	5.07 a.m.	5.20 a.m.	---	---	14	8	3
July 7	---	---	5.11 a.m.	5.21 a.m.			
July 7	5.29 a.m.	5.39 a.m.	---	---	10	98	1
July 7	7.17 a.m.	7.24 a.m.	---	---	7	28	1
July 7	7.52 a.m.	7.59 a.m.	---	---	7	4	1
July 7	8.03 a.m.	8.10 a.m.	---	---	7	17	1

[1] These portions of table taken from Table 6-39 of Bulletin No. 22 of the Division of Water Resources, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."
[2] Time elapsed before next interruption.

TABLE 6-39[1]—Continued

OPERATION OF LIFT SPANS TO ACCOMMODATE WATER TRAFFIC AS OBSERVED JULY 6-7, 1925, POINT SAN PABLO[1]

Lockages as in Table 6-32, neglecting vessels not requiring lifting of span bridge at upstream end of locks with 50-foot under-clearance.[1]

Date[1]	Lift span operation[1]				Bridge traffic[1]		Number of boats passed
	314-foot span		140-foot span		Waiting, minutes	Moving, minutes[2]	
	Begun	Ended	Begun	Ended			
July 7	8.27 a.m.	8.37 a.m.	----	----	10	15	1
July 7	8.52 a.m.	8.59 a.m.	----	----	7	39	1
July 7 }							
July 7 }	9.38 a.m.	9.56 a.m.	----	----	18	53	2
July 7 }							
July 7 }	10.49 a.m.	10.59 a.m.	----	----	10	17	2
July 7	11.16 a.m.	11.23 a.m.	----	----	7	----	1
July 7 }							
July 7 }	11.29 a.m.	11.39 a.m.	----	----	10	85	2
July 7	1.04 p.m.	1.14 p.m.	----	----	10	15	1
July 7	1.29 p.m.	1.36 p.m.	----	----	7	58	1
July 7	2.34 p.m.	2.41 p.m.	----	----	7	29	1
July 7	----	----	} 3.10 p.m.	3.30 p.m.			
July 7	----	----	}				
July 7 }					} 38	11	5
July 7 }	3.29 p.m.	3.48 p.m.					
July 7 }							
July 7 }							
July 7 }	3.59 p.m.	4.09 p.m.	----	----	10	3	2
July 7	4.12 p.m.	4.22 p.m.	----	----	10	5	1
July 7 }							
July 7 }	4.27 p.m.	4.40 p.m.	----	----	13	45	2
July 7	5.25 p.m.	5.35 p.m.	----	----	10	9	1
July 7	5.44 p.m.	5.51 p.m.	----	----	7	12	1
July 7 }							
July 7 }	6.03 p.m.	6.13 p.m.	----	----	10	16	2
July 7	6.29 p.m.	6.36 p.m.	----	----	7	7	1
July 7	6.43 p.m.	6.53 p.m.	----	----	10	15	1
July 7	7.08 p.m.	7.18 p.m.	----	----	10	----	1

[1] These portions of table taken from Table 6-39 of Bulletin No. 22 of the Division of Water Resources, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."

[2] Time elapsed before next interruption.

TABLE 6-40[1]

OPERATION OF LIFT SPANS TO ACCOMMODATE WATER TRAFFIC AS OBSERVED JULY 6-7, 1925[1]

Summary of bridge traffic interruptions for 24 hour period*

Site	Number of times spans are raised		Interruptions					Total time, without interference	
	60 and 80-foot locks	110-foot locks	Number	Average time in minutes	Maximum time in minutes	Total time		Hours	Minutes
						Hours	Minutes		
Army Point	14	No lock	14	9.7	16	2	16	21	44
Dillon Point	25	No lock	25	9.4	21	3	54	20	6
Point San Pablo	33	3	33	11.0	38	6	2	17	58

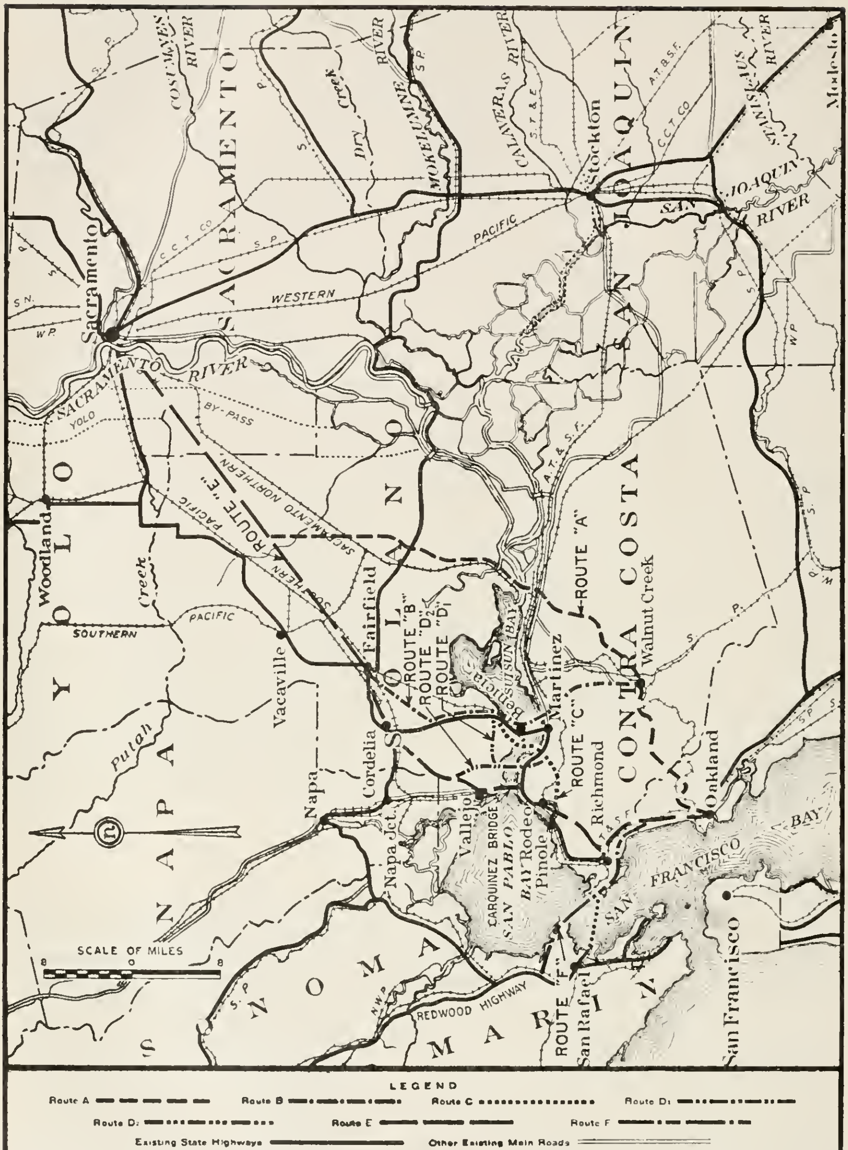
*Begins at 5.45 p.m., July 6, at Point San Pablo and Dillon Point, and 6.00 p.m. at Army Point.
[1] Complete Table 6-40 of Bulletin No. 22 of the Division of Water Resources, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."

The above tables assume a perfectly working organization and combination of lift bridges, dock gates and boat movements. Boats would move slowly under the bridge, since they would be either entering or leaving the ship locks. As a result of locking, boats would come in groups, and the opening and closing of the three or four separate locks, with their separate drawbridges, might overlap, causing long delays for highway traffic even though there were no confusion or carelessness. Even for the year 1925, Table 6–39 shows one delay of 38 minutes followed by only eleven minutes to clear highway traffic; then ten minutes delay with three minutes to clear traffic; then another ten minutes delay with five minutes to clear traffic. A slight increase in the water traffic would have closed the highway for more than an hour, an intolerable condition on any but roads of minor importance. Not only must a low elevation crossing be on a road of minor importance, but the road must remain so or a new crossing built, losing the money invested in the participation, except the small amount which might be written off through usage. As water traffic increased, highway traffic would decrease because of the increased interference. The tables submitted were worked out for drawbridges with 50-foot clearance before raising. No information is given for a clearance of 70 feet, but the Southern Pacific Company has built a bridge across the strait at Army Point with a normal clearance of 70 feet under the drawbridge. From data they have gathered, relative to water traffic, they expect to have to raise this drawbridge an average of five times each 24 hours with an average interruption of twenty minutes in train service. The time of interruption does not include delays that would be caused by locking, which might add five to fifteen minutes, depending on the number of boats locked at one time. Comparison of this total time of interruption of 100 minutes with Table 6–40, which gives the total time of interruptions at Army Point at 136 minutes, indicates that 70-foot clearance would reduce interruptions by 25 per cent over a 50-foot clearance.

Limitation of Barrier as a Highway Crossing.

The large volume of traffic which may be anticipated and which is predicted from our studies, makes it impossible for a low-level crossing on a barrier to be considered for a through highway because of interruption by navigation. Since the amount of interruption would be only slightly reduced by the 50 and 70-foot elevations, only the high elevation of 135 feet or more could be considered as suitable and satisfactory for a highway crossing. This immediately would impose the necessity of rising to this elevation, which, for acceptable grades, would require in the neighborhood of 3000 feet. The northerly approaches of several of the crossings would make this a very difficult and probably a prohibitively expensive feature. The high-level crossing would in effect create the necessity of constructing a bridge crossing founded on piers reaching to solid rock, which, due to the nature of its design and construction and the danger which might result to these foundations by the character of a barrier construction, would better be a distinct and separate structure from a barrier.

PLATE B-I



STATE HIGHWAYS AND POSSIBLE ROUTES OF TRAVEL FOR UTILIZATION OF A SALT WATER BARRIER AS A HIGHWAY CROSSING

CHAPTER III

CONSIDERATION OF INDIVIDUAL ROUTES AND CROSSINGS

The first five proposed locations were considered as crossings in connection with routings for a main trunk highway between the bay area and the Sacramento Valley, and the sixth, or San Pablo Point site, as a crossing for a highway serving traffic from the Redwood Highway and the north coast counties directly to the Eastbay cities. The relative utility of the various routes for serving highway traffic varies. This utility may be established and will be more definitely again referred to in the following detail discussion of the individual routes. The various routes and combination of routes have been worked out between Sacramento and Oakland at Fourteenth and Broadway, utilizing the salt water barrier sites as crossings. They are shown on Plate B-I, "State Highways and Possible Routes of Travel for Utilization of a Salt Water Barrier as a Highway Crossing." The San Pablo site, in conjunction with road connections to the Redwood Highway and Eastbay points is also shown.

The air line distance from Sacramento to Oakland, Fourteenth and Broadway, is 70 miles. The present traveled road by way of Davis, Fairfield, Napa Junction, Carquinez Bridge, which is the Vallejo Junction Barrier site, and Richmond is about 96 miles. This route can be shortened to 80 miles or less by taking a southwesterly course, on a new routing, across the Yolo By-pass to Fairfield; thence continuing in the same direction, passing north of Cordelia and crossing the Southern Pacific Railway at the mouth of Jamison Canyon and following the course of the American Canyon to the Napa-Solano County line; thence, in a southerly direction, through the easterly edge of Vallejo to Carquinez Bridge; thence, southwesterly, passing east of Rodeo and through Refugio Valley and San Pablo Creek on a new routing to Richmond; thence, southeasterly, over San Pablo avenue to Oakland. This routing is shown on Plate B-I as Route E. This crossing of the strait would serve Sacramento and west-side traffic and, with short connections, also would serve Napa and Lake County and much of the up-coast traffic as well. The alignment could be made very good and the grades easy. It appears to be the shortest practicable route between Sacramento and Oakland, except Route A, and would be served by the Carquinez Bridge, which carries a three-lane roadway at present and which can be widened to a four-lane roadway when traffic demands require it.

The report of the California Highway Commission on toll bridges in the state predicts a total traffic of 2,500,000 cars crossing the Carquinez Bridge in 1950, or an average of 7000 cars per day. The graph on page 57 of the Toll Bridge report indicates the average for July, 1950, may be 10,000 per day. Observed relations between average and peak traffic in this vicinity indicates a peak hourly traffic of 1000 cars in 1950. A three-lane, or 30-foot, roadway will carry 2000 cars per hour. It therefore appears that the Carquinez Bridge is 20 years ahead of traffic needs and far ahead of highway facilities leading up to it.

It is possible to shorten Route E another two miles, making it as short as any other route, by going straight through Sulphur Springs Mountains with a tunnel. The saving in distance might justify such expense if the anticipated traffic of 1935 were used as a basis of calculation. Further study along this line seems warranted, but is not necessary for this report.

With the exception of Route A, Chipps Island crossing, other routes using other barrier sites as a crossing would add to the distance which may be obtained on the present facility, and would add considerable mileage of new routing requiring construction. In addition to this there also would be required a considerably larger expenditure for construction of approaches to these sites. This also is true of the Chipps Island crossing. The existing (Route E) crossing of the strait on the Carquinez Bridge lies in the best position for connecting roads from other territory in which fairly large volumes of traffic originate. With the exception of Route D and D-2, which, however, add distance, the possibility of retaining this valuable feature gradually diminishes as the location of a barrier crossing progresses eastward. The most easterly site at Chipps Island does not afford such possibility for any areas lying north of the crossing. In other words, the volume of traffic for a crossing at Chipps Island would depend entirely on the travel originating in and around the lower Sacramento Valley.

In order to make accurate comparisons, it would be necessary to make careful estimates of costs and evaluate advantages and disadvantages of each route, but the apparent small probability of a satisfactory cooperative solution makes it appear inadvisable to do more than make approximations of such costs.

Route A.

This route, 78 miles in length, takes a southwesterly course from Sacramento across the Yolo Basin for a distance of 25 miles; thence, southerly, through the low rolling Montezuma Hills to Montezuma Station on the Sacramento Northern Railroad; thence, southwesterly paralleling the railroad, across Van Sickle Island, Chipps Island, and the Sacramento River to West Pittsburg; thence, continuing southwesterly, through the hills by way of Lawler Ravine to Walnut Creek; thence westerly, by way of the Tunnel road to Oakland. This is probably the shortest practicable route to Oakland, but the saving over Route E is only two miles. Its alignment would be good, but slightly inferior to Route E. Its grades and rise and fall also would be slightly greater.

The chief objections to this route are as follows:

A drawbridge would be necessary across the Sacramento River. This drawbridge would be required because of the long approaches necessary on both sides for a high crossing, there being no high ground on either side, and the doubtful foundations available for high piers. Two miles of pile trestle approach would be required on the north side of the Sacramento River across the tidelands of Van Sickle Island and Chipps Island, where 50 to 90-foot piling were used in the railroad trestle to procure footing, being driven through 30 to 60 feet of soft mud and 30 feet into clay for support. It was found by experience that these tidelands would not support an embankment.

There also is the objection that, when the Vacaville-Dunnigan cut-off is built, this route would not serve west-side traffic bound for East-bay points. This route would only serve such traffic as comes through Sacramento. It would require construction of considerable more new highway than any of the other routes and, because of the two mile trestle approach, the low elevation crossing of the river would cost nearly as much as high crossings over the Carquinez Strait.

Barrier plans for crossing these tidelands have not been worked out, but it is the belief of railroad engineers, who have had years of experience with this semifluid mud, that it flows under the slightest inequality of pressure and that it is impracticable to build an embankment across this unstable ground. Levees do not hold because water flows through this mud or peat, coming up in "boils" on the lower side. Levees are continually settling and breaking, indicating that an embankment would not be a suitable foundation for a roadway. It is therefore assumed that the two-mile trestle approach would have to be built independently of a barrier and some distance from it.

Since there is no traffic across the river in this vicinity it is difficult to predict what traffic might take this route if it were built, but it is believed 600,000 cars per annum is a very liberal estimate. All of this traffic would have to pass through the tunnel into Oakland, necessitating large expenditures for additional facilities, and forcing traffic into a heavily congested area and inconvenient approach to other bay crossings.

These 40 miles of new road would cost $7,000,000, including participation in a barrier crossing. The estimated traffic of 600,000 vehicles would save two miles of travel, and at five cents per mile, a saving of $60,000 per annum would be effected. At 4½ per cent interest this would justify the expenditure of only $1,333,000. With a normal increase in traffic the construction of this road would not be justified before 1950.

Furthermore, the saving effected by combining highway and barrier appears to be very small, probably not more than $750,000, a very small per cent of the total cost of a barrier. In comparison, $2,000,000 spent in revising the line of Route E between Cordelia and Richmond, would shorten the distance nine miles and add but twelve and one-half miles to the state highway system. With one and one-half times the traffic and four and one-half times the mileage saved, six and three-fourths times as much, or $9,000,000, could be spent in saving distance. Using the minimum figure of three cents per mile as the cost of operating a vehicle, an expenditure of $5,000,000 could be justified in improving Route E and using the existing Carquinez Bridge. This improvement already is an economical demand and the greater length already is a part of the present State highway system. Route A would be an additional parallel routing not economically justified until present routes become inadequate to serve traffic.

Route B.

This Route, 83 miles long, leaves Route A 25 miles southwest of Sacramento and continues southwesterly to Fairfield; thence, southerly, around the west side of Suisun Bay to Army Point; thence, southeasterly, across the strait parallel and west of the Southern Pacific bridge to Suisun Point; thence, southerly, crossing the Southern Pacific tracks on an overhead structure, joining the present county highway between Martinez and Walnut Creek; thence, southeasterly, over this highway to Walnut Creek; thence, westerly, over the Tunnel road to Oakland.

The advantages of this route are that it would require a comparatively small amount of new highway construction and the addition of a small mileage to the system. It would carry Sacramento traffic and west-side Sacramento Valley traffic into Oakland over a different route than that taken by Napa and Lake counties traffic, relieving San Pablo Avenue of that much congestion.

The objections to Route B are:

It is three miles longer than Route E. It has inferior alignment. The location of the Southern Pacific bridge at the Army Point site probably will prevent a barrier from obtaining a satisfactory location at this site. The first mile south of Suisun Point is a maze of industrial facilities which might present insurmountable right of way difficulties for a highway. It concentrates through traffic into a highly congested area. It affords poor distribution of traffic to destination other than Oakland.

Route C.

This route, 82 miles long, leaves Route B three miles north of Army Point and takes a southwesterly direction through Benicia over its main street; thence, southerly, across the strait and through the ridge, by way of a tunnel, into Franklin Canyon; thence, westerly, by way of Franklin Canyon, Rodeo Creek and Refugio Valley to a point one mile east of Pinole; thence, southwesterly, through the hills to Richmond; thence, southeasterly, along San Pablo Avenue to Oakland. This route would require fewer miles of new construction than any other route, with the exception of Route E, but a high crossing would be absolutely necessary because of the tunnel which can not be lowered to meet a low crossing.

The barrier plans for this site provide for ship locks on the Benicia side which, for a high crossing, would necessitate a 2500-foot approach down the main street of Benicia in order to pass over the locks on a high crossing. Such an arrangement could not be considered and it does not appear practicable to place locks on the south side because of the steep slope of the rock foundation. This barrier location too is imperiled by the Sunol fault.

Route D.

This route utilizes the Dillon Point site and may pass either side of the Sulphur Springs Mountains.

Route D-1, 84 miles long, leaves Route B at the junction of Routes B and C and thence runs west to Southampton Bay; thence, south, crossing the strait at Dillon Point and climbing over the ridge and dropping into Franklin Canyon, where it joins with Route C and follows it to Oakland.

Route D-2, 84.5 miles long, leaves Route B at Fairfield and continues southwesterly through American Canyon to the Napa-Solano County line; thence, southerly, through the hills to a connection with D-1 at Southampton Bay.

Route D is the longest of all routes and would serve no useful purpose which can not be served equally well by other shorter routes. Even local traffic from Benicia bound for Oakland can be routed by way of Carquinez Bridge without loss of distance by building two miles of road along the north shore of the strait.

The Dillon Point crossing presents the best opportunity to combine a high-level highway bridge with a salt water barrier, but like most ideal bridge sites it is not in the right place.

Route E.

This route, 80 miles long, leaves Route D-2 at Chabot Lake, near Vallejo, and runs south through the suburbs of Vallejo to the Carquinez Bridge, crosses the bridge and turns southwesterly to Rodeo; thence, south, to a connection with Route C in Refugio Valley; thence, following Route C, to Oakland as previously described.

Route F.

This route would leave the Redwood Highway about four miles north of San Rafael and take an easterly course along Gallinas Creek to its mouth; thence, along the shore of San Pablo Bay, in a southeasterly direction, to San Pedro Point; thence, continuing southeast, across San Pablo Strait to San Pablo Point; thence, continuing southeasterly, along the top of the narrow ridge to Point Richmond; thence, easterly, through a low saddle in the ridge and across the mud flats through South Richmond to San Pablo Avenue. This route would connect Eastbay cities with the Redwood Highway in a very direct and satisfactory manner.

Estimates of Costs.

The following table of estimated costs for barriers is taken from Bulletin No. 22:

Estimate number	*Plate number*		
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

* 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.

It is estimated that a high elevation four-lane highway bridge could be built across Carquinez Strait for from $5,000,000 to $6,000,000 and that a highway bridge across San Pablo Strait would cost \$15,000,000. The plans for estimate No. 13 above provide foundation for a high roadway crossing. This foundation would not reduce the cost of a highway bridge more than \$3,000,000, which is 5½ per cent of the estimated cost of the barrier, \$53,300,000. Since the Dillon Point site presents far better conditions for a combined structure than any other Carquinez Strait crossing, it follows that an even smaller percentage could be contributed from highway funds for any of the others.

Estimate No. 16, \$82,100,000, provides for a combined barrier and highway across San Pablo Strait, but the plan provides for a low elevation highway crossing with 50-foot clearance and drawbridges. A low elevation crossing would be especially unsatisfactory at this site because of the larger volume of water traffic, as indicated in Table 6–39. It appears that if a barrier could be built at San Pablo Point, a low elevation road could be placed on the barrier and a high crossing over the ship locks obtained by locating the locks in a cut through San Pablo Point, some distance south of the promontory, and allowing sufficient distance to make the ascent on solid support. This site is the only one which would permit of a low elevation road along the top of the barrier and a high crossing over the locks. A high elevation crossing of the locks would necessitate moving the locks southward about 1500 feet. The cost of adding the highway to these plans probably would be \$3,000,000.

The estimated traffic, however, on this route is now approximately 330,000 cars per year. Statistics indicate that, when ferries are replaced by bridges or such facility, a normal increase of from 30 to 50 per cent may be expected during the first year of the operation. On this basis, assuming an increase of 40 per cent in traffic, the traffic using the crossing replacing the Richmond-San Rafael ferry would be approximately 460,000 the first year. An increase of three per cent per year to 1950 and two per cent beyond that time to 1980 may be considered a reasonable increase in traffic. On the basis of this traffic, the estimated expenditure would not be warranted until 1955, unless unprecedented development would occur in Marin and Alameda counties. Furthermore, a franchise for a toll bridge near the Point San Pablo site has been granted. If this bridge was constructed there would be no need to consider combining a highway crossing with a barrier in this vicinity.

APPENDIX C

EVAPORATION AND TRANSPIRATION

With Special Reference to a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

by

Charles H. Lee

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LIST OF PLATES

LETTER OF TRANSMITTAL

Mr. Edward Hyatt,
State Engineer,
Sacramento, California.

Dear Sir: I herewith transmit my report on "Evaporation and Transpiration With Special Reference to a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."

This report has been prepared as requested in your letters of June 2, June 7 and August 22, 1930.

Conclusions herein relative to rates of evaporation and transpiration are based upon all pertinent data available to date. Evaporation rates, although based on estimates, are believed to closely approximate the actual values, especially during the period of greatest intensity, including the summer months. Transpiration rates are believed to be reasonably accurate, but are subject to possible modification in the future, if and when further data become available.

Classified acreage data, as furnished by your office, are included in the report, with discussion of probable changes due to construction of a barrier and recommended rates of evaporation and transpiration to be applied. Estimated total losses by evaporation and transpiration from natural vegetation have not been determined, as it was understood this would be done by your office.

Respectfully submitted,

Charles H. Lee
Consulting Engineer.

San Francisco, California,
August 27, 1930.

ACKNOWLEDGMENT

In the preparation of this report helpful assistance and data have been obtained from the engineering staff of the Division of Agricultural Engineering, Bureau of Public Roads, United States Department of Agriculture, headed by W. W. McLaughlin, Associate Chief; the United States Army Engineers, working under the direction of Major E. H. Ropes; the San Francisco office of the United States Weather Bureau, under the direction of E. H. Bowie, Meteorologist; Professors F. J. Veihmeyer and W. W. Weir, and others of the College of Agriculture, University of California; C. W. Schedler, President, Association of Industrial Water Users, Pittsburg.

Cooperation of the following organizations and individuals in making available valuable meteorological and evaporation records also is acknowledged:

Shell Oil Company,
Hercules Powder Company,
California and Hawaiian Sugar Refining Corporation, Ltd.,
Union Oil Company,
Mountain Copper Company, Ltd.,
American Smelting and Refining Company,
Chabot Observatory,
University of California, Department of Geography,
University of California Farm at Davis,
Alviso Salt Company,
East Bay Municipal Utility District,
H. L. Haehl, Consulting Engineer, San Francisco.

Information relative to the physiological characteristics of natural plant species found in a salt water barrier area has been furnished by:

Dr. J. G. Brown, Professor of Plant Pathology, University of Arizona.

Dr. D. T. MacDougal, Director of the Carnegie Botanical Laboratories.

Dr. W. W. Robbins, Associate Professor of Botany, University of California at Davis.

CHAPTER I

SUMMARY AND CONCLUSIONS

Construction of a barrier to stop the advance of salt water into the upper reaches of Suisun Bay and the delta of the Sacramento and San Joaquin rivers would greatly increase the demands for fresh water in these areas. Evaporation losses from water surface, which, in periods of shortage in stream flow, are now supplied by the inflow of salt water from San Francisco Bay, would have to be provided from river flow or mountain storage. The same source would have to be depended upon to supply transpirational losses from marginal vegetation.

Salt marsh and salt-resistant vegetation, from which transpiration is now curtailed by excess of salinity, would be replaced by fresh-water varieties which consume water at a greater rate and which will extend over a larger area. These increased water losses, because of the extensive areas involved, would have an important bearing not alone upon plans for mountain storage in connection with a salt water barrier, but possibly upon its feasibility.

The purpose of this report is to present the results of studies to determine the evaporation and transpiration losses to be expected from a lake created by a salt water barrier and to describe the available data and the analytical methods used in reaching conclusions.

Because of the great importance of these losses in any study of the feasibility of a barrier, unusual efforts have been made to arrive at accurate values for the rates of evaporation in different portions of the barrier area and for the rates of transpiration from different types of vegetation. These studies are described on the following pages with supporting data presented in the form of tabulations and plates at the end of the report, and have resulted in the following conclusions:

1. A salt water barrier area would extend over four topographic units within which the meteorological factors influencing the rate of evaporation from water differ appreciably.

2. The following tabulation indicates the average rate of monthly evaporation from fresh water, as found for each topographic unit:

Month	San Pablo Bay	Carquinez Strait	Suisun Bay	River Delta
	In inches	In inches	In inches	In inches
January	0.98	0.96	0.93	0.90
February	1.70	1.65	1.65	1.60
March	2.53	2.55	2.81	2.75
April	3.58	3.82	3.82	4.12
May	5.00	5.80	6.15	7.25
June	5.00	6.55	7.10	9.10
July	5.75	7.10	7.60	10.10
August	5.35	6.25	6.90	9 35
September	4.70	5.25	5.90	7.15
October	3.40	3.80	3.85	4 00
November	1.60	1.60	1.60	1 65
December	1.02	1.02	1.02	1.01
Year	40 61	46.35	49.33	58.98

3. Any degree of salinity which might reasonably occur above a salt water barrier would not appreciably reduce the rate of evaporation below that for fresh water.

4. The types of natural vegetation now growing on marginal and other lands within a barrier area are:

San Pablo Bay—Samphire, pickleweed, creek sedge.
Suisun Bay—Tule and cat-tail, salt grass, and mixed growths of foxtail with salt grass, samphire and pickleweed with salt grass, and tule with creek sedge.
Delta—Tule and cat-tail, willow.

5. The probable ultimate types of natural vegetation, after construction of a barrier, would be:

San Pablo Bay—Tule and cat-tail, salt grass.
Suisun Bay—Tule and cat-tail, salt grass, willow.
Delta—Tule and cat-tail, willow.

6. Values for average monthly rates of transpiration from natural vegetation which ultimately would grow in a barrier area have been adopted, after study of all available information, as follows:

Month	Tule and cat-tail	Salt grass[1]	Willows	
			In large groves	Isolated trees
	In feet	In feet	In feet	In feet
January	0.16	0.06	0.04	0.09
February	0.09	0.08	0.03	0.05
March	0.30	0.12	0.08	0.16
April	0.74	0.24	0.20	0.41
May	1.10	0.36	0.30	0.60
June	1.28	0.43	0.35	0.70
July	1.53	0.56	0.42	0.84
August	1.32	0.58	0.36	0.73
September	1.18	0.39	0.33	0.65
October	0.98	0.29	0.27	0.54
November	0.59	0.22	0.16	0.32
December	0.36	0.14	0.10	0.20
Year	9.63	3.47	2.64	5.29

[1] Values for average annual depth to water table of two feet.

7. Values for transpiration from oak trees may be considered as 60 per cent of that from willows.

CHAPTER II

AREAS

The locations for a salt water barrier extend over four topographic units as follows:

San Pablo Bay, Carquinez Strait, Suisun Bay and the delta, the latter extending from the junction of the two rivers at Chain Island to the head of tidal action in the period of low stream flow as indicated in Plate C-I, "Geographical Variation of Mean Monthly Temperature in San Francisco Bay and Sacramento-San Joaquin Delta Region."

Each of these areas has distinctive meteorological characteristics and also differing types of marginal vegetation. Thus they naturally constitute separate units for the differentiation of rates of evaporation and transpiration. For purposes of estimating losses which would occur from the back water area above each barrier site, a further subdivision has been made for the various sites as follows:

Point San Pablo, Dillon Point, Benicia and Chipps Island, also shown on Plate C-I.

The areas considered in this report are those from which evaporation and transpiration would occur with construction of a salt water barrier, the source of which would be fresh water from the Sacramento and San Joaquin rivers and their tributaries. It was assumed that average water surface behind a barrier would be at elevation 2.5 feet above U. S. Geological Survey mean sea level datum. The areas would consist primarily of fresh-water surfaces in the two bays, open sloughs, and sloughs, drains, ponds, etc., within levees. Surrounding and adjoining these water surfaces would be large areas of natural vegetation. There also would be irrigated and cultivated lands within reclaimed areas bordering the bays and in the delta. Water losses from the latter and areas in weeds are not considered in this report.

The sources of data for land and water areas in San Pablo Bay are a detailed field survey made by the State in August, 1930, using U. S. Coast and Geodetic charts, and U. S. Geologic Survey maps, and an airplane photographic survey made by the U. S. Army Engineers. The results of these surveys are shown under the first and third columns of the tabulation below. The middle column indicates the probable classification during the years following construction of a barrier and prior to more extensive use of the land for agriculture, as indicated by field inspection. The basis for this change in classification is discussed in Chapter IV.

The land and water classification data for Suisun Bay are based on a detailed field survey made by the State in August, 1930, using copies of the airplane photographs obtained by the U. S. Engineers. The results of the survey are tabulated below, the second column indicating the conclusion as to probable classification during the years following construction of a barrier and prior to more extensive use of the land for agriculture.

LAND AND WATER CLASSIFICATION—SAN PABLO BAY AREA

Survey of August, 1930

Present classification	Probable classification during years immediately following construction of a barrier	Acres
Open tidal water Point San Pablo to Dillon Point*	Water	78,400
Grain and plowed ground	Crop	23,910
Pickle weed	Salt grass	11,210
Foxtail	Salt grass	8,580
Tule, cat-tails, sedges, etc.	Tule	5,870
Salt grass	Salt grass	4,310
Wild oats	Weeds	2,670
Drains, ponds, inland water, etc.	Water	1,490
Levees and roads	Levees and roads	750
Natural grasses	Salt grass	720
Bare	Bare	440
Corn and truck	Crop	330
Wire grass	Tule	230
Weeds	Weeds	150
Lamb's-quarter	Salt grass	50
Mud flats	Tule	50
Beans	Crop	20
Greasewood	Brush	20
Total		139,200

* Elevation plus 2.5 U. S. G. S. Datum.

LAND AND WATER CLASSIFICATION—SUISUN BAY AREA

Survey of August, 1930

Present classification	Probable classification during years immediately following construction of a barrier	Area in acres		
		Above Chipps Island site	Above Benicia site	Above Dillon Point site
Open tidal water*	Water	2,730	32,480	33,810
Salt grass	Salt grass	2,400	22,540	22,570
Pickle weed	Salt grass	1,000	14,250	14,380
Tules, cat-tails, etc.	Tule	1,050	13,930	13,970
Grain, stubble, plowed, etc.	Crop	480	3,720	3,720
Foxtail	Salt grass	150	3,430	3,430
Wire grass	Tule	390	3,220	3,220
Drains, ponds, inland water, etc.	Water	130	2,540	2,540
Bare land	Bare	50	930	930
Levees, roads, etc. (bare portion)	Bare	100	790	790
Wild oats	Weeds	20	770	770
Blue grass	Salt grass	560	560	560
Mud flats	Tule		450	520
Asparagus	Crop		500	500
Lamb's-quarter	Salt grass		390	390
Weeds (unclassified)	Weeds		270	270
Beans	Crop		210	210
Miscellaneous	Bare	90	90	90
Eucalyptus	Trees		20	20
Alfalfa	Crop		10	10
Totals		9,150	101,100	102,700

* Elevation plus 2.5 U. S. G. S. Datum.

Delta areas are as furnished by the State, and are based on U. S. Geological Survey maps for land areas and U. S. Army Engineers' maps for tule and water surface areas, with examination in the field, particularly of tule areas. It is not believed material change in natural

PLATE C–I

LEGEND

T	Temperature station
H	Relative humidity station
W	Wind station
—— ——	Isotherm
▬	Salt water barrier sites
››››››››	Crest of air drainage divide
▪	Water evaporation station
···········	Boundary of delta area
○—○—○	Boundary of Suisun and San Pablo Bay marsh land area

GEOGRAPHICAL VARIATION

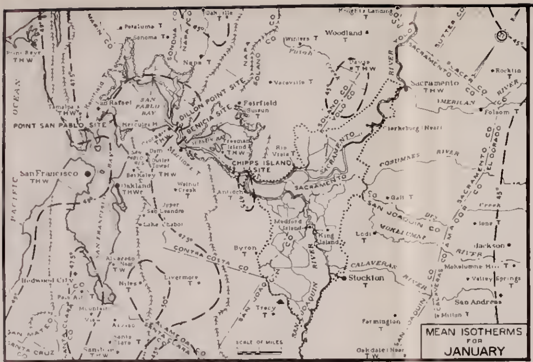
OF

MEAN MONTHLY TEMPERATURE

IN

SAN FRANCISCO BAY AND

SACRAMENTO-SAN JOAQUIN DELTA REGION



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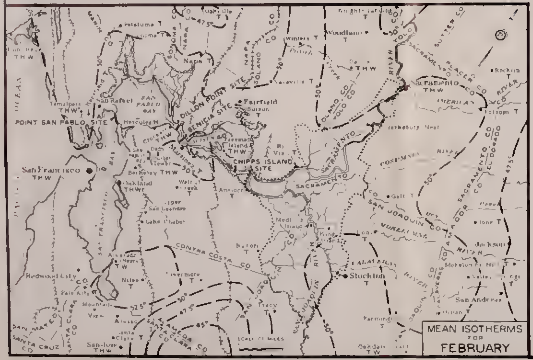

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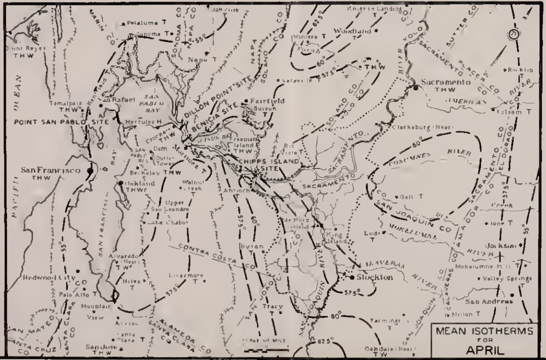
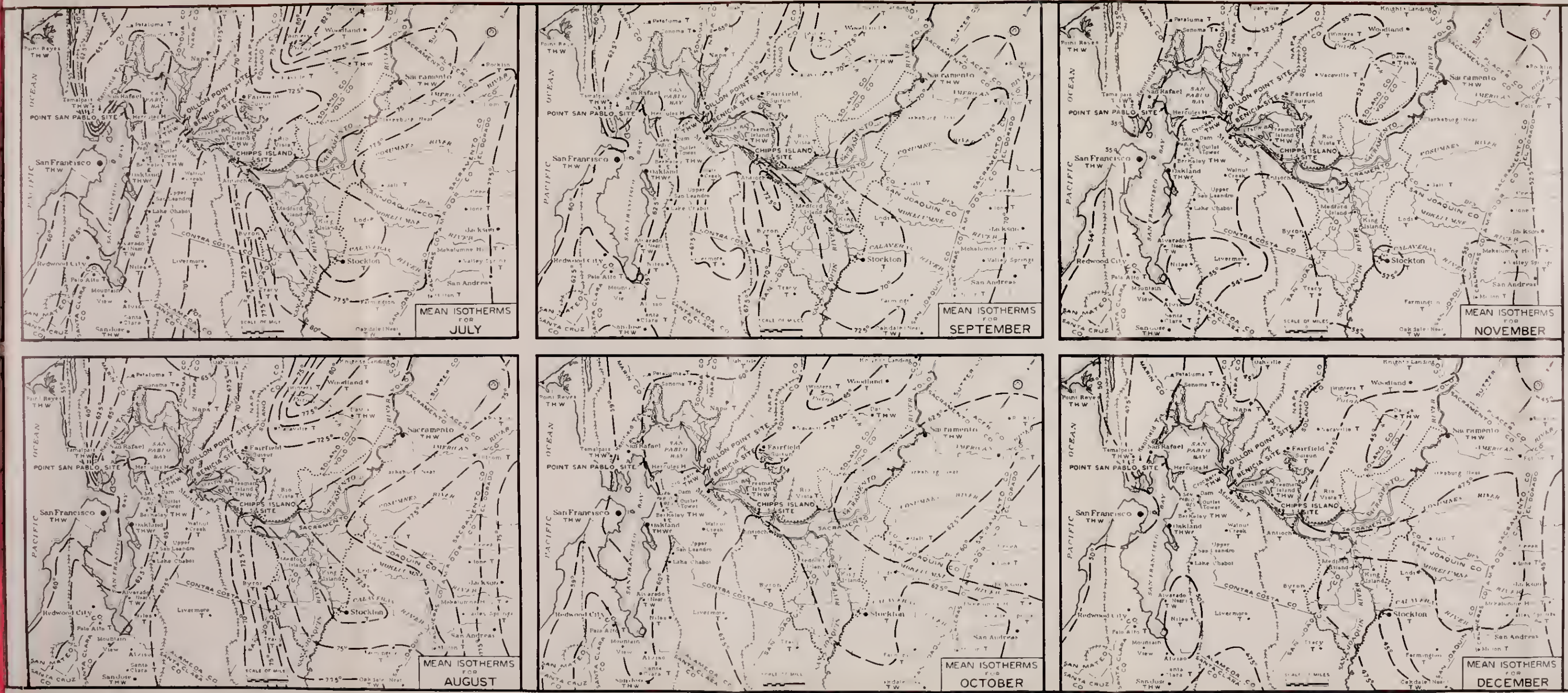


MEAN ISOTHERMS FOR APRIL

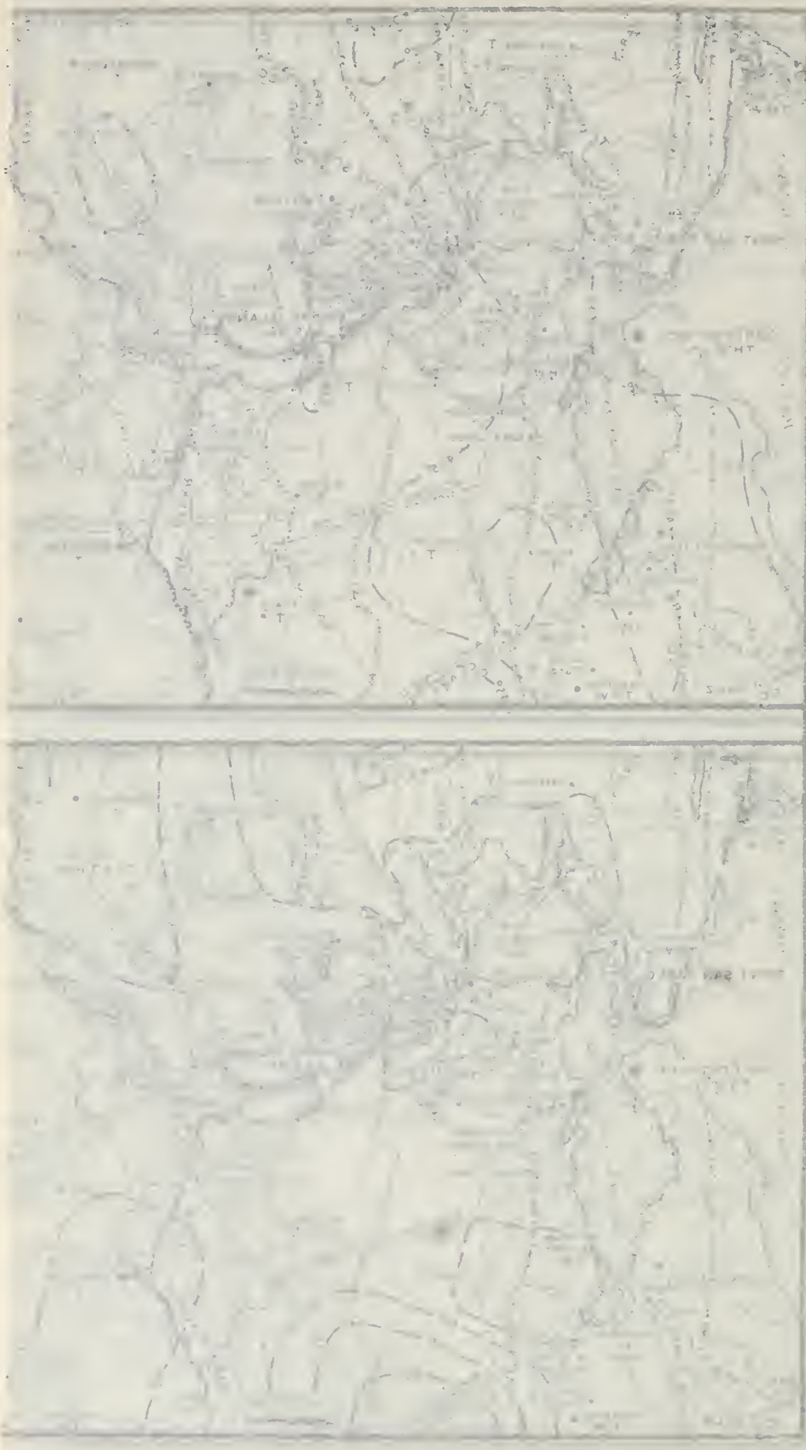
MEAN ISOTHERMS FOR JUNE



LEGEND

- T — Temperature station
- H — Relative humidity station
- W — Wind station
- Isotherm
- Salt water barrier sites
- Crest of air drainage divide
- Water evaporation station
- Boundary of delta area
- Boundary of Suisun and San Pablo Bay marsh land area

GEOGRAPHICAL VARIATION OF MEAN MONTHLY TEMPERATURE IN SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA REGION



vegetation would take place in the delta after construction of a barrier. The classification for present conditions is as follows:

LAND AND WATER CLASSIFICATION OF DELTA AREA OF SACRAMENTO AND SAN JOAQUIN RIVERS

1929 Survey

	Acres
I. Total gross area[1]	488,600
II. Gross unreclaimed area in channels:	
A. Area of water surface	38,700
B. Area of tules	5,300
C. Area of willows	1,200
D. Area of brush and oaks	1,800
Total	47,000
III. Gross reclaimed area:	
A. Levees—	
1. Willows	4,400
2. Weeds and bare land	7,400
Total	11,800
B. Area within levees—	
1. Sloughs and drains:	
a. Water surface	6,400
b. Tules	2,100
Total	8,500
2. Agricultural lands:	
a. Irrigated crops[2]	321,800
b. Nonirrigated crops and idle land above five feet in elevation—U. S. G. S. Datum	64,000
c. Idle improved lands below five feet—U. S. G. S. Datum	26,300
d. Flooded land within delta boundaries	9,200
Total	421,300
Total (Item B)	429,800
Total (Item III)	441,600
Total area of water surface[3]:	
(From Items II-A, III-B-1-a and III-B-2-d)	54,300
Total area of tules:	
(From Items II-B and III-B-1-b)	7,400
Total area of willows:	
(From Items II-C and III-A-1)	5,600

[1] This total gross area includes 1100 acres of water surface between delta boundary and stream gaging stations. Gross area of delta equals 487,500 acres.
[2] Based upon 1929 crop survey of Sacramento-San Joaquin River Supervisor.
[3] Includes 1100 acres of water surface between delta boundary and stream gaging stations. Area of water surface in delta equals 53,200 acres.

The above classifications for conditions during the first few years after construction of a barrier and prior to extension of agriculture as the result of availability of a continuous supply of fresh water have been summarized in Table C-1 accompanying this report. The areas in this table may be used for application of monthly evaporation and transpiration values in computing total evaporation and transpiration losses for the different barrier sites.

CHAPTER III

EVAPORATION

Meteorology.

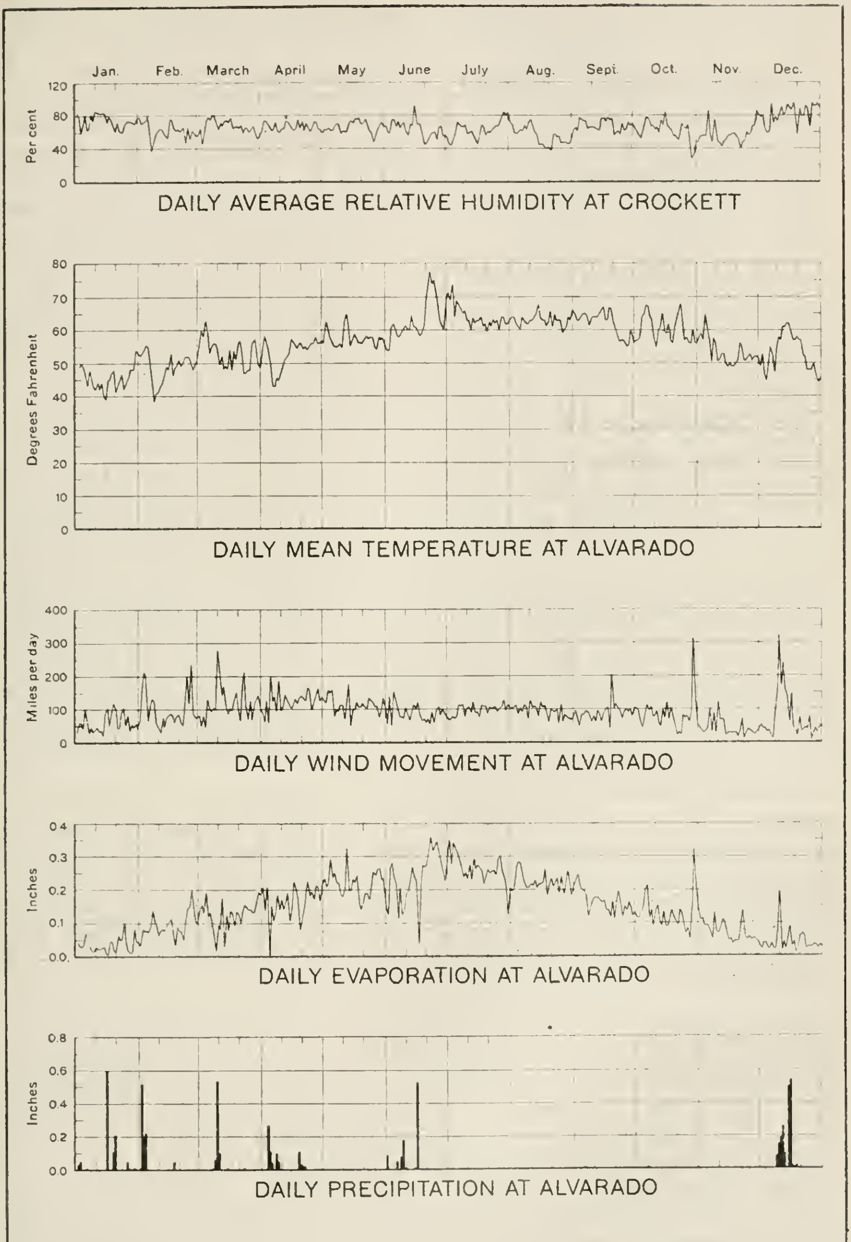
The rate of evaporation from a water surface for any period of time is largely controlled by various meteorological factors, such as temperature and humidity of the air, wind movement, precipitation, etc. Temperature of the water surface also is an important factor and for highly mineralized water specific gravity must be considered. Of the meteorological factors, air temperature is by far the most important. Humidity and wind have a minor influence over long periods, but may be of great importance during intervals of one or two days.

The relation of evaporation to these meteorological factors is illustrated strikingly by daily values at Alvarado for the year 1929 as reported by the U. S. Weather Bureau and set up in Plate C-II, "Meteorological Records at Crockett and Alvarado, California, for 1929." Temperature fluctuations throughout the year are consistently reflected in evaporation, except when suppressed by high humidity accompanying rain storms, while wind effects are only apparent on isolated days, such as February 26th and October 28th, when dry north winds occurred. Humidity observations are not made at Alvarado, but conditions at Crockett, on the upper end of San Pablo Bay, are quite similar. A continuous record of relative humidity is kept there by the California and Hawaiian Sugar Refining Corporation, and daily averages from this record have been plotted at the top of Plate C-II. Reference to this plate indicates the unimportant influence of humidity upon evaporation, except for short periods.

Temperature—In view of the importance of temperature, a detailed study has been made of average monthly air temperatures throughout the project area. For this purpose the records published by the U. S. Weather Bureau have been very useful. It was found that sufficient long term records (exceeding ten years) were available to draw isotherms, or lines of equal air temperature, upon a small scale map of the bay region as has been done in Plate C-I. The records at 76 stations were used, extending from Ukiah and Nevada City, on the north, to Monterey, Merced and Sonora, on the south, which records are set forth in detail in Table C-2. Isotherms were drawn on working sheets upon which all stations were plotted in order to establish the broad aspects of temperature distribution throughout central California. Isotherms for the bay region, as shown on the more restricted area embraced in Plate C-I were traced from the working sheets. Temperature differences of two and one-half degrees Fahrenheit are represented by the isotherms.

Study of the various monthly isotherms reveals some very interesting conditions. The months November to March are characterized by slight temperature differences throughout the area, with maximum

PLATE C-II



METEOROLOGICAL RECORDS
AT
CROCKETT AND ALVARADO CALIFORNIA
FOR 1929

differences between various points not exceeding five degrees and a range during the five months of from 45 to 55 degrees. November shows clearly the local tempering effect of the warm bay water. The months April to October show a far different condition. Temperatures remain fairly constant along the coast at approximately 55 degrees, but build up progressively in the interior to a July maximum of 80 degrees on the west side of the San Joaquin Valley and 82.5 degrees on the west side of the Sacramento Valley.

The controlling factors in temperature distribution during these months are, first, the centers of heating represented by the flat land areas of the valleys and especially the Great Valley; and second, the great area of cool water in the Pacific Ocean off the coast of California. The heating influence of the valleys is first apparent in April and disappears in October. The cooling influence of the ocean is not effective until the trade winds from the west begin during the latter part of May. It continues until the middle of September.

The topography of the bay region has a strong influence upon distribution of the cool air from the ocean. The Coast Range acts as a barrier to inland air movement, except through the gap from the Golden Gate to Colma Valley, just south of San Francisco. Here cool air flows into the San Francisco Bay area and thence southeast toward Santa Clara Valley and northeast into San Pablo Bay. From the latter there is a strong flow through Carquinez Strait gap, across Suisun Bay and into the Great Valley through the gaps north and south of Montezuma Hills, shown by the months of May to September on Plate C-I. One arm of cool air extends into the Sacramento Valley beyond Sacramento and another into the San Joaquin to a point slightly southeast of Stockton. Beyond these points there is general mingling of warm and cool air with loss in identity of the cool streams from the bay.

The sharp differences of temperature induced by these cooling air currents within comparatively short distances are ample evidence of the importance of a temperature study in connection with evaporation from the lake of a salt water barrier. During July, for example, there is a 20 degree difference in temperature between the lower end of San Pablo Bay and the warmest portion of the delta. There also are important differences between air temperature over water and adjacent land throughout the area.

Relative Humidity—Relative humidity is the percentage of water vapor in the air at a given temperature, as compared with that at saturation with the same temperature. It is a measure of the ability of the air to absorb moisture. A high relative humidity, such as 90 per cent, indicates the air is nearing saturation, while a low value, such as 20 per cent, indicates extreme dryness of the air.

There are insufficient stations at which relative humidity is observed to map relative humidity variations for the project area. The only station at which a continuous record is kept, from which daily maximum and minimum values can be obtained, is that maintained by the California and Hawaiian Sugar Refining Corporation at Crockett. Other stations at which measurements are made at fixed hours each day are those maintained by the U. S. Weather Bureau at San Francisco, San Jose, Mount Tamalpais, Point Reyes, Sacramento, Fresno and Red

Bluff. Records of a similar character also are kept at Oakland by the Chabot Observatory, at Berkeley by the University of California, and at Hercules by the Hercules Powder Company.

All available relative humidity records have been compiled in Table C-3, segregated according to time of observation. The location of these stations is indicated on Plate C-I. It appears from this table that relative humidity is fairly constant throughout the year near the coast at San Francisco and Berkeley, with a slight increase during the summer months when fog prevails much of the time. At interior points, however, there is considerable variation between winter and summer, winter values being equal or slightly higher than those in the bay region and summer values far less. The stations at Hercules and Crockett, on San Pablo Bay, although but a short distance from San Francisco and Berkeley, show a marked reduction.

There is a close relationship between humidity and temperature observable in the records in Table C-3, both for the same station and among widely separated stations. In order to study this relation Plate C-III, "Relation of Average Monthly Temperatures and Relative Humidity," has been prepared. This plate shows that among the four stations, San Francisco, Crockett, Sacramento and Fresno, the average monthly relative humidity varies uniformly in an inverse ratio with average monthly temperature during the months April to October, and that there is a similar relation at the individual stations of Fresno, Sacramento and Crockett. Only minor variations occur during the winter months and the relationship is not so clear. The data is sufficient, however, to indicate a uniform variation of relative humidity with air temperature throughout the project area for at least the months April to October. This relationship has been utilized in later studies presented in this report.

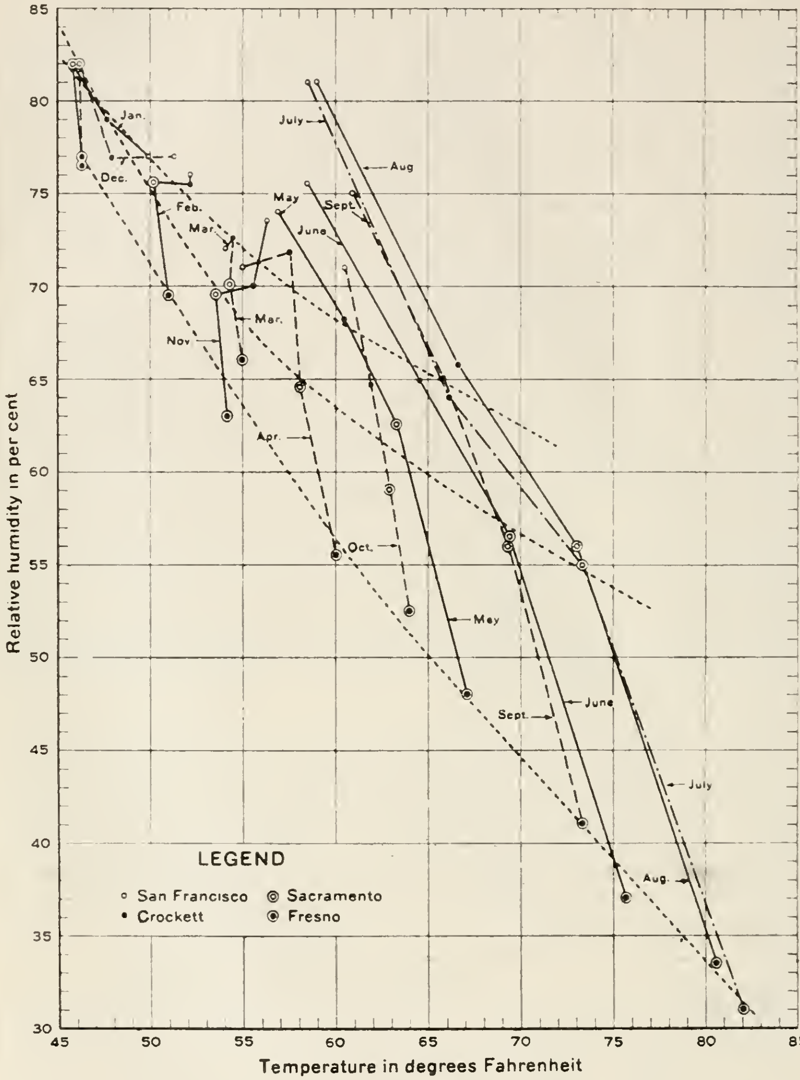
Wind Movement—Wind movement is measured in terms of miles traveled by the air during a stated period of time, as registered by an anemometer. It varies greatly at the same geographic location, depending upon the height of the point of measurement above the ground surface. Robert E. Horton publishes a table, based on experiment, for reduction of wind velocity at any level to that one foot above the ground.* The following typical values taken from this table indicate the great differences to be expected at various levels:

Wind velocity in miles per hour at height H	Wind velocity in miles per hour one foot above ground			
	H=10 feet	H=50 feet	H=100 feet	H=200 feet
2	1.85	1.53	1.37	1.22
5	4.25	3.30	2.84	2.48
10	7.75	5.70	4.85	4.12
20	13.90	9.70	8.10	6.80
30	19.30	13.20	10.85	9.10

It is evident that in comparing wind movement at two stations consideration should be given to the height of the anemometer above the ground.

* Hydrology of the Great Lakes by Robert E. Horton in collaboration with C. E. Grunsky, 1927.

PLATE C-III



RELATION OF

AVERAGE MONTHLY TEMPERATURES AND RELATIVE HUMIDITY

All available wind movement records in the vicinity of a barrier are listed in Table C-4, with a description of each record, including height above the ground. Average monthly wind movements at all stations are listed in Table C-5. Wind movement at Alvardo, Davis, Oakdale and Suisun Bay is measured practically at the ground level and can be directly compared. It is to be noted that Alvarado and Oakdale are in close agreement, while windage at Davis is less than one-third that at these stations and Suisun Bay 50 per cent greater. Instrumental exposures are at widely differing heights above the average ground surface at other stations set forth in Table C-4 and direct comparisons of the records can not be made without correction. It is apparent, however, that with the exception of Davis and wind gaps such as at Selby, great differences of windage do not occur at ground level in the vicinity of the area under consideration.

Precipitation—Average monthly and annual precipitation at stations in the vicinity of this area, as observed by the U. S. Weather Bureau, are presented in Table C-6. The greatest annual precipitation occurs near the coast, generally ranging between 22 and 26 inches. In the interior valleys the annual precipitation ranges from twelve to nineteen inches. As is characteristic of precipitation throughout California, the months of June, July and August are practically without rain, while very little falls during May, September and October. More than 80 per cent falls during the cooler months—November to April. The abnormal meteorological conditions occurring during storm periods are thus confined to the months of least evaporation.

Meteorological Districts—The topography of the area exerts a controlling influence upon meteorological conditions during the period of trade winds when evaporation rates are at a maximum. The successive ranges of hills, all at right angles to the direction of prevailing wind, act as barriers to the flow of cool air from the Pacific Ocean. Air currents are concentrated at wind gaps such as Golden Gate, Colma Valley, San Pablo Strait, Carquinez Strait and to the north and south of Montezuma Hills. The successive basins between wind gaps are successive stages in changing air temperature and relative humidity as set forth in Plates C-I and C-III. Because of these conditions San Pablo Bay, Carquinez Strait, Suisun Bay and the delta, each represent distinct meteorological districts and have important differences in rates of evaporation. These districts have been selected as natural units within which uniform evaporation rates may be determined.

Temperature of Bay Water.

The basic law governing evaporation, discovered by John Dalton more than 100 years ago, is that evaporation rate is proportional to the difference between vapor pressure in the air above the water surface and the maximum vapor pressure of the air at the temperature of the water surface. Temperature of bay water is therefore pertinent to a study of evaporation.

The only extended record of this character obtainable is that kept by the Shell Oil Company at the Martinez Refinery at the lower end of Suisun Bay and reproduced on Plate C-IV, "Relative Water and Air Temperatures in Suisun Bay Region." Observations are made 2300 feet from the south shore approximately 1000 feet off the center line of the main channel and adjacent to the company's wharf. Water is subject to tidal action and minor river currents. Temperatures are observed at a uniform level of thirteen feet above the bottom at a depth of ten feet at high water and one foot at low water.

Comparison of average monthly air temperatures at Antioch, 20 miles upstream, and Crockett, five miles downstream, indicates that water temperature closely follows air temperature, but with a varying degree of lag. The difference is greatest during June, July and August, the months of maximum temperature, and in November and February, when rapid changes occur in air temperature. The tempering effect of warm river and bay water upon cooler air temperature during November is noticeable on the isotherm map for November.

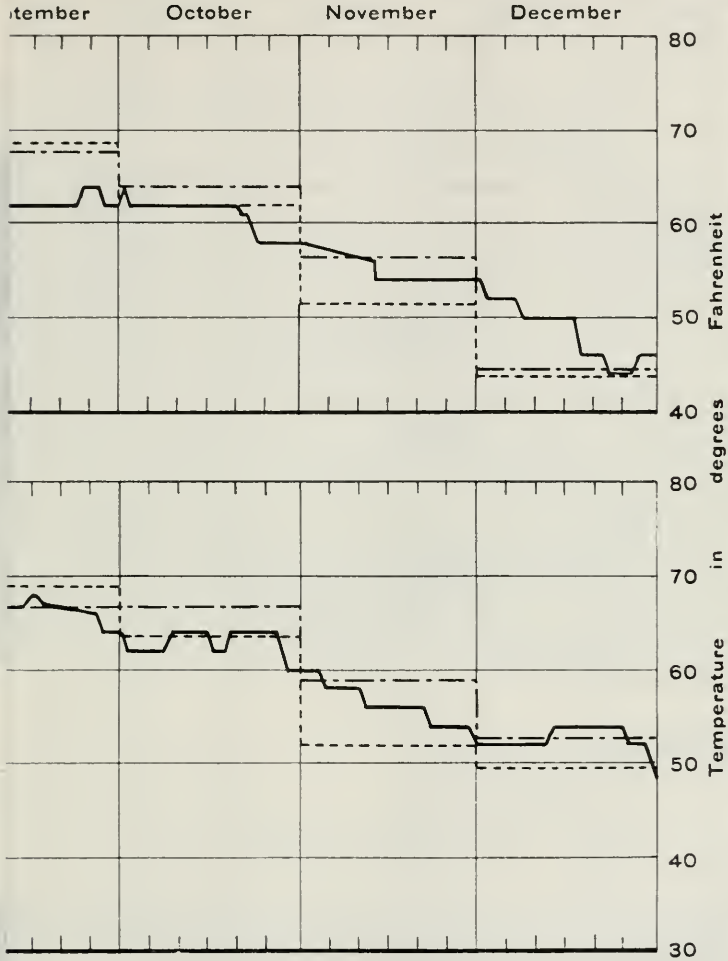
Evaporation from Fresh Water.

Evaporation is the process by which substances pass from liquid to vapor. It represents a definite loss in weight and volume of the liquid, which loss can be readily measured. The usual method of measuring the rate of evaporation from water surface is by observing, at regular intervals, the level of water in a pan or tank exposed to the atmosphere. The rate of evaporation differs greatly for different exposures and sizes of the container in which measurements are made and factors must be applied to any measuring device of this character to obtain the evaporation from a large water surface exposed to similar meteorological conditions.

Measurement—The measurement of evaporation often is complicated by precipitation falling into the container. The amount of precipitation at any point bears no relation to the amount of evaporation at that point, so that to make comparison of evaporation rates at different points it is necessary to determine the absolute or gross evaporation. This is accomplished by placing a rain gauge near the evaporation container and after a storm adding the observed depth to the last previous evaporation gauge reading. This requires attention during heavy rain so that water may be dipped out if the container threatens to overflow. Evaporation records are often kept without giving attention to precipitation. Defective records have not been considered in preparing this report, all data, as far as known, having been observed in an approved manner and represent gross evaporation.

Local Evaporation Data—A thorough canvass has been made for evaporation records kept in the vicinity of a lake formed by a salt water barrier. Fifteen such records have been assembled and all pertinent data compiled in Table C-7. These data include location, authority, period of observation, type of equipment, size and setting of pan or tank and measured annual depth of evaporation. Tabulations of monthly evaporation at each station are presented in tables accompanying this report, as follows:

Table C- 8—Alvarado (near), U. S. Weather Bureau.
Table C- 9—Alviso (near), Alviso Salt Company.
Table C-10—Lake Chabot, East Bay Water Company.
Table C-11—Upper San Leandro Reservoir, East Bay Water Company and East Bay Municipal Utility District.



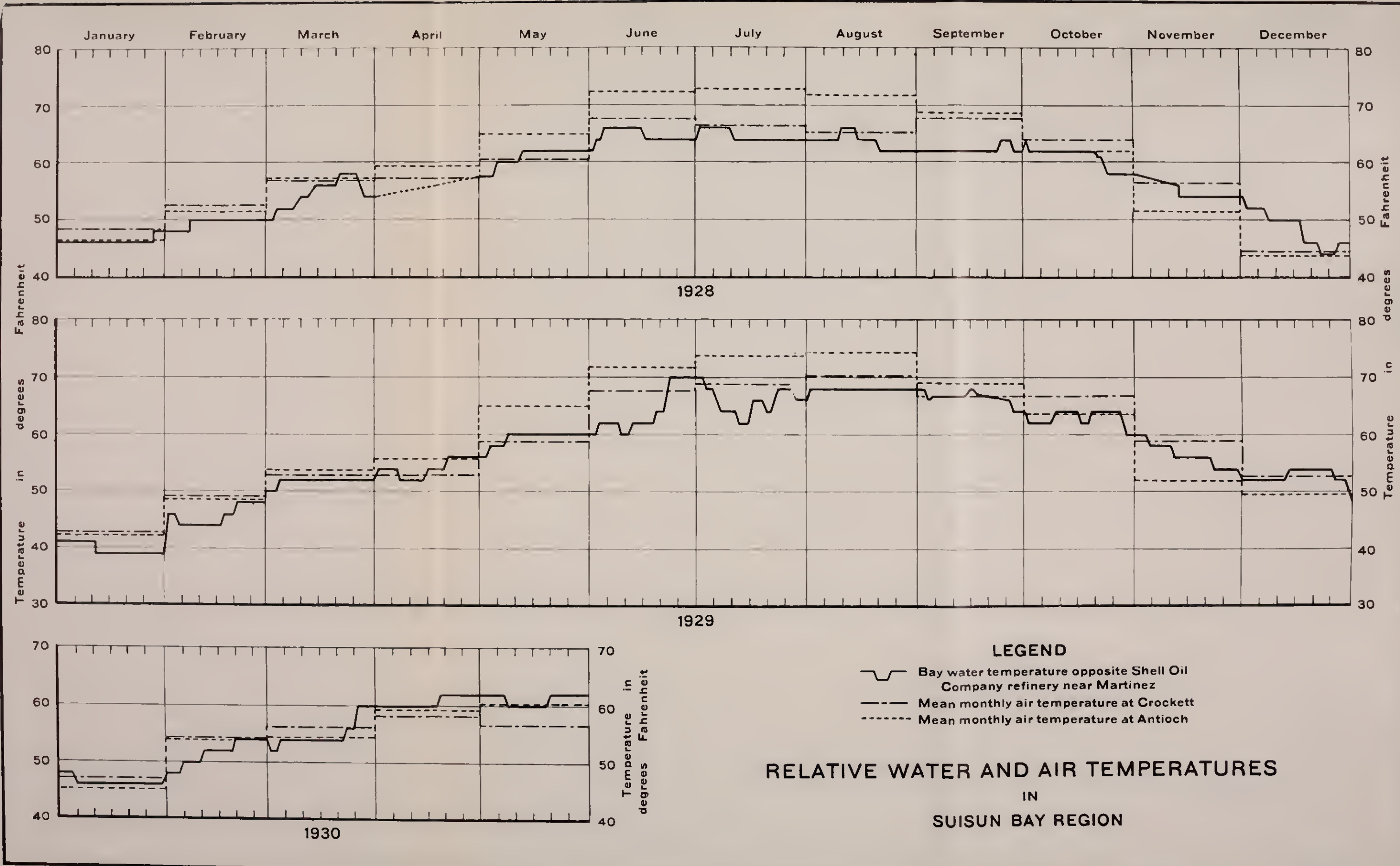
LEGEND

ⅰater temperature opposite Shell Oil
ɔmpany refinery near Martinez
monthly air temperature at Crockett
monthly air temperature at Antioch

R AND AIR TEMPERATURES

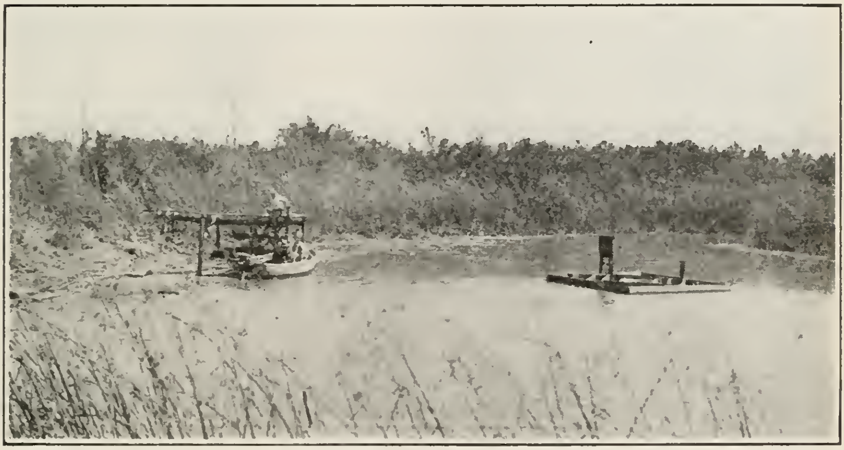
IN

ɪISUN BAY REGION



RELATIVE WATER AND AIR TEMPERATURES IN SUISUN BAY REGION

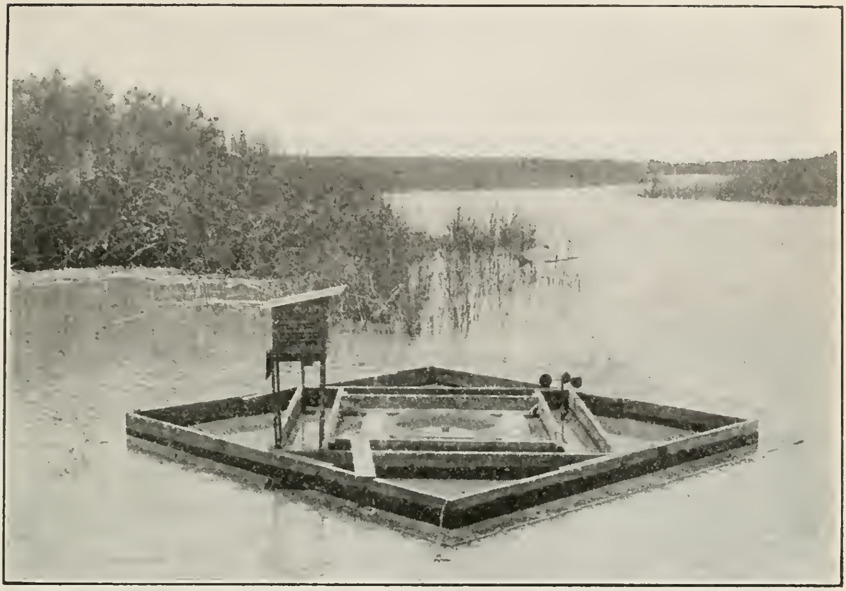
PLATE C-V

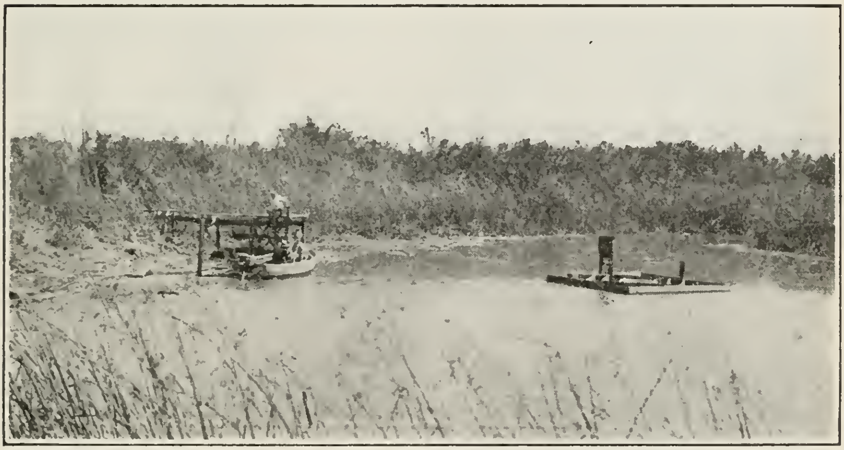


FLOATING EVAPORATION PAN IN SHALLOW WATER

Located near Noyce Slough in Suisun Bay and maintained by United States Engineering Department. Also shows typical growth of tules and aquatic vegetation.

PLATE C-V



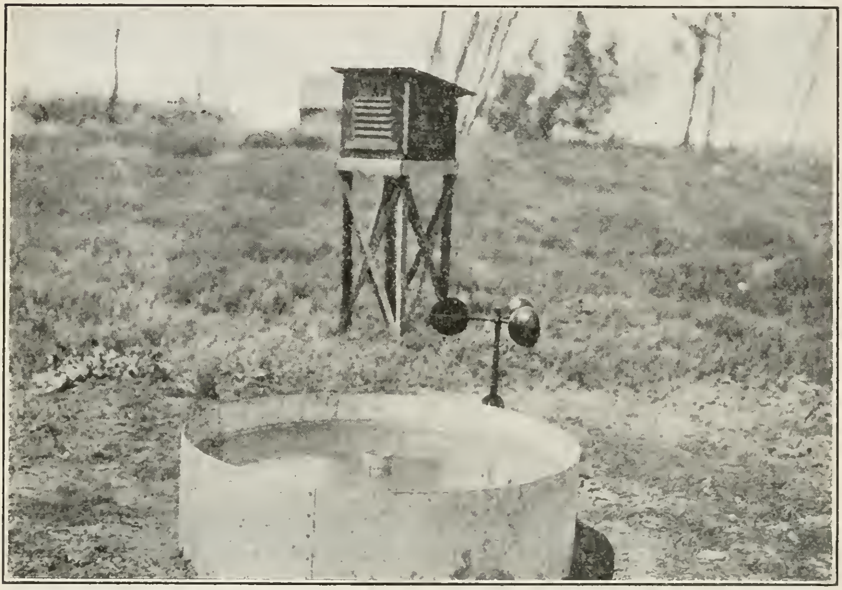


FLOATING EVAPORATION PAN IN SHALLOW WATER

Located near Noyce Slough in Suisun Bay and maintained by United States Engineering Department. Also shows typical growth of tules and aquatic vegetation.

Table C-12—San Pablo Reservoir near outlet tower, East Bay Water Company and East Bay Municipal Utility District.
Table C-13—Same at dam.
Table C-14—University of California Campus at Berkeley, U. S. Department of Agriculture, Office of Experiment Stations.
Table C-15—University of California Campus at Davis.
Table C-16—Reclamation District No. 999, U. S. Department of Agriculture, Division of Agricultural Engineering.
Table C-17—Woodward Reservoir near Oakdale, U. S. Weather Bureau.
Tables C-18, C-19, C-20—Suisun Bay. U. S. Engineering Department.

PLATE C-VI



EVAPORATION LAND PAN

Located on Dutton Island and maintained by United States Engineering Department. Typical growth of salt grass in background.

These measurements have been kept in various types and sizes of containers and under widely different surroundings. At Alvarado, Alviso, Davis and Woodward Reservoir, the U. S. Weather Bureau Class "A" ground pans have been used and observations made in accordance with a prescribed routine. Records at Lake Chabot, Upper San Leandro and San Pablo Reservoirs and Suisun Bay are from floating pans, and at Berkeley and Reclamation District No. 999 in soil tanks. No rigid routine of observation was followed in procuring the floating pan and soil tank records, but it is believed the records, as tabulated, are reasonably accurate. Where there were gaps of several days or question existed regarding the procedure followed with respect to precipitation such portions of the record were omitted from the tables.

Correction Coefficients—The experimental work of various investigators has shown that wide differences exist between the results of evaporation measurements made in small containers and that from a large water surface such as a reservoir or lake. There also is a wide variation even among small containers, as is well illustrated by the column in Table C-7 headed "Observed Annual Depth of Evaporation." The first seven stations, all of which are adjacent to San Francisco Bay and have similar meteorological conditions, show results differing by as much as 40 per cent. It is obvious that before definite monthly and annual rates can be determined for the different subdivisions of the area some method must be found for correcting observations in small containers for application to a large water surface.

The most complete experimental work published on this subject, is that carried on by the U. S. Department of Agriculture, Bureau of Public Roads, Division of Irrigation Investigations, at Denver, Colorado. This work was conducted under the direction of the late R. B. Sleight. Preliminary results were published in the Journal of Agricultural Research (July 30, 1917) and final data are to be found in Transactions, American Society of Civil Engineers (Vol. 90, pages 308, 309 and 373). In the latter publication Sleight summarized all his work with varying shapes, sizes and setting of containers. He classified the containers in common use as follows:

Cylindrical ground surface pans (U. S. Weather Bureau Class A Stations, etc.)

Square ground tanks.

Cylindrical ground tanks.

Square floating pans (U. S. Geological Survey Standard).

Cylindrical floating pans.

Curves were prepared for each type, showing the relation between area of water surface and evaporation as a percentage of that from a twelve-foot ground tank set two and three quarters feet* in the soil. Most of the coefficients thus determined have been recently confirmed at Fort Collins, Colorado, in more thorough investigations by the U. S. Department of Agriculture. In these an 80-foot water-tight tank was used as a basis for comparison (Unpublished manuscript by Carl Rohwer).

After reviewing the work of Sleight and Rohwer and becoming acquainted with conditions at each local evaporation station, an appropriate coefficient for use in reducing local records to the conditions of a large water surface, such as has been done in Tables C-7 to C-20, was selected. The greatest reduction is that for the U. S. Weather Bureau Class A stations where a factor of 0.70 has been applied. The least reduction was for the four-foot circular floating pan for which a factor of 0.96 was adopted. Values for other containers lie between these extremes.

Method of Estimating Evaporation—An examination of available evaporation records, corrected for large water surface conditions, indicates

* Transactions, American Society of Civil Engineers, Vol. 90, figure 9, page 309.

that, although the values at different local stations differ consistently with the differing local meterological conditions, there are yet no records which can be directly applied to the four meteorological subdivisions of the area as indicated in Table C-7 and Plate C-I. A method has therefore been devised to utilize the longest and most reliable records by modifying the values in conformity with local meteorological conditions in each subdivisional area. This method is based upon meteorological relations established; first, as to the controlling influence of air temperature upon evaporation, as shown on Plate C-II; and second, the uniform variation of relative humidity with air temperature within a barrier area as shown on Plate C-III.

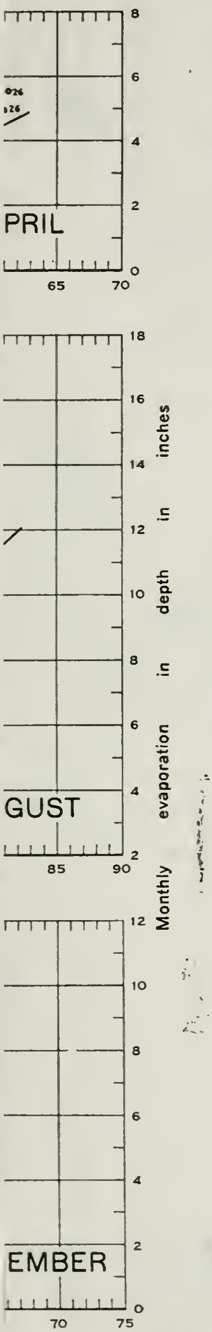
The first step in applying the method was to select two base evaporation stations. Meteorological conditions at Alvarado are very similar to those surrounding San Pablo Bay, and the record extends over a period of six years. Conditions at Woodward Reservoir near Oakdale are generally comparable with those at the eastern margin of the delta region and a twelve-year record is available, of which six are common to both stations. These two stations, representative of the extreme ends of the area, were chosen as base stations.

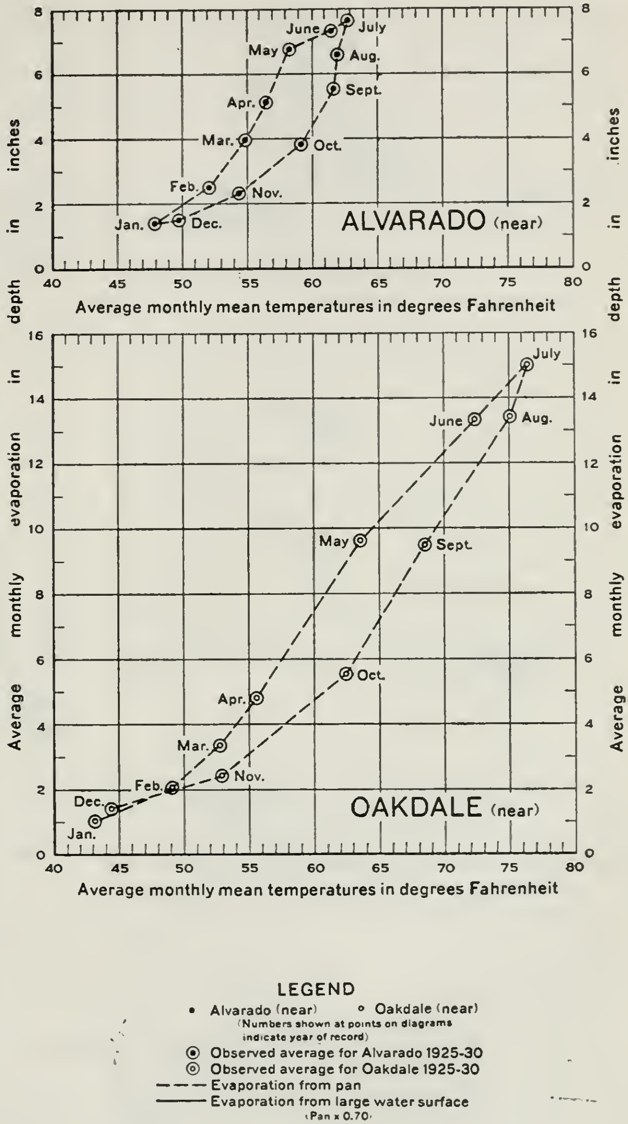
Inspection of isotherms on Plate C-I shows a progressively increasing temperature from San Pablo Bay to the delta, especially during the months April to October, while Plate C-III indicates a uniform variation of relative humidity with temperature between these two points. The evaporation at points intermediate between San Pablo Bay and the delta, being controlled by both temperature and humidity, should therefore be proportional to temperature alone. Graphs showing this relation are presented on Plate C-VII, "Relation of Monthly Evaporation and Temperature at Oakdale and Alvarado, California." These afford a means of determining monthly evaporation for any point or area in the vicinity of a salt water barrier where average temperature is observed or can be estimated.

As a check upon the method, the monthly evaporation has been computed at seven stations lying between Alvarado and Oakdale and set up in Table C-21 for comparison with the corrected measured values. The comparison is aided by reference to the percentage values in Table C-22. The annual evaporation depths, as computed, agree within five per cent at all stations except Davis, where the computed value is 23.9 per cent greater than measured. This difference probably is due to the low windage at Davis, which is approximately 25 per cent of that at other stations in the bay and delta region such as Alvarado, Berkeley, San Jose, San Francisco, Sacramento and Oakdale.

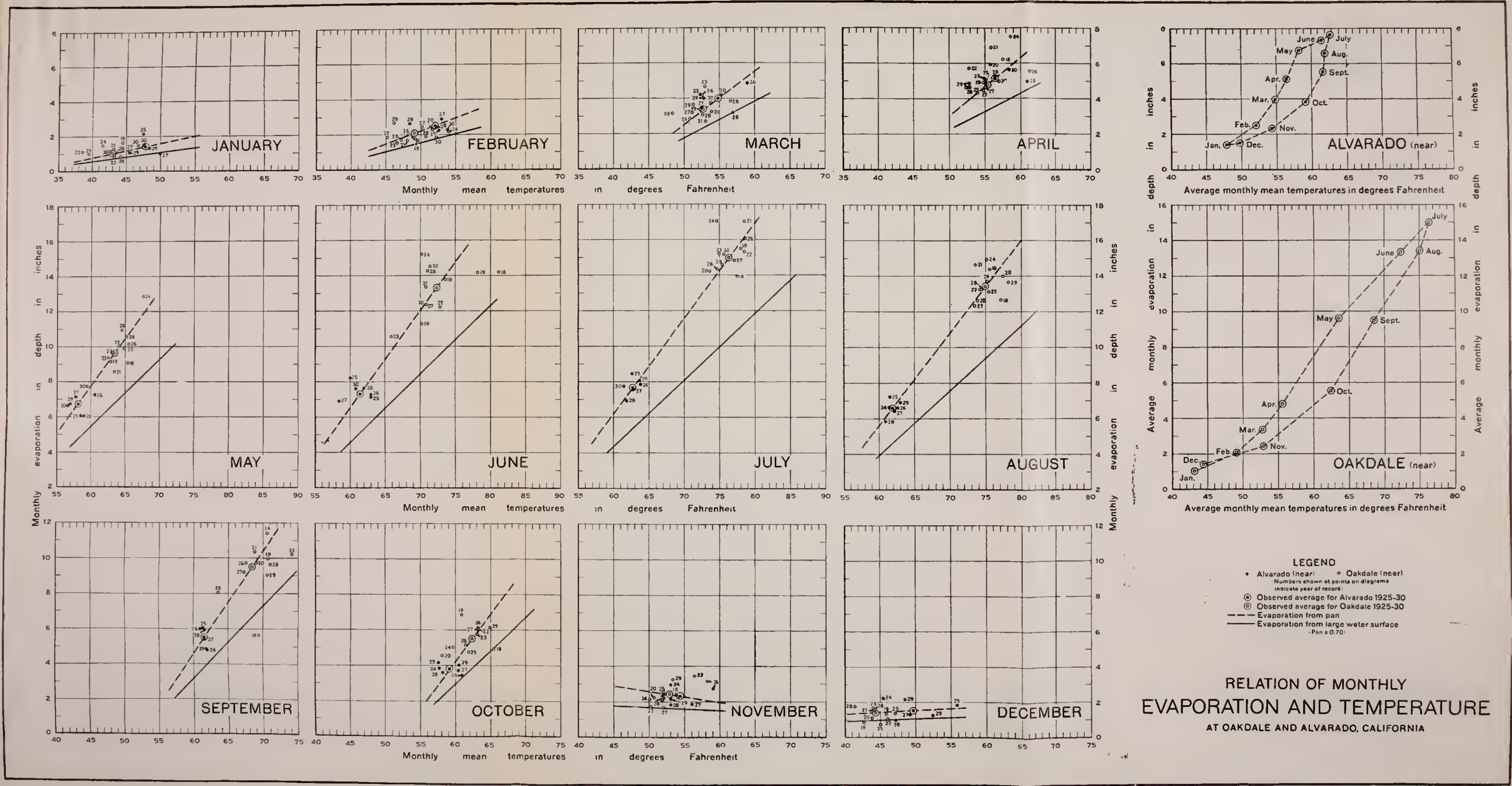
Comparison of monthly values shows agreement to within ten per cent during summer months, both for floating pan and ground tank records. The measurements made by the U. S. Engineering Department in Suisun Bay in deep water are in especially close agreement, as well as those at Upper San Leandro and San Pablo reservoirs. In late summer the computed values at Reclamation District No. 999 are high, due possibly to vegetation around the tank and the low water level in the tank at the end of weekly periods of observation.

Monthly values as computed in the early part of the year exceed measured values, probably due to the fact that base station records are from ground pans on platforms where water temperature follows air





RELATION OF MONTHLY
EVAPORATION AND TEMPERATURE
AT OAKDALE AND ALVARADO, CALIFORNIA



RELATION OF MONTHLY
EVAPORATION AND TEMPERATURE
AT OAKDALE AND ALVARADO, CALIFORNIA

temperature very closely. Check records on the other hand are from ground tank or floating pans, the temperature of which follows the well known temperature lag of soil and water. In the latter part of the year computed values fall below measured values for the same reason.

On the whole, the comparison shows a remarkable agreement between computed and observed values and adds to the confidence with which this method can be used.

Estimated Monthly Evaporation—Application of the method consists of the computation of average monthly evaporation for each meteorological subdivision of the area, using the average monthly air temperatures as determined from the monthly isotherms plotted in Plate C-I. These values are entered on Plate C-VII and the average monthly evaporation read off. The results are tabulated in Table C-23 for the subdivisional areas of San Pablo Bay, Carquinez Strait, Suisun Bay and the delta.

The annual depths of evaporation applicable to large fresh-water surfaces in each of these areas are as follows:

San Pablo Bay	40.61 inches	(3.38 feet)
Carquinez Strait	46.35 inches	(3.86 feet)
Suisun Bay	49.33 inches	(4.11 feet)
Delta	58.98 inches	(4.92 feet)

The similar value used by Walker R. Young in estimating evaporation from all portions of a salt water barrier lake was 3.50 feet (Table 10-1, Bulletin 22, Division of Water Resources, State Department of Public Works).

Evaporation from Salt Water.

The presence of soluble salts in solution tends to decrease the rate of evaporation from water. There is no published data on this subject pertaining to sea water. An experimental study of evaporation from Owens Lake brine, varying in specific gravity from 1.11 to 1.37, has been made. This experimental determination, which was checked by detailed lake level and inflow measurements and pan evaporation observations on Owens River, indicated the rate of evaporation from Owens Lake brine, expressed as a percentage of that from distilled water, varies proportionally with the specific gravity of the brine, but in inverse ratio.* It is probable the results obtained for Owens Lake brine are applicable to sea water. At a specific gravity of 1.03, which approximates that of sea water, the rate of evaporation as determined is 97 per cent of that from fresh water. For any degree of salinity which might reasonably occur above a salt water barrier it is improbable there would be any appreciable reduction in evaporation rate below that for fresh water.

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* Transactions, American Society of Civil Engineers, Vol. 90, page 333.

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* Transactions, American Society of Civil Engineers, Vol. 90, page 333.

CHAPTER IV

TRANSPIRATION FROM NATURAL VEGETATION

Transpiration is the physiological process by which plants, growing in air, give off water vapor from their breathing organs. It is one phase of the process of plant respiration by which air is inhaled and waste products exhaled. The respiratory mechanism of plants is composed of innumerable breathing cells contained in the foliage. These cells cannot perform their functions unless the interior lining of the cell is moist. Plant leaves are enclosed in a relatively impervious skin or epidermis which protects the walls of breathing cells from drying. When exposed to light the food manufacturing processes of a green plant are stimulated and require a continually changing volume of air in contact with the moist cell walls. Automatically controlling the flow to and from the breathing cells are small openings in the epidermis known as stomata, occurring principally on the under side of the leaves. These pores are guarded by two lips which act together as a delicately adjusted valve responding instantly to changes in light intensity, temperature, humidity, water supply, etc.

One of the principal functions of the stomata is to maintain the proper degree of moisture on the walls of the breathing cells. This is accomplished by their control of the amount of air admitted to the cell and hence the rate of water lost by evaporation from the cell walls in the process of transpiration. Any reduction of water supply in contact with the plant roots, causing deficiency of moisture for plant use, causes the stomata to close until the proper quantity of air is being admitted for the plant to do its work under the new conditions. Plants subject to great variation in water supply or arid atmospheric conditions develop exterior mechanism for throttling transpiration, such as thickening of the epidermis, growth of hairs on the under side of the leaf, etc. A thin smooth epidermis, such as exhibited by the willow tree, is most favorable for a high rate of transpiration.

The rate of transpiration differs for different plant varieties, for different light and meteorological conditions, for changing amount and character of water supply, and during the different periods of the annual growth cycle. Plants which naturally grow with their roots submerged or in contact with the water table so as to have an abundant and permanent water supply are among the most active consumers of water. Exception occurs, however, for plants whose roots are in contact with water containing large quantities of salt or alkali. The presence of excessive amounts of mineral salts retards or stops growth and causes plants to develop protective measures similar to those employed in the presence of deficient water supply. A common method is by the addition of water storage cells in the stems and leaves, thus producing a fleshy type of growth such as the samphire or pickleweed when growing in salty or alkaline soil.

Classification of Natural Vegetation.

Field inspection has shown the existence of several types of natural vegetation growing on the island and marginal land within the area. In San Pablo Bay the creek sedge (spartina glabra) predominates in marshland subject to periodic flooding by the salt-water tides. This plant, shown in Plate C-VIII, is a vivid green in color and from a distance has the appearance of a coarse grass· On uncultivated reclaimed land or higher swampy land the fleshy samphire (salicornia), or pickleweed, predominate, with occasional areas of salt grass (distichlis spicata) and on higher land foxtail. The salt grass is shown on Plate C-VI. All of these varieties, although growing with an abundant water supply at their roots, have low rates of transpiration due to protective measures against the accumulation of excessive amounts of salt. In view of the change from salt to fresh water in San Pablo Bay, if a barrier were built at the Point San Pablo site, no study has been

PLATE C-VIII

CREEK SEDGE NEAR MOUTH OF PETALUMA CREEK

made of transpiration from existing types of vegetation in this area as changes in predominant types would occur. It should be noted, however, that in brackish water areas near the heads of sloughs where winter run-off is discharged, the predominant vegetation is of fresh-water types such as tule, cat-tail, etc., and that here little change could be expected.

In Suisun Bay, the tule, shown in Plate C-V, a variety of sedge (scirpus), and cat-tail (typha) predominate in marsh areas. These species grow with their roots submerged. Scattered areas of creek sedge and samphire or pickleweed also are to be found, especially along the Contra Costa shore. The tule and cat-tail growth in Suisun Bay is not as luxuriant as in the delta, but its presence on tidal overflow and submerged marginal land is in great contrast to the bare tidal flats of San Pablo Bay. The small amount of tule in San Pablo Bay marshes indicates it is not adapted to water that is predominantly salty. It is probable that the advance of salt water into Suisun Bay during the summer months has a retardant effect upon the tule growth.

Reclaimed land, which is not cultivated, and swamp land at too high a level to be flooded support a predominant growth of salt grass, with occasional areas of wire grass (fresh-water sedge) on low-lying land, foxtail on higher land and samphire or pickleweed on soil with a high mineral content. It is probable that with the construction of a barrier the area of tule and cat-tail in the Suisun Bay area would increase with corresponding decrease of creek sedge and samphire or pickleweed. Salt grass probably would remain for many years, replacing foxtail on higher levels.

Natural vegetation in the delta of the Sacramento and San Joaquin rivers, due to reclamation and intensive cultivation, is almost entirely confined to slough and stream borders, submerged levee berms, etc. It consists principally of tules and cat-tails, with a few isolated areas of reed grass. Willow trees grow quite generally along tops and higher slopes of levees. It is probable that prior to reclamation of delta lands, beginning about 1900, the 180,000 acres of peat land in the delta all supported a tule, cat-tail and reed growth. This has largely disappeared, due to drainage and the encroachment of cultivation.

Construction of a salt water barrier would bring about certain changes in natural vegetation in the area. The tule and cat-tail would probably soon replace creek sedge around the margins of San Pablo Bay, and it is possible that, with the permanent maintenance of water level at 3.0 feet above mean sea level, there might be an extension of the area capable of supporting tule growth. Salt grass would gradually displace much of the samphire or pickleweed and foxtail now growing on the higher lands. In Suisun Bay the existing tule and cat-tail growth would become more luxuriant, replacing creek sedge where now present, and extending into new areas where the higher water level would provide conditions favorable for growth. Salt grass would probably persist on higher ground, slowly replacing present areas of samphire or pickleweed and foxtail. In the delta little changes of natural vegetation could be anticipated as a result of the construction of a salt water barrier.

Three types of natural vegetation would ultimately prevail throughout the area—tule and cat-tails on land flooded either permanently or during the early part of the growing season, salt grass and associated species on higher swampy ground and uncultivated reclaimed land where the average depth to water table is approximately two feet, and willows along levees and on uncultivated reclaimed land with permanent water table. Areas of weeds may also be expected.

Measurement of Transpiration.

Measurements of transpiration rates from growing vegetation have been made by various methods. The most accurate method is by measurement of the total amount of water, including precipitation, received by field plots during the growing season, correction being applied for difference of soil moisture percentage at the beginning and end of the season. This method is only practical where the water table is at considerable depth and there is no loss by deep percolation. The more common method is by growing plants in tanks where all water used during the growing season can be volumetrically measured. The results of tank measurements have been found to closely check field measurements where the tanks are located in a field of the growing vegetation and are closely surrounded so that there is no appreciable gap between vegetation within and without the tanks. For isolated tanks a reduction factor must be applied to results in order to correct for the increased loss due to greater wind movement, light intensity and temperature, and the absence of an extensive vapor blanket. No conclusive work has been done to determine the value of reduction factors applicable to various types of vegetation growing in isolated tanks and the best factor to use in any given case must be arrived at by approximation.

Practice differs with regard to the inclusion of evaporation from soil with transpiration. For individual large plants and trees some experimenters have sealed the top of the tank so that transpiration alone has been measured. Transpiration measurements from field crops, however, usually include evaporation from the soil beneath and immediately surrounding the plant, as well as the actual loss by plant transpiration. All transpiration data used in this report, except that from willows, include both soil evaporation and transpiration.

Tule and Cat-tail.

Tule and cat-tail thrive in fresh-water marsh areas and along sluggish stream borders. The plants grow close together and attain an average height of from six to eight feet. The stalks are not hollow and jointed like grass, but are filled with continuous pith from root crown to tip. They habitually grow with roots submerged, at least during the early portion of the growing season. The roots draw moisture directly from the water and in order to obtain the necessary amount of plant food a far greater amount of water must be pumped up through the plant than in the case of ordinary types of vegetation which draw upon soil moisture with its greater percentage of mineral matter in solution. The structure of the tule is so well adapted to its work that it may well be called a "natural pump." A relatively thin and smooth epidermis with numerous stomata completely envelopes the whole plant. The area of the epidermis of a tule stalk one inch in diameter at the base and eight feet high is 96 times that of the horizontal cross section of the stalk at the water surface. The cat-tail is similar in character to the tule. It is evident that a high rate of transpiration is to be expected from vegetation of this type.

The most extensive series of transpiration measurements for tule and cat-tail are those by the U. S. Department of Agriculture, Bureau of Public Roads, Division of Agricultural Engineering, in Reclamation District No. 999 near Clarksburg. Six tanks each of tule and cat-tail were set in the ground in an open field and water added weekly so as to flood the soil surface. The record covers a complete annual cycle and is given in Tables C-24 and C-25. Measurements also have been made by the U. S. Department of Agriculture from single tanks at Santa Ana and in Temescal Canyon near Corona, the latter tank being set in the river bottom and surrounded by heavy vegetation. The U. S. Geological Survey also has made measurements from a tank set in a tule marsh at Mud Lake, Idaho.

The results of measurements at Clarksburg and Santa Ana agree substantially, the annual totals being 19.27 and 17.79 feet, respectively.

The lower value at Santa Ana is probably due to lower summer temperature and higher humidity, with resulting lower rate of evaporation. The results at Temescal Canyon are considerably lower than at Santa Ana. This must result largely from the differing surroundings, since evaporation rates are practically the same. The tank in Temescal Canyon reflects more nearly the conditions in a large stand of tule than does the isolated tank in the open field at Santa Ana. The measurements at Mud Lake reflect marsh conditions, as well as lower temperatures and shorter growing season, and, when corrected for temperature, agree closely with the results obtained in the Temescal Canyon tank.

The group of tule and cat-tail tanks in Reclamation District No. 999 are exposed to meteorological conditions typical of the delta and Suisun Bay and the observations set forth in Table C-25 cover a complete annual cycle. The results obtained from these tanks should be closely representative of tule and cat-tail growth in the delta and Suisun Bay when corrected for conditions of close growth. The correction factor applicable to circular ground surface water evaporation pans of the same diameter as the tule tanks (25½ inches) is 0.59.* Such pans are placed on a wooden platform slightly above the surface of the ground and the conditions closely simulate those for isolated tule tanks, except that the water surface lies slightly below the rim of the pan, while the tule growth is fully exposed to wind, which would suggest a factor less than 0.59.

Comparison of measurements at the tule tanks in Temescal Canyon and at Santa Ana for the months of April and May, 1930, given in Table C-25, when growing conditions in the two tanks were most nearly comparable gives the following result:

$$\frac{\text{Tank A in Temescal Canyon}}{\text{Tank 19 near Santa Ana}} = \frac{2.15 \text{ feet}}{3.35 \text{ feet}} = 0.64$$

This value is probably greater than the true factor as it is not evident that vegetation surrounding Tank A is in close contact with that in the tank so as to give a continuous stand.

During the summer of 1930 the Department of Agriculture established two soil tanks each of tule and cat-tail on King Island in a thick stand of tules. The tanks were placed in recesses on either side of an avenue four to six feet wide and 30 feet long, cut into the lee side of a large tule stand. The cleared space around the tanks was eighteen inches and a barrier was placed at the entrance of the avenue to prevent air circulation. The tule plants were dug up, including 90 per cent of the root system, and planted with as little disturbance as possible. Measurements commenced July 23, 1930. The results, as reported by Major O. V. P. Stout, are as follows:

Tank No. 1 (cat-tail)	=July 23 to August 20,	1.18 feet in 31 days.
	July 31 to August 14,	1.31 feet in 31 days.
Tank No. 2 (cat-tail)	=July 23 to August 20,	1.44 feet in 31 days.
	July 31 to August 14,	1.31 feet in 31 days.
	August 6 to August 20,	1.31 feet in 31 days.
Tank No. 3 (tules)	=July 23 to August 20,	1.31 feet in 31 days.
	July 31 to August 14,	1.31 feet in 31 days.
Tank No. 4 (tules)	=August 6 to August 20,	1.31 feet in 31 days.
	July 23 to August 20,	1.44 feet in 31 days.
	July 31 to August 14,	1.31 feet in 31 days.

* Transactions, American Society Civil Engineers, Vol. 90, page 308, tank No. 69.

The average rate for the four tanks for the period July 31 to August 20, when conditions had become settled, is 1.31 feet per month. The rate for the ten tanks at Reclamation District No. 999 for the same period is 2.85 feet per month. Comparing these measurements a factor of 0.46 is obtained. This value is possibly low and may increase as the roots become better established in the King Island tanks.

It is believed the errors in the above three values are more or less compensating and that some intermediate value will represent as close an approach to the true value of the factor as present information will permit. A value of 0.5 has been adopted for use in this report as the correction factor to be applied to transpiration measurements from isolated tule and cat-tail tanks. This value is tentative and may be changed when comparative measurements covering a longer period of time are available.

The monthly values for transpiration from tule and cat-tail in the delta and Suisun Bay, as computed from Reclamation District No. 999 data by use of this factor, are tabulated in Table C-28.

Salt Grass.

Salt grass is a coarse perennial which grows in alkaline soil with an average depth to water table of between two and ten feet. It is sod forming and can be easily transplanted, although it requires more than one season for the roots to reestablish themselves to the water table. Its habit of growth does not favor abnormally large transpiration. In fact, in order to protect itself from the toxic effect of excessive alkali salts it has exterior protection against too active transpiration, consisting of a hard scale on the exterior surface of the epidermis.

The most complete set of measurements of transpiration from salt grass is that made near Independence, California.* Seven large soil tanks were established in an area of luxuriant natural salt grass. Fresh sod was placed on the soil on each tank during the early spring and the water table raised to within a few inches of the surface and then allowed to slowly recede to fixed depths, varying in the different tanks from one to seven feet. Water was introduced at the bottom from a feed tank and careful record kept of all water used by the growing plants. Root systems were not fully established the first season and it was not until the third season that dependable values were obtained for all tanks. Transpiration values were plotted against depth to water table and graphs drawn, from which transpiration can be taken off for any depth to the water table. This information is given in Tables C-24 and C-26. Due to the surroundings of these tanks a correction factor is not required for reduction of measurements to field conditions. In order to make use of the data in a salt water barrier area, however, a reduction factor is necessary in accordance with the well established fact that transpiration is proportional to evaporation.†

Measurements of salt grass transpiration extending over one season have recently been made at Santa Ana by the United States Department of Agriculture. Six tanks were used, the water table being held at two-foot depth in one set of three tanks, and at four-foot depth in the

* Transactions, American Society of Civil Engineers, Vol. 78, pages 181 to 193.
† Same, Vol. 78, pages 227 to 230.

other. This information also is given in Tables C-24 and C-26. The season's results indicate less transpiration for similar depths to water than at Independence, but the monthly values show an increasing rate of loss during the second season. It is believed that the observed monthly values at Santa Ana during the first growing season do not represent values which will be obtained when root systems have become fully established. Measurements from October, 1929, to April, 1930, however, may be reasonably close to final values for the tanks with two-foot depth to water. Values for the months of May to September, 1929, are probably as much less than those for the same months in 1930, as were the 1910 results at Independence below those of 1911. The increase at Independence from 1910 to 1911 was 30 per cent * and it is believed a similar percentage may be used to correct observed final values at Santa Ana. Such values may be used as representative of average conditions in the Suisun Bay area, where salt grass is most prevalent, since the measured annual evaporation rate at Santa Ana, as reported by the United States Department of Agriculture and corrected for large water surface (70.51 inches$\times$0.70=49.35 inches), equals that estimated for the Suisun Bay area in Table C-23.

Another and probably more accurate method for arriving at monthly values for transpiration from salt grass in the Suisun Bay area for the months of May to September, is by reduction of the 1911 measurements at Independence proportionally to the respective evaporation depths at Independence and Suisun Bay for the same months. Comparison of the evaporation depths at Independence and Suisun Bay gives a correction factor of 0.75.† The results by the two methods are practically equal for the whole year as indicated by the following tabulation:

MONTHLY TRANSPIRATION FROM SALT GRASS AT SUISUN BAY
FOR DEPTH TO WATER TABLE OF TWO FEET

Month	Computed from Santa Ana measurements	Computed from Independence measurements	
	In inches	In inches	In feet
January	0.72	0.72	0.06
February	0.92	0.92	0.08
March	1.40	1.40	0.12
April	2.90	2.90	0.24
May	3.18	4.31	0.36
June	5.72	5.17	0.43
July	7.33	6.71	0.56
August	7.20	6.90	0.58
September	4.60	4.65	0.39
October	3.52	3.50	0.29
November	2.66	2.66	0.22
December	1.64	1.64	0.14
Annual	41.79	41.48	3.47

It is believed that the monthly results computed from Independence measurements are most nearly representative of transpiration from salt grass in the Suisun Bay area for depth to water table of two feet, and these values have been adopted in this report and are given in Table C-28.

* Transactions, American Society of Civil Engineers, Vol. 78, page 192, figure 10.
† Transactions, American Society of Civil Engineers, Vol. 78, page 177.

Willow.

The willow is a water-loving tree and in semiarid and arid regions is found only where its roots can easily feed upon capillary moisture in the soil directly above a water table or adjacent to a permanently flowing stream. Freedom from alkali in the soil or high mineral content in adjacent water are necessary for its growth. The habit of growth and physiological structure of the willow is favorable among trees for relatively large transpiration losses during the growing season. It has dense foliage of thin smooth leaves, with high density of stomata per unit leaf area and leaves arranged so as to receive a maximum of direct sunlight, together with ample continuous supply of pure water at its roots. In the delta region the meteorological environment is also favorable to high transpiration rate with high percentage of sunlight hours and warm temperature.

The most extensive experimental data upon which to base computations of transpiration losses from trees are those obtained by F. R. Höhnel at the Austrian Forest Experiment Station at Mariabrumm from 1878 to 1880. The method followed was to measure, during the growing season, the water consumed by five to six-year-old seedling trees growing in pots and at the end of the season to determine the dry weight of the matured leaves, not including twig, branch or trunk. The result was expressed as pounds of water transpired per pound of dry leaf as indicated in Table C-27. These experiments give results typical of Central Europe. The first year's work was to determine the minimum amount of water necessary to maintain normal growth under the local conditions. The experiments of the second and third years were to determine the maximum amount trees would consume under most favorable atmospheric and water supply conditions. The year 1880 was particularly favorable for this purpose because of the shortage in rainfall and consequent dryness of the atmosphere. The water supply was constant and its amount limited only by the consuming ability of the trees.

Inspection of the tree varieties for which data was obtained shows that there are three broad classes of trees represented. First, broadleaf deciduous trees with normal occurrence on stream borders or in moist soil (Nos. 1 to 5); second, deciduous trees with normal occurrence away from streams in well drained soils and on hillsides (Nos. 6 to 12); and third, evergreen conifers (Nos. 13 to 16). Examination of the averages at the bottom of Table C-27 shows that the average transpiration per pound of dry leaves agrees within a reasonable range for each of these groups, being greatest for the first group and least for the third. The first group is representative of the willow, alder and cottonwood.

The water supply conditions under which willows grow in the delta correspond most nearly with those under which the experiments of 1880 were carried on, since the trees feed directly from a permanent and shallow water table. It is believed the results obtained in 1880 for the first group of trees is most representative of the willow as it grows in the delta. The average of these results is 948.6 pounds of water per pound of dry leaf substance. Correcting this for the difference in water evaporation rates (58.98/24=2.46) a value of 2330 pounds of water per pound of dry leaf substance is obtained for delta conditions.

The weight of dry willow leaves per acre of land surface varies greatly, depending upon the size and age of the trees and the proximity of adjacent trees. An isolated tree or line of trees obviously will produce a larger quantity than a thick grove where most of the foliage is at the top of the trees. The leaves from a group of year-old saplings, ten feet in height, in close growth on sandy bottom land with shallow water table, have been gathered and found to represent a dry weight per acre of 2367 pounds. For the average run of trees in the delta, 3500 pounds would probably be nearer the truth. The above values indicate a transpiration rate of

$$\frac{2330 \text{ pounds of water per pound of dry leaves} \times 3500 \text{ pounds of dry leaves per acre}}{43{,}560 \text{ square feet} \times 1 \text{ foot} \times 62.5 \text{ pounds}} = 3.00 \text{ feet in depth per annum}$$

The only available local data are those obtained by the U. S. Department of Agriculture at Santa Ana during 1930. In the early spring a clump of willow was planted in a six-foot diameter tank three feet deep, in which the water table was maintained at a depth of two feet below the surface. Very little water was lost by evaporation from the soil. The area of top foliage was approximately equal to that of the tank and the height varied from seven to eight feet. The measured transpiration was 0.415 feet for June and 0.611 feet for July. The loss during the same months from the adjacent tule tank (No. 19) was 1.92 and 2.38 feet, respectively, the willow loss thus being 21.6 and 25.6 per cent of that from the tule. It is probable that with full establishment of the willow roots this value might increase to possibly 27.5 per cent. As both willow and tule tanks were in the open and the foliage had a similar exposure, this relation may be considered as indicative of the relative transpiration rates of willow singly or in clumps, and tule in isolated tanks. For willow in large groves a correction factor of 0.5, as found for tule in tanks, may be applied to values for isolated trees. An average of the values for large groves and isolated trees may be used for trees in rank along levees. Applying these factors to monthly values of tule transpiration, as measured at Reclamation District No. 999, the corresponding values for willow transpiration are shown in the last two columns of Table C-28. The annual value of 2.64 feet for willows in large groves agrees closely with the value derived from European measurements of transpiration. The annual value of 5.29 feet for isolated trees is approximately one-half that from the tules in extensive stands and exceeds the annual evaporation from water surface in the delta. Transpiration values adopted for willow and oak are tentative and subject to change when local measurements become available. For oaks the data in Table C-27 indicates that values 60 per cent of that for willows may be used.

TABLE C-I

PROBABLE CLASSIFICATION AND ACREAGE OF EVAPORATION AND TRANSPIRATION AREAS OF A SALT WATER BARRIER LAKE FIRST FEW YEARS AFTER CONSTRUCTION OF A BARRIER

Elevation of normal water surface +2.50 feet U. S. G. S. datum

Topographic unit	Barrier site	Area of water surface in acres	Area of tule and cat-tail in acres	Area of salt grass in acres	Area of willow in acres	Area of brush and oaks in acres	Area of weeds in acres	Agricultural land			Area of bare levee and roads in acres	Total
								Irrigated area in acres	Non-irrigated area in acres	Idle area in acres		
San Pablo Bay	San Pablo to Dillon Point	79,890	6,150	24,870	-	20	2,820	350	23,910	-	1,190	139,200
Suisun Bay	Dillon Point to Benicia	1,330	110	160	-	-	-	-	-	-	-	1,600
Suisun Bay	Benicia to Chipps Island	32,160	16,160	37,060	-	20	1,020	720	3,240	-	1,570	91,950
Suisun Bay	Above Chipps Island	2,860	1,440	4,110	-	-	20	-	480	-	240	9,150
Delta	Above Chain Island	[1]54,300	7,400	-	5,600	1,800	3,700	321,800	64,000	26,300	3,700	[2]488,600
Totals		170,540	31,260	66,200	5,600	1,840	7,560	322,870	91,630	26,300	6,700	730,500

[1] Includes 1100 acres of water surface between delta boundary and stream gaging stations. Total area of water surface in delta equals 53,200 acres.
[2] This total area includes 1100 acres of water surface between delta boundary and stream gaging stations. Total gross area of delta equals 487,500 acres.

TABLE C-2

AVERAGE MONTHLY TEMPERATURES AT ALL STATIONS IN VICINITY OF A SALT WATER BARRIER

All averages obtained from Climatology of California (Bulletin L), Summary of Climatological Data for California by Sections, published in 1922 and 1923, or from Annual Summaries of Climatological Data, as published by U. S. Weather Bureau and based on ten years or more of record, except as noted.

Station	Temperature in degrees Fahrenheit												
	January	February	March	April	May	June	July	August	September	October	November	December	Average
Alvarado (near[1])	47.8	52.0	54.8	56.4	58.6	61.3	62.9	61.9	61.6	59.1	54.3	49.8	56.7
Antioch	47.6	51.3	55.8	61.5	66.4	73.6	77.2	75.7	72.8	64.8	55.0	48.9	62.6
Auburn	45.0	48.2	51.2	56.1	62.4	71.4	77.0	76.0	69.2	62.4	52.0	46.5	59.8
Berkeley	48.0	50.8	52.6	55.7	57.7	61.0	62.0	61.8	62.7	60.2	54.4	49.0	56.3
Brooks[4]	44.5	50.4	53.6	57.7	66.9	74.1	80.6	77.6	72.5	63.8	54.3	46.7	61.9
Byron	46.4	50.4	56.4	61.5	67.1	75.5	80.9	77.5	71.8	63.3	53.9	47.8	62.8
Calistoga	48.1	50.1	53.5	57.8	61.5	69.6	72.6	70.3	66.7	60.0	53.4	49.2	59.4
Cloverdale	46.8	50.2	52.9	57.0	60.8	67.0	70.8	70.2	67.8	61.6	53.8	47.6	58.9
Colusa	45.6	49.4	53.5	58.2	64.7	71.8	76.8	75.2	69.7	61.8	52.3	44.9	60.3
Crockett	47.7	52.2	54.5	57.6	60.5	64.6	66.2	66.7	65.8	61.9	55.6	47.9	58.4
Davis	44.6	48.6	52.9	57.2	63.1	70.0	74.6	73.2	69.2	61.4	51.8	44.6	59.3
Denair	45.0	48.2	53.3	57.7	63.8	71.1	76.4	75.0	69.8	61.8	51.0	44.9	59.8
Dunnigan	46.3	49.2	55.0	62.4	70.3	77.9	81.8	79.7	74.6	69.3	55.0	47.3	64.1
East Park	43.0	46.4	49.7	55.2	62.2	70.6	76.8	71.2	68.6	58.8	50.6	43.6	58.1
Farmington	45.7	50.1	53.9	59.1	66.1	73.7	78.2	76.2	72.0	63.7	54.7	47.0	61.7
Folsom	46.6	50.2	54.2	59.5	65.4	73.2	79.6	77.4	72.8	64.0	54.3	47.1	62.0
Galt	47.3	50.3	55.2	61.2	67.1	74.6	79.0	77.4	72.0	63.0	54.0	48.7	62.5
Georgetown	46.4	48.4	51.9	55.4	62.4	70.9	78.8	77.9	73.3	63.6	55.4	48.5	61.0
Grafton	46.1	49.6	51.9	55.4	57.8	62.0	64.7	64.4	64.0	59.6	52.5	46.4	56.2
Healdsburg	46.6	50.4	53.2	57.4	61.3	66.7	69.3	68.4	66.8	61.3	53.2	46.9	58.4
Hollister	47.2	50.2	52.4	55.2	57.7	62.4	64.8	64.7	63.9	60.0	53.2	47.2	56.6
Hullville	40.7	43.4	47.5	51.3	56.3	63.2	71.0	71.0	65.4	58.1	49.0	42.2	55.0
Independence	38.2	42.2	48.5	55.1	63.0	72.3	78.1	76.1	68.0	57.5	47.2	39.3	57.1
Ione	46.6	49.2	53.9	58.7	65.0	73.6	78.6	78.1	71.6	58.7	53.4	48.2	61.6
Kentfield	45.7	49.2	51.8	55.6	57.6	62.8	66.0	64.6	64.3	59.2	52.4	46.3	56.3
Knights Landing	46.8	50.3	54.8	59.2	66.6	72.3	77.4	76.6	70.9	62.7	54.1	48.4	61.6
Lick Observatory	40.2	40.3	41.8	46.3	51.0	60.2	69.5	68.8	62.8	54.8	47.7	42.4	52.1
Livermore	48.6	51.5	53.6	56.9	61.1	69.2	70.3	69.9	68.3	62.6	54.7	49.3	59.6
Lodi	46.2	50.1	54.7	58.3	63.4	69.1	73.7	73.0	69.7	62.3	53.6	47.3	60.1
Los Banos	48.8	50.9	55.4	62.6	68.3	75.4	80.0	78.8	72.8	64.6	55.2	48.6	63.4
Los Gatos	47.7	50.0	52.3	56.3	59.7	64.8	67.8	67.2	65.6	60.8	54.0	48.4	57.9
Martinez	46.4	49.2	52.9	57.0	61.2	66.7	68.4	66.5	64.9	59.7	53.0	47.8	57.8
Marysville	45.8	49.9	54.3	59.4	64.8	72.8	77.8	76.2	70.9	63.3	53.2	46.7	61.3
Merced	45.6	49.6	53.6	58.3	64.5	72.8	79.0	77.0	71.4	62.6	52.4	45.7	61.0
Milton (near)	46.7	50.6	51.8	58.1	63.7	72.2	78.0	74.2	71.7	64.4	55.1	46.9	61.1
Modesto	46.6	50.1	55.9	62.2	69.4	76.6	81.5	79.7	74.7	65.3	55.8	48.1	63.8
Mokelumne Hill	44.0	47.1	49.4	54.6	59.4	68.8	76.7	74.7	68.5	60.9	52.1	44.6	58.4

Monterey	50.2	51.2	53.9	55.8	58.2	60.8	61.0	61.9	61.5	58.2	54.3	51.7	56.6
Mt. Tamalpais	43.8	45.2	46.9	50.8	54.1	62.1	67.4	68.4	65.0	58.6	50.6	45.2	54.8
Napa	46.8	50.1	52.2	55.8	59.2	64.9	66.8	66.2	65.6	61.0	53.4	47.8	57.5
Nevada City	40.8	42.8	45.0	50.4	55.1	62.6	68.8	68.0	63.1	55.8	48.2	41.9	53.6
Newman	46.9	51.3	55.2	61.1	67.7	75.2	80.3	75.6	72.2	64.3	54.9	46.9	62.6
Niles (near)	51.7	54.4	56.7	59.9	62.9	67.2	68.9	69.0	68.3	62.3	56.8	52.4	60.9
Oakdale (near)	45.1	48.5	53.1	57.4	63.8	72.1	78.0	76.7	70.8	62.8	54.2	44.7	60.6
Oakland	48.1	50.8	53.1	56.4	58.6	62.3	63.2	62.5	63.0	59.7	54.2	48.6	56.7
Oakville	43.6	47.2	49.8	54.3	58.0	62.6	66.0	64.6	63.8	58.9	50.8	43.8	55.3
Palo Alto[2]	47.2	52.4	54.1	56.7	60.5	64.4	65.3	64.6	62.9	60.1	54.2	48.1	57.5
Petaluma	45.8	49.8	52.0	54.6	57.2	62.2	65.2	65.4	64.0	59.8	52.6	47.2	56.4
Placerville	41.8	44.4	47.2	52.1	56.2	65.8	72.2	69.4	64.2	55.7	47.4	42.0	54.8
Point Reyes	49.4	49.9	50.3	50.6	51.2	52.4	53.6	54.5	56.4	55.5	53.8	50.7	52.4
Rio Vista[3]	45.6	50.8	54.3	58.0	63.6	70.4	74.5	72.6	69.3	62.4	53.7	45.4	60.0
Rocklin	45.4	49.2	52.8	58.0	63.1	70.3	76.4	74.9	70.3	63.0	53.0	45.6	60.2
Sacramento	45.8	50.1	54.3	58.1	63.3	69.4	73.3	73.0	69.3	62.9	53.6	46.2	60.0
St. Helena	46.2	48.8	52.5	57.0	61.0	67.0	70.8	69.4	66.2	60.4	52.8	46.4	58.2
Salinas	50.2	51.4	53.2	55.6	57.7	59.4	61.7	61.8	62.4	58.9	53.8	49.6	56.4
San Francisco	49.9	52.2	54.2	55.0	56.8	58.5	58.5	59.1	60.9	60.5	56.3	51.3	56.1
San Jose	48.1	50.9	53.1	56.3	58.5	62.7	66.5	66.1	64.2	60.1	53.2	47.7	57.3
Santa Clara	48.0	50.6	52.8	56.0	58.4	63.0	66.1	65.8	64.4	59.8	53.5	48.2	57.2
Santa Cruz	49.2	50.8	52.8	55.2	56.8	60.4	61.9	62.3	62.0	58.8	54.0	49.4	56.0
Santa Rosa	46.2	49.0	51.2	54.4	57.6	63.0	65.2	64.4	63.8	59.0	51.8	46.8	56.0
Sonoma	49.0	50.0	52.3	54.6	59.2	61.6	65.4	65.6	64.7	60.4	55.4	48.5	57.2
Sonora	44.7	48.0	51.2	56.7	62.5	70.3	76.7	74.9	68.9	59.1	51.6	45.4	59.0
Stockton	45.1	49.6	52.6	57.4	62.2	69.6	73.2	71.8	68.6	61.3	52.2	44.6	59.0
Suisun	47.2	51.5	55.8	59.9	63.8	68.3	71.1	70.7	69.8	63.0	54.8	48.6	60.4
Tracy	46.9	50.5	54.8	60.9	69.1	75.9	79.9	77.5	72.0	63.5	54.2	49.6	62.9
Ukiah	44.5	47.8	50.2	55.1	59.2	65.8	71.7	70.9	65.9	60.0	50.2	44.6	57.1
Upper Lake	44.0	47.0	49.2	54.8	59.5	66.7	73.9	73.1	66.9	59.4	50.8	44.4	57.6
Vacaville	46.8	50.1	53.6	57.6	62.8	68.2	74.0	73.4	69.4	62.6	54.4	47.7	60.1
Valley Springs	46.8	51.2	54.8	60.9	66.2	74.1	80.0	77.9	72.1	64.3	56.4	47.9	62.7
Walnut Creek	46.7	50.9	54.0	58.1	63.0	69.2	74.0	72.1	68.8	62.0	-----	-----	56.6
Watsonville	49.2	51.2	52.6	54.8	57.2	59.8	60.6	60.7	60.6	58.0	53.6	49.6	55.7
Westley	47.8	51.9	56.2	64.0	70.1	77.6	82.7	79.2	74.0	66.8	56.7	48.5	64.6
Wheatland	45.0	49.6	52.7	58.2	63.6	71.2	76.5	74.4	69.2	61.0	51.8	44.0	59.8
Williams	46.1	50.0	54.6	61.1	69.3	78.1	83.5	81.0	74.2	64.5	54.0	47.2	63.6
Winters	46.9	51.5	56.0	63.1	70.6	79.6	85.5	81.3	74.6	66.9	56.3	48.4	65.1
Woodland	46.2	49.9	54.5	59.9	66.9	74.3	78.7	76.2	71.1	63.7	54.8	48.4	62.0

[1] Six year averages.
[2] Seven year averages.
[3] Eight year averages.
[4] Nine year averages.

TABLE C-3

AVERAGE MONTHLY RELATIVE HUMIDITY AT VARIOUS HOURS OF THE DAY FOR ALL STATIONS IN VICINITY OF A SALT WATER BARRIER

Records from U. S. Weather Bureau and exceeding ten years in length, except as noted

Station	Relative humidity as per cent												
	January	February	March	April	May	June	July	August	September	October	November	December	Average
Maximum Observations													
Crockett[1]	92	94	92	91	86	86	86	87	87	86	89	92	89
5 a.m. Observations													
Fresno	87	84	84	77	70	56	48	52	60	71	78	87	73
Independence	69	66	57	47	46	37	36	40	41	50	57	61	51
Mt. Tamalpais	77	77	76	68	67	53	43	44	52	58	69	73	63
Sacramento	88	87	84	81	82	77	78	78	76	76	83	90	82
San Francisco	85	84	83	83	85	88	92	92	88	85	84	83	86
Red Bluff	86	85	82	75	69	58	51	52	57	66	77	85	70
8 a.m. Observations													
Berkeley[2]	89	86	87	84	83	82	86	87	86	85	85	86	85

Noon Observations[5]

Davis[3]	80	64	62	52	45	35	35	38	34	43	59	74	52
Fresno	63	60	55	37	33	26	22	24	32	39	50	69	42
Independence	22	38	28	16	20	14	16	16	20	24	22	36	23
Hercules[4]	76	74	75	67	62	56	61	62	61	64	63	73	66
Red Bluff	66	58	56	45	37	32	26	28	38	47	56	68	46
Sacramento	80	73	65	56	46	43	41	42	46	51	63	82	57
San Francisco	69	68	61	59	63	63	70	70	62	57	63	71	64
San Jose	64	65	62	50	50	46	50	49	50	53	58	71	56

Minimum Observations

Crockett[1]	66	57	53	52	48	44	42	44	43	45	51	62	51

5 p.m. Observations

Fresno	66	55	48	34	26	18	14	15	22	34	48	67	39
Independence	50	40	28	22	20	16	17	17	20	28	35	45	28
Mt. Tamalpais	76	78	75	64	62	48	39	40	47	55	69	73	60
Point Reyes	86	86	85	84	87	88	90	91	91	86	85	85	87
Red Bluff	69	57	51	40	35	28	18	20	27	36	52	68	42
Sacramento	76	64	56	48	43	36	32	34	36	42	56	74	50
San Francisco	72	70	67	67	70	71	76	78	71	68	68	72	71
San Jose	68	63	61	55	54	51	52	53	53	54	61	70	58

8 p.m. Observations

Berkeley[2]	82	85	87	85	85	84	85	87	85	83	82	84	84

[1] From original records of California and Hawaiian Sugar Refining Corporation, Ltd., 1923-1930.
[2] From Meteorological Synopsis (35 years) publication University of California, 1922.
[3] From original records of University of California, 1926-1930.
[4] From original records of Hercules Powder Company, 1927-1930.
[5] Records less than ten years, except Fresno and San Francisco.

TABLE C-4

LIST OF WIND MOVEMENT RECORDS AT ALL STATIONS IN VICINITY OF A SALT WATER BARRIER

Location	Authority	Reference	Length record	Anemometer equipment		
				Type	Setting	Height above average ground surface in feet
Alvarado	U. S. Weather Bureau	Climatological Summary, 1922	7 years	4-cup	Same wooden support as pan	$1\frac{3}{4}$
Berkeley	University of California	Meteorological Synopsis	6 years	4-cup	10-foot support on building	85 approximately
Davis	University of California	Original record	5 years	4-cup	Same wooden support as pan	$1\frac{3}{4}$
Fresno	U. S. Weather Bureau	Climatological Summary, 1922	35 years	4-cup	Tower on building	98
Independence	U. S. Weather Bureau	Climatological Summary, 1922	21 years	4-cup	Tower	25
Mt. Tamalpais	U. S. Weather Bureau	Climatological Summary, 1922	22 years	4-cup	Tower	18
Oakdale	U. S. Weather Bureau	Annual summaries	10 years	4-cup	Same wooden support as pan	$1\frac{3}{4}$
Oakland	Chabot Observatory	Original record	10 years	4-cup	6-foot pole on building	26
Point Reyes	U. S. Weather Bureau	Climatological Summary, 1922	31 years	4-cup	Tower	50
Sacramento	U. S. Weather Bureau	Climatological Summary, 1922	30 years	4-cup	Tower on building	117
San Francisco	U. S. Weather Bureau	Climatological Summary, 1922	52 years	4-cup	40-foot tower on building	243
San Jose	U. S. Weather Bureau	Climatological Summary, 1922	15 years	4-cup	20-foot tower on building	110
Selby	American Smelting and Refining Company	Original record	1 year	4-cup	18-foot tower on bluff	210
Suisun Bay (Freeman Island)	U. S. Engineering Department	Original record	3 months	3-cup	On float	1
Suisun Bay (Noyce Slough)	U. S. Engineering Department	Original record	3 months	3-cup	On float	1

TABLE C-5

AVERAGE MONTHLY WIND MOVEMENT AT ALL STATIONS IN VICINITY OF A SALT WATER BARRIER

Records from U. S. Weather Bureau exceeding ten years in length, except as noted

Station	Total in miles												
	January	February	March	April	May	June	July	August	September	October	November	December	Average
Alvarado[3] (near)	2,153	3,231	3,548	4,065	4,505	4,010	4,408	4,375	3,655	3,240	2,624	2,617	3,536
Berkeley[2]	3,618	4,228	4,119	4,313	4,668	4,651	4,956	4,434	3,818	3,436	3,686	3,978	4,159
Davis[4]	873	1,196	1,078	1,022	1,158	1,109	956	872	1,004	929	950	1,134	1,023
Fresno	3,348	3,254	4,241	4,896	5,803	5,976	5,506	4,985	4,248	3,497	2,952	3,050	4,313
Independence	4,762	4,882	6,770	6,336	6,216	5,688	5,282	4,836	4,608	4,687	4,536	4,910	5,293
Mt. Tamalpais	15,029	13,019	13,541	13,752	14,582	13,320	11,234	10,267	11,016	11,978	13,320	15,475	13,044
Oakdale (near)	3,223	3,490	3,399	3,285	3,896	4,329	4,197	4,730	4,030	3,381	2,929	3,563	3,704
Oakland[1]	2,983	2,711	2,390	2,489	2,630	2,573	2,667	2,480	1,930	1,984	2,285	3,421	2,545
Point Reyes	13,169	13,293	15,550	17,136	19,567	19,296	16,740	14,806	13,104	12,722	11,952	12,425	14,980
Sacramento	5,729	5,492	6,250	6,336	6,696	6,408	6,398	6,175	5,328	4,985	4,680	5,059	5,795
San Francisco	5,506	5,085	6,547	7,272	8,333	9,072	9,746	9,002	7,272	5,803	4,824	5,059	6,960
San Jose	4,613	4,136	4,315	4,464	4,687	4,464	4,538	4,241	3,672	3,571	3,528	4,166	4,200
Selby[5]	7,466	5,507	7,592	8,544	10,532	10,802	12,507	11,388	8,343	7,347	5,556	7,604	8,599
Suisun Bay[6] (Freeman Island)	----------	----------	----------	----------	5,986	6,106	6,741	----------	----------	----------	----------	----------	----------
Suisun Bay[6] (Noyce Slough)	----------	----------	----------	----------	6,232	7,087	7,614	----------	----------	----------	----------	----------	----------

[1] From original records at Chabot Observatory, 1920-1930.
[2] From Meteorological Synopses, University of California, 1924-1930.
[3] Seven-year averages.
[4] From original records at University of California Farm, 1926-1930.
[5] From original records of American Smelting and Refining Company, at Selby, July, 1929, to June, 1930.
[6] From original records of U. S. Engineering Department, May to July, 1930.

TABLE C-6

AVERAGE MONTHLY PRECIPITATION AT TYPICAL STATIONS IN VICINITY OF A SALT WATER BARRIER

Records from U. S. Weather Bureau and exceeding ten years in length

Station	Precipitation in inches												
	January	February	March	April	May	June	July	August	September	October	November	December	Average annual
Antioch	2.81	2.03	1.95	0.70	0.42	0.10	*T	0.02	0.36	0.58	1.25	2.46	12.68
Berkeley	5.59	4.42	3.98	1.37	1.03	0.19	0.02	0.05	0.61	1.25	2.46	4.49	25.46
Davis	3.87	2.81	2.41	1.09	0.63	0.14	0.01	0.01	0.33	0.72	1.61	3.40	17.03
Kentfield	10.49	8.22	6.97	2.46	1.91	0.39	0.01	0.02	0.91	2.57	4.79	8.40	47.14
Lodi	4.06	2.74	3.50	1.09	1.08	0.20	T	0.02	0.40	1.03	1.95	3.16	19.23
Napa	5.26	3.88	3.34	1.72	0.85	0.19	0.01	0.02	0.52	1.11	2.38	4.18	23.46
Niles	3.69	3.07	2.94	1.40	0.74	0.19	T	0.03	0.29	1.01	2.08	3.35	18.79
Oakdale (near)	2.87	2.21	2.58	1.14	0.64	0.14	T	0.01	0.25	0.67	1.43	2.27	14.21
Oakland	5.13	3.88	3.64	1.55	0.84	0.26	0.02	0.04	0.52	1.29	2.57	4.04	23.78
Petaluma	5.52	3.89	2.71	1.58	0.74	0.19	0.02	0.01	0.32	1.06	2.46	5.10	23.62
Rio Vista	4.34	2.94	2.55	0.80	0.68	0.15	T	0.02	0.51	0.87	1.66	2.87	17.39
Sacramento	3.72	3.02	2.57	1.51	0.78	0.15	0.00	0.00	0.38	0.92	1.88	3.03	17.96
San Francisco	4.54	3.85	3.14	1.61	0.80	0.08	0.02	0.01	0.45	1.12	2.35	3.95	22.02
San Jose	3.00	2.39	2.60	1.08	0.53	0.11	0.00	0.02	0.35	0.73	1.47	2.59	14.87
Santa Clara	3.34	2.62	2.79	0.93	0.58	0.14	T	0.03	0.44	0.78	1.54	2.95	16.14
Stockton	3.04	2.29	2.15	1.03	0.63	0.11	T	0.01	0.28	0.64	1.46	2.71	14.35
Vacaville	6.19	3.93	3.82	1.74	1.16	0.12	0.00	0.03	0.37	1.16	2.63	5.38	26.53

* Trace.

TABLE C-7

LIST OF FRESH-WATER EVAPORATION RECORDS IN VICINITY OF A SALT WATER BARRIER

Location	Authority	Reference	Length of record	Equipment			Observed annual depth of evaporation in inches	Coefficient for adjustment to large water surface	Adjusted annual depth of evaporation in inches
				Type	Size	Setting			
Alvarado (near)	U. S. Weather Bureau	Climatological data	6 years	Class A land pan	4 feet in diameter, 10 inches deep.	On wooden platform	54.760	0.70	38.33
Alviso (near)	Alviso Salt Company	Correspondence	1 year	Class A land pan	4 feet in diameter, 10 inches deep.	On wooden platform	57.816	0.70	40.47
Mountain View	U. S. Department of Agriculture.	Hilgardia Vol. 2, No. 6, page 200.	9 months	Ground tank	3 feet in diameter, 3 feet deep.	In ground 2.75 feet	Incomplete	0.82	....
Lake Chabot	E. B. W. Co.* and E. B. Mun. Utility Dist.	Correspondence	6 years	Floating pan	21 inches in diameter, 10 inches deep.	Submerged	47.34	0.825	39.06
Upper San Leandro Reservoir.	E. B. W. Co. and E. B. Mun. Utility Dist.	Correspondence	2 years (broken)	Floating pan	3 by 3 feet square, 18 inches deep.	Submerged	48.25	0.89	42.90
San Pablo Reservoir (dam).	E. B. W. Co. and E. B. Mun. Utility Dist.	Correspondence	7 years	Floating pan	3 by 3 feet square, 18 inches deep.	Submerged	47.60	0.89	42.30
San Pablo Reservoir outlet tower.	E. B. W. Co. and E. B. Mun. Utility Dist.	Correspondence	6 years	Floating pan	3 by 3 feet square, 18 inches deep.	Submerged	46.58	0.89	41.45
Berkeley, University of California Campus.	U. S. Department of Agriculture.	Bulletin 177, office of Experiment stations.	1 year	Ground tank	22 inches in diameter, 28 inches deep.	In ground	41.55	0.76	31.58
Davis, University of California Campus.	University of California Agricultural Experiment Station.	Correspondence and original records.	5 years	Class A land pan	4 feet in diameter, 10 inches deep.	On wooden platform	64.283	0.70	45.00
King Island	U. S. Department of Agriculture.	Correspondence	5 years partial and broken	Land tank	34 inches in diameter, 29 inches deep.	In ground 26 inches	Incomplete	0.81	....
Medford Island	U. S. Department of Agriculture.	Correspondence	1 year partial	Land tank	34 inches in diameter, 29 inches deep.	In ground 26 inches	Incomplete	0.81	....

* East Bay Water Company and East Bay Municipal Utility District.

TABLE C-7—Continued

LIST OF FRESH-WATER EVAPORATION RECORDS IN VICINITY OF A SALT WATER BARRIER

Location	Authority	Reference	Length of record	Equipment			Observed annual depth of evaporation in inches	Coefficient for adjustment to large water surface	Adjusted annual depth of evaporation in inches
				Type	Size	Setting			
Reclamation District 999 (near Clarksburg).	U. S. Department of Agriculture.	Correspondence	3 years partial and broken	Land tank	34 inches in diameter, 29 inches deep.	In ground 26 inches	Incomplete	0.81	----------
Oakdale, Woodward Reservoir.	U. S. Department of Agriculture.	Climatological data	12 years	Land tank	4 feet in diameter, 10 inches deep.	On wooden platform	82.85	0.70	58.00
Suisun Bay (deep water near Freeman Island).	U. S. Engineering Department.	Original records	3 months	Floating pan	4 feet in diameter, 18 inches deep.	Partially submerged	Incomplete	0.96	----------
Suisun Bay (shallow water in Noyce Slough).	U. S. Engineering Department.	Original records	3 months	Floating pan	4 feet in diameter, 18 inches deep.	Partially submerged	Incomplete	0.96	----------

TABLE C-8

RECORD OF MONTHLY EVAPORATION NEAR ALVARADO

From records of U. S. Weather Bureau. Class A Land Pan; four feet in diameter

Month	Depth in inches							
	1924	1925	1926	1927	1928	1929	1930	Average
January	----------	2.111	----------	1.004	1.312	1.095	1.462	1.397
February	----------	2.246	----------	2.890	2.470	2.635	2.273	2.503
March	----------	4.201	4.850	3.509	3.222	3.984	4.180	3.991
April	----------	4.909	4.978	5.162	5.129	4.876	5.630	5.114
May	----------	6.092	7.262	7.013	6.075	6.740	6.612	6.632
June	----------	8.222	7.304	6.922	7.623	7.134	7.604	7.468
July	----------	8.453	7.850	7.599	6.912	8.082	7.751	7.774
August	6.643	7.234	6.638	6.413	5.797	6.898	----------	6.604
September	6.028	6.061	5.964	5.431	4.801	4.845	----------	5.522
October	3.861	4.181	3.479	3.709	3.611	4.007	----------	3.808
November	2.962	2.307	2.735	1.854	1.829	2.168	----------	2.309
December	2.235	1.840	2.194	1.305	0.976	1.279	----------	1.638
Annual	----------	57.677	----------	52.811	49.757	53.743	----------	54 760

Correction factor for large fresh-water surface—0.70 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373).

TABLE C-9

RECORD OF MONTHLY EVAPORATION AT ALVISO

From records of Alviso Salt Company. Class A Land Pan, U. S. Weather Bureau type; four feet in diameter

Month	Depth in inches		
	1929	1930	Average
January	----------	0.678	0.678
February	----------	1.929	1.929
March	----------	4.030	4.030
April	5.103	5.754	5.428
May	7.671	7.348	7.510
June	7.912	----------	7.912
July	8.915	----------	8.915
August	8.082	----------	8.082
September	4.688	----------	4.688
October	4.417	----------	4.417
November	2.338	----------	2.338
December	1.889	----------	1.889
Annual	----------	----------	57.816

Correction factor for large fresh-water surface—0.70.

TABLE C-10

RECORD OF ADJUSTED MONTHLY EVAPORATION AT LAKE CHABOT

From records kept by Peoples Water Company and East Bay Water Company, prepared by Hydrographic Division, East Bay Municipal Utility District, L. Standish Hall, chief hydrographer. Floating Pan, 21 inches in diameter.

Month	Depth in inches								
	1917	1918	1919	1920	1921	1922	1923	1924	Average
January	---------	1.60	---------	---------	2.21	0.97	1.77	3.04	1.92
February	1.12	0.32	---------	---------	2.40	0.74	2.49	2.66	1.62
March	1.16	1.02	---------	---------	3.25	0.94	4.73	2.11	2.20
April	1.84	3.17	---------	---------	4.88	2.10	2.80	2.83	2.94
May	4.61	6.43	---------	---------	4.31	3.41	4.29	4.20	4.54
June	5.94	6.65	---------	6.38	7.80	5.96	4.85	3.83	5.92
July	6.72	7.22	---------	6.65	7.68	7.38	6.12	4.89	6.66
August	6.85	5.13	---------	6.86	6.06	6.89	6.93	4.76	6.21
September	5.92	---------	---------	6.16	6.72	6.19	6.05	3.89	5.82
October	5.31	---------	---------	4.26	5.85	3.85	5.34	---------	4.92
November	3.18	---------	---------	1.56	4.25	2.71	3.25	---------	2.95
December	2.10	---------	---------	0.88	1.35	1.51	2.50	---------	1.67
Annual	---------	---------	---------	---------	---------	---------	---------	---------	47.34

Correction factor for large fresh-water surface —0.825.

Exterpolated on curve U. S. Geological Survey, Standard Floating Pan for area 3.06 square feet, figure 9, page 309, Vol. 90, Transactions, American Society of Civil Engineers.

TABLE C-11

RECORD OF MONTHLY EVAPORATION AT UPPER SAN LEANDRO RESERVOIR

From records of East Bay Municipal Utility District. Floating Pan (No. 5); three by three feet square.

Month	Depth in inches						
	1925	1926	1927	1928	1929	1930	Average
January	---------	1.54	---------	---------	---------	---------	1.54
February	[1]1.14	1.95	---------	---------	---------	1.09	1.52
March	3.85	2.67	---------	---------	---------	2.54	3.02
April	3.04	3.96	---------	---------	---------	4.00	3.67
May	3.64	4.65	---------	4.72	---------	5.04	4.51
June	6.70	8.35	---------	9.30	4.32	---------	7.17
July	7.60	---------	---------	6.26	8.12	---------	7.33
August	6.10	---------	---------	6.00	7.52	---------	6.54
September	5.10	---------	---------	6.51	5.72	---------	5.78
October	3.50	---------	---------	4.02	[2]2.44	---------	3.76
November	2.00	---------	---------	---------	---------	---------	2.00
December	1.41	---------	---------	---------	---------	---------	1.41
Total	---------	---------	---------	---------	---------	---------	48.25

[1] Record begins February 6, 1925.

[2] Record ran October 1 to 12 only.

Correction factor for large fresh-water surface —0.89 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373).

TABLE C-12

RECORD OF MONTHLY EVAPORATION AT SAN PABLO RESERVOIR

From records of East Bay Municipal Utility District. Floating Pan (No. 1) near dam; three by three feet square.

Month	Depth in inches										
	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	Average
January	----------	----------	0.63	1.56	0.87	[1]1.18	[1]0.69	[1]0.95	[1]0.85	----------	0.96
February	----------	----------	1.71	1.59	[1]0.73	[1]1.46	[1]0.20	1.66	[1]1.92	1.14	1.30
March	----------	----------	3.30	[2]3.28	3.18	[1]3.52	2.29	[1]1 44	1.93	2.22	2.65
April	----------	5.68	3.87	[1]4.40	3.59	3.61	[1]2.80	[1]3.65	3.42	3.41	3.83
May	----------	5.05	6.03	6.13	4.81	6.22	6.14	5.05	5.62	4.36	5.49
June	----------	5.54	4.43	[2]7.29	[2]6.62	[1]7.24	[2]5.75	7.22	[1]5.90	----------	6.37
July	----------	6.08	7.48	[2]6.86	[1]6.62	7.69	7.33	[2]5.34	[1]7.12	----------	6.82
August	----------	8.10	6.46	[2]6.67	6.38	[1]6.99	6.14	[2]5.44	[1]5.94	----------	6.52
September	----------	5.89	6.25	6.69	5.25	[1]5.51	6.12	5.01	----------	----------	5.83
October	5.43	2.17	4.61	[1]3.23	[1]4.40	[1]3.44	4.40	3.81	----------	----------	3.94
November	3.36	2.40	2.78	2.12	2.62	[1]1.37	1.48	[2]2.48	----------	----------	2.33
December	2.42	0.50	1.77	[1]0.89	1.70	[1]2.15	[2]1.40	[2]1.60	----------	----------	1.56
Total	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	47.60

[1] One or more days estimated.
[2] Record doubtful due to wind action one or more days.
Correction factor for large fresh-water surface —0.89 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373)

TABLE C-13

RECORD OF MONTHLY EVAPORATION AT SAN PABLO RESERVOIR

From records of East Bay Municipal Utility District. Floating Pan (No. 3) near outlet tower; three by three feet square

Month	Depth in inches									
	1921	1922	1923	1924	1925	1926	1927	1928	1929	Average
January			0.99	0.70	[1]0.96	1.05	[1]0.52	[1]0.89	0.78	0.84
February			1.26	1.68		0.98		1.48	1.93	1.05
March			3.10	[2]3.46		[1]2.59	[1]2.26	[2]1.08	2.30	2.11
April		3.71	4.05	[1]4.13		3.96	[1]3.77	[1]3.59	3.51	3.82
May		5.24	7.21	[1]6.69		5.56	[1]5.84	4.36	5.80	5.81
June		6.52	5.91	[2]7.93			[1]5.70	7.13	6.35	6.59
July		6.08	8.19	[2]7.82			7.49	[2]5.47	[1]7.23	7.05
August		6.56	7.42	6.69			5.84	5.53	6.09	6.35
September		5.61	7.42	7.46		[1]5.89	[1]5.22	4.94		5.22
October		2.79	5.99	4.01	4.56	[2]3.49	[2]4.47	2.61		3.99
November		2.76	3.16	2.10	2.30	[2]2.43	1.67	[2]2.22		2.38
December		0.46	1.59	0.74	1.51	[1]2.26	[1]1.31	[2]1.70		1.37
Total										46.58

[1] One or more days estimated.
[2] Record doubtful due to wind action one or more days.
Correction factor for large fresh-water surface —0.89 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373).

TABLE C-14

RECORD OF MONTHLY EVAPORATION AT BERKELEY

From records of U. S. Department of Agriculture, Experiment Station, University of California Campus. (See Bulletin No. 177, page 36.) Tank set in ground; diameter 22 inches; depth 28 inches.

Month	Depth in inches	
	1904	1905
January	----------	1.00
February	----------	1.36
March	----------	2.11
April	----------	3.14
May	----------	4.70
June	----------	5.68
July	----------	5.52
August	----------	5.09
September	----------	4.65
October	2.84	4.27
November	1.44	2.68
December	1.01	1.35
Annual	----------	41.55

Correction factor for large fresh-water surface —0.76 (Interpolated from Figure 9, page 309, Vol. 90, Transactions American Society of Civil Engineers).

TABLE C-15

RECORD OF MONTHLY EVAPORATION AT DAVIS

From original records of University of California Farm. Class A Land Pan U. S. Weather Bureau type; four feet in diameter.

Month	Depth in inches					
	1926	1927	1928	1929	1930	Average
January	----------	[2]0.898	[1]0.921	----------	----------	0.920
February	----------	----------	1.813	2.305	2.089	2.069
March	----------	2.966	1.928	3.733	[1]3.346	2.993
April	----------	5.276	4.794	5.064	4.196	4.833
May	7.799	8.165	8.584	9.025	6.340	7.983
June	[1]10.286	9.320	----------	[2]8.636	9.555	9.449
July	11.287	10.567	10.249	10.469	----------	10.643
August	9.652	8.745	9.904	[3]9.352	----------	9.413
September	7.867	7.688	7.720	6.848	----------	7.531
October	4.350	4.926	4.995	5.212	----------	4.871
November	1.970	1.344	1.881	3.408	----------	2.151
December	1.450	1.404	----------	----------	----------	1.427
Annual	----------	----------	----------	----------	----------	64.283

Correction factor for large fresh-water surface—0.70 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373).

[1] One day estimated.
[2] Two days estimated.
[3] Three days estimated.

TABLE C-16

RECORD OF MONTHLY EVAPORATION AT RECLAMATION DISTRICT No. 999, NEAR CLARKSBURG

From records of U. S. Department of Agriculture, Bureau of Public Roads, Division of Agricultural Engineering. Tank set in ground; diameter 34 inches; depth 29 inches.

Month	Depth in inches			
	1926	1927	1928	Average
January				
February				
March				
April				
May		9.36		9.36
June	12.7	9.1		10.92
July	12.0	10.3	10.7	11.03
August	8.2	9.1	9.1	8.76
September	7 2		7.7	7.45
October			5.3	5.30
November				
December				
Year				

Correction factor for large fresh-water surface —0.81 (Interpolated from Figure 9, cylindrical ground tanks, Transactions, American Society of Civil Engineers, Vol. 90, page 309).

TABLE C-17

RECORD OF MONTHLY EVAPORATION NEAR OAKDALE

From records of U. S. Weather Bureau. Class A land pan; four feet in diameter

Month	Depth in inches													
	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	Average
January	-------	1.622	1.469	1.261	1.085	0.832	1.485	0.830	-------	1.144	0.952	1.000	1.140	1.165
February	-------	1.676	2.304	1.694	1.882	1.518	2.162	1.762	1.893	2.434	1.699	2.668	1.861	1.963
March	-------	3.359	3.254	2.694	3.144	4.646	4.189	2.819	3.866	3.183	3.060	3.615	3.710	3.462
April	6.213	4.896	5.929	6.900	5.720	4.477	7.512	4.306	5.528	4.660	4.665	4.634	4.976	5.417
May	9.071	9.152	10.947	8.582	9.888	9.358	12.826	-------	10.144	9.649	10.522	10.105	7.749	9.833
June	14.226	13.798	12.379	13.373	12.223	10.570	15.219	-------	14.194	12.369	14.275	11.283	14.528	13.203
July	13.942	15.497	14.209	17.034	15.331	15.232	17.060	-------	16.046	14.819	14.341	14.598	15.185	15.191
August	12.670	14.394	13.990	14.651	13.246	13.127	14.939	12.624	13.713	12.345	13.248	13.673	-------	13.552
September	5.647	9.964	9.743	10.351	11.785	10.195	11.412	8.068	9.721	9.184	9.625	9.016	-------	9.559
October	4.964	6.880	4.560	-------	6.044	5.784	5.026	4.783	6.140	6.060	5.171	6.149	-------	5.596
November	2.289	4.443	2.223	-------	1.738	3.408	2.151	2.112	3.144	1.639	2.150	3.257	-------	2.596
December	0.847	1.323	1.127	-------	1.057	1.682	-------	0.738	1.566	1.592	1.788	1.385	-------	1.311
Annual	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	82.848

Correction factor for large fresh-water surface —0.70 (Tables 15 and 45, Transactions, American Society of Civil Engineers, Vol. 90, pages 308 and 373).

TABLE C-18

RECORD OF DAILY EVAPORATION FOR MAY, 1930, AT U. S. ENGINEERING DEPARTMENT OBSERVATION STATION IN SUISUN BAY

From original records of United States Engineering Department.

Day of month	Depth in inches			
	[1]Deep water pan near Freeman Island	[1]Shallow water pan No. 1 in Noyce Slough	[1]Marsh pan on Simmons Island	[2]42-inch circular land pan on Dutton Island
1	[3]0.170	[3]0.170	------------	------------
2	.179	.224	------------	------------
3	.201	.201	0.201	0.224
4	[3].063	[3].063	[3].063	* [3].063
5	.144	.144	.145	.144
6	.246	.246	.224	.224
7	.224	.269	.225	.269
8	.220	.210	.165	.164
9	.224	.224	.220	.250
10	.269	[4].240	.180	.269
11	[4].224	[4].268	.225	.265
12	.134	.179	.180	.179
13	224	.224	.180	.269
14	.201	.269	.225	.313
15	.179	.313	.225	.269
16	.224	.224	.180	.269
17	.224	.224	.224	.269
18	.224	.224	.180	.269
19	.224	.224	.225	.313
20	.201	.224	.180	.313
21	.224	.269	.225	.269
22	.246	.246	.202	.291
23	.269	.269	.225	.358
24	.224	[4].224	.269	.358
25	.269	.269	.225	.313
26	.269	.269	.269	.313
27	.269	.224	.180	.269
28	.269	.287	.225	.269
29	.134	.179	.135	.134
30	.224	.269	.180	.224
31	.269	[4].336	.225	.291
Totals	6.665	7.205	------------	------------

[1] Floating circular pan, four feet in diameter, eighteen inches deep; water surface approximately six inches below rim on outside and three and one-half inches inside. Correction factor for large fresh-water surface —0.96.
[2] Set on surface of ground.
[3] Estimate from United States Weather Bureau evaporation record near Oakdale.
[4] Estimate from comparison of deep and shallow pan records for adjacent days with similar pan temperature differences.
* Rain filled all pans to overflowing. No refill necessary.

TABLE C-19

RECORD OF DAILY EVAPORATION FOR JUNE, 1930, AT U. S. ENGINEERING DEPARTMENT OBSERVATION STATION IN SUISUN BAY

From original records of United States Engineering Department

Day of month	Depth in inches							
	[1]Deep water pan near Freeman Island	[1]Shallow water pan No. 1 in Noyce Slough	[1]Marsh pan on Simmons Island	[2]42-inch circular land pan on Dutton Island	[2]72-inch circular land pan on Dutton Island	[2]24-inch circular land pan on Dutton Island	[2]24-inch square land pan on Dutton Island	United States Weather Bureau Class A land pan on Dutton Island
1	0.224	[3]0.280	0.202	0.313				
2	.269	*[3].336	.225	.313				
3	.224	[3].268	.225	.313				
4	.246	.313	.247	.358				
5	.246	.291	.247	.336				
6	.224	.291	.225	.336				
7	.269	.313	.270	.403				
8	.269	.358	.225	.403				
9	.313	.358	.270	.358				
10	.291	.358	.270	.358				
11	.269	.336	([4])	[5].358				
12	.403	.425	.180	.134	0.172	0.488	0.547	
13	.313	.403	.225	.459	.389	.538	.625	
14	.313	.403	.225	.448	.359	.538	.416	
15	.269	.358	.269	.358	.299	.404	.364	
16	.269	.269	.090	.358	.299	.134	.312	
17	.358	.313	.180	.358	.366	.404	.390	
18	.313	.269	.180	.381	.374	.404	.416	
19	.291	.269	.202	.358	.344	.337	.416	0.293
20	.179	.179	.090	.179	.127	.134	.182	.155
21	.246	.291	.157	.291	.262	.304	.364	.275
22	.269	.269	.180	.358	.299	.337	.364	.293
23	.269	.313	.180	.358	.299	.270	.312	.293
24	.246	.269	.180	.224	.239	.304	.364	.275
25	.291	.291	.180	.358	.314	.337	.364	.344
26	.291	.313	.135	.291	.306	.337	.416	.310
27	.224	.246	.157	.336	.269	.337	.416	.344
28	.269	.358	.202	.425	.389	.404	.468	.379
29	.269	.381	.180	.493	.374	.404	.521	.430
30	.224	.313	.180	381	.381	.471	.573	.465
Totals	8.150	9.434		10.442				

[1] Floating circular pan, four feet in diameter, eighteen inches deep; water surface approximately six inches below rim on outside, and three and one-half inches inside. Correction factor for large fresh-water surface —0.96.

[2] Set on surface of ground.

[3] Estimate from comparison of deep and shallow pan records for adjacent days with similar pan temperature differences.

[4] Moved marsh pan to new location.

[5] Land pan out for cleaning approximately one hour.

* Moved shallow pan to new location.

TABLE C-20

RECORD OF DAILY EVAPORATION FOR JULY, 1930, AT U. S. ENGINEERING DEPARTMENT OBSERVATION STATION IN SUISUN BAY

From original records of United States Engineering Department

Day of month	Depth in inches							
	[1]Deep water pan near Freeman Island	[1]Shallow water pan No. 1 in Noyce Slough	[1]Marsh pan on Simmons Island	[2]42-inch circular land pan on Dutton Island	[2]72-inch circular land pan on Dutton Island	[2]24-inch circular land pan on Dutton Island	[2]24-inch square land pan on Dutton Island	United States Weather Bureau Class A land pan on Dutton Island
1	0.291	0.403	0.202	0.515	0.418	0.538	0.521	0.465
2	.269	.358	.247	.493	.359	.404	.468	.396
3	* [3].291	.403	.225	* [3].500	.396	.471	.521	.431
4	.269	.313	** [3].180	.403	.359	.404	.468	.413
5	.269	.358	.180	.425	.358	.438	.442	.431
6	.269	.314	.157	.380	.328	.404	.390	.344
7	.358	.358	.180	.381	.381	.336	.416	.397
8	.336	.335	.157	.358	.336	.404	.468	.326
9	.268	.268	.134	.290	.231	.201	.260	.327
10	.224	.224	.134	.336	.240	.336	.364	.327
11	.269	.313	.179	.335	.328	.404	.364	.465
12	.291	.335	.157	.380	.344	.370	.416	.310
13	.268	.358	.180	.336	.322	.404	.416	.362
14	.313	.358	.180	.403	.388	.472	.520	.585
15	.269	.313	.180	.448	.351	.404	.520	.448
16	.291	.335	.180	.380	.396	.404	.416	.516
17	.269	.336	.180	.403	.299	.404	.416	.379
18	.269	.336	.157	.358	.358	.404	.416	.516
19	.268	.313	.179	.403	.262	.371	.390	.379
20	.246	.313	.180	.380	.373	.302	.442	[3].344
21	.313	.380	.224	.369	.403	.370	.442	.379
22	.291	.291	.180	.336	.328	.404	.364	.344
23	.246	.313	.180	.358	.324	.308	.364	.336
24	.291	.291	.180	.291	.337	.269	.312	.327
25	.224	.281	.180	.358	.284	.506	.364	.310
26	.268	.291	.180	.358	.336	.404	.520	.379
27	.269	.291	.180	.380	.299	.336	.312	.327
28	.246	.291	.180	.291	.321	.336	.364	.310
29	.223	.246	.157	.269	.231	.336	.312	.276
30	.246	.314	.180	.291	.246	.404	.468	.441
31	.291	.291	.225	.515	.426	.472	.572	.413
Totals	8.505	9.924	5.594	11.723	10.362	12.020	13.028	12.039

[1] Floating circular pan, four feet in diameter, eighteen inches deep; water surface approximately six inches below rim on outside and three and one-half inches inside. Correction factor for large fresh-water surface —0.96.

[2] Set on surface of ground.

[3] Estimate from comparison of deep and shallow pan records for adjacent days with similar pan temperature differences.

*Deep and land pan out for cleaning.

**Marsh pan out for cleaning.

TABLE C-21

COMPARISON OF AVERAGE MONTHLY EVAPORATION FROM LARGE FRESH-WATER SURFACE, AS MEASURED AND COMPUTED FOR VARIOUS STATIONS IN VICINITY OF A SALT WATER BARRIER

Month	Alvarado (1924 to 1930)				Lake Chabot (1917 to 1924)			
	[2]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches	[1]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches
		Pan evaporation in inches	[4]Corrected evaporation in inches			Pan evaporation in inches	[4]Corrected evaporation in inches	
January	47.8	1.40	0.98	0.98	48.5	1.92	1.58	1.01
February	52.0	2.50	1.75	1.75	51.0	1.62	1.34	1.65
March	54.8	3.99	2.79	2.79	53.5	2.20	1.82	2.52
April	56.4	5.11	3.58	3.58	56.0	2.94	2.43	3.49
May	58.2	6.74	4.72	4.70	60.0	4.54	3.75	5.40
June	61.4	7.35	5.15	5.15	64.0	5.92	4.89	6.15
July	62.7	7.64	5.35	5.35	64.5	6.66	5.50	5.80
August	61.9	6.60	4.62	4.60	63.0	6.21	5.13	5.00
September	61.6	5.52	3.86	3.86	63.0	5.82	4.81	4.45
October	59.1	3.81	2.67	2.68	60.0	4.92	4.06	3.03
November	54.3	2.31	1.62	1.62	54.5	2.95	2.43	1.61
December	50.6	1.52	1.06	1.06	48.5	1.67	1.38	1.03
Year	56.7	54.49	38.15	38.12	57.2	47.37	39.12	41.14

TABLE C-21—Continued

COMPARISON OF AVERAGE MONTHLY EVAPORATION FROM LARGE FRESH-WATER SURFACE, AS MEASURED AND COMPUTED FOR VARIOUS STATIONS IN VICINITY OF A SALT WATER BARRIER

Month	Upper San Leandro Reservoir (1925 to 1929)				San Pablo Reservoir at dam (1921 to 1929)			
	[1]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches	[1]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches
		Pan evaporation in inches	[4]Corrected evaporation in inches			Pan evaporation in inches	[4]Corrected evaporation in inches	
January	48.0	1.54	1.37	0.99	47.5	0.96	0.86	0.95
February	51.0	1.95	1.74	1.65	50.5	1.30	1.16	1.60
March	54.0	3.26	2.90	2.62	53.3	2.65	2.36	2.50
April	56.5	3.50	3.12	3.60	56.5	3.83	3.41	3.60
May	60.5	4.34	3.86	5.60	61.0	5.49	4.89	5.80
June	64.5	7.17	6.38	6.30	63.0	6.37	5.67	5.78
July	65.5	7.33	6.53	6.40	64.5	6.82	6.07	5.80
August	64.0	6.54	5.82	5.40	64.0	6.52	5.81	5.40
September	64.0	5.78	5.15	4.85	64.0	5.83	5.19	4.85
October	61.0	3.76	3.35	3.40	61.0	3.94	3.51	3.40
November	54.0	2.00	1.78	1.64	54.5	2.33	2.07	1.61
December	48.5	1.41	1.26	1.03	48.5	1.56	1.39	1.03
Year	57.6	48.58	43.26	43.48	57.4	47.60	42.39	42.32

TABLE C-21—Continued

COMPARISON OF AVERAGE MONTHLY EVAPORATION FROM LARGE FRESH-WATER SURFACE, AS MEASURED AND COMPUTED FOR VARIOUS STATIONS IN VICINITY OF A SALT WATER BARRIER

Month	Berkeley, University of California Campus (1905)				Davis, University of California Campus (1926 to 1930)			
	[2]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches	[2]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches
		Pan evaporation in inches	[4]Corrected evaporation in inches			Pan evaporation in inches	[4]Corrected evaporation in inches	
January	48.7	1.00	0.76	1.02	45.4	0.92	0.64	0.84
February	50.6	1.36	1.03	1.61	49.4	2.07	1.45	1.50
March	54.3	2.11	1.60	2.68	53.2	2.99	2.10	2.45
April	55.1	3.14	2.39	3.28	56.0	4.83	3.38	3.49
May	55.6	4.70	3.57	3.70	63.5	7.98	5.59	6.75
June	58.4	5.68	4.32	4.00	72.5	9.45	6.62	9.40
July	61.4	5.52	4.20	4.80	74.3	10.64	7.45	9.45
August	59.8	5.09	3.87	3.90	72.3	9.41	6.59	8.40
September	60.4	4.65	3.54	3.40	68.2	7.53	5.27	6.60
October	58.0	4.27	3.25	2.27	63.2	4.87	3.41	4.22
November	52.9	2.68	2.04	1.68	53.4	2.15	1.50	1.66
December	47.4	1.35	1.03	1.02	44.7	1.43	1.00	0.99
Year	55.2	41.55	31.60	33.36	59.7	64.27	45.00	55.75

TABLE C-21—Continued

COMPARISON OF AVERAGE MONTHLY EVAPORATION FROM LARGE FRESH-WATER SURFACE, AS MEASURED AND COMPUTED FOR VARIOUS STATIONS IN VICINITY OF A SALT WATER BARRIER

Month	Suisun Bay, deep water (1930)				Suisun Bay, shallow water (1930)			
	[1]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches	[1]Average temperature in degrees Fahrenheit	Measured evaporation		[3]Computed evaporation in inches
		Pan evaporation in inches	[4]Corrected evaporation in inches			Pan evaporation in inches	[4]Corrected evaporation in inches	
January	47.0	----------	----------	0.93	47.0	----------	----------	0.93
February	51.0	----------	----------	1.65	51.0	----------	----------	1.65
March	54.5	----------	----------	2.72	54.5	----------	----------	2.72
April	57.5	----------	----------	3.82	57.5	----------	----------	3.82
May	61.5	6.66	[6]5.99	6.00	61.5	7.20	6.91	6.00
June	67.0	8.15	[5]7.31	7.30	67.0	9.43	9.05	7.30
July	70.5	8.50	[6]7.41	8.00	70.5	9.92	9.51	8.00
August	69.5	----------	----------	7.50	69.5	----------	----------	7.50
September	67.0	----------	----------	6.10	67.0	----------	----------	6.10
October	62.0	----------	----------	3.80	62.0	----------	----------	3.80
November	55.0	----------	----------	1.59	55.0	----------	----------	1.59
December	48.0	----------	----------	1.03	48.0	----------	----------	1.03
Year	59.2	----------	----------	50.44	59.2	----------	----------	50.44

TABLE C-21—Continued

COMPARISON OF AVERAGE MONTHLY EVAPORATION FROM LARGE FRESH-WATER SURFACE, AS MEASURED AND COMPUTED FOR VARIOUS STATIONS IN VICINITY OF A SALT WATER BARRIER

Month	Reclamation District 999 (1926 to 1928)				Oakdale (1924 to 1930)			
	[1]Average temperature in degrees Fahrenheit	Measured evaporation: Pan evaporation in inches	Measured evaporation: [4]Corrected evaporation in inches	[3]Computed evaporation in inches	[2]Average temperature in degrees Fahrenheit	Measured evaporation: Pan evaporation in inches	Measured evaporation: [4]Corrected evaporation in inches	[3]Computed evaporation in inches
January	45.5	----------	----------	0.85	43.0	1.01	0.71	0.71
February	50.5	----------	----------	1.60	49.0	2.09	1.46	1.45
March	54.5	----------	----------	2.72	52.7	3.38	2.36	2.35
April	58.5	----------	----------	4.05	55.4	4.80	3.36	3.35
May	63.5	9.36	7.58	6.75	63.5	9.63	6.74	6.75
June	70.0	10.92	8.85	8.45	72.3	13.33	9.33	9.35
July	74.5	11.03	8.90	9.50	76.3	14.80	10.36	10.35
August	73.0	8.76	7.11	8.65	75.0	13.42	9.40	9.40
September	69.5	7.45	6.04	7.10	68.4	9.50	6.65	6.65
October	62.5	5.30	4.30	4.00	62.3	5.56	3.89	3.90
November	53.0	----------	----------	1.67	52.8	2.41	1.69	1.68
December	46.0	----------	----------	1.00	44.3	1.41	0.99	0.98
Year	60.1	----------	----------	56.34	59.6	81.34	56.94	56.92

[1] Long term average as taken from isothermic map.
[2] Average as observed for period of evaporation record.
[3] From evaporation—temperature diagrams.
[4] For large water surface; for correction factor see Table C-7.
[5] Correction factor for 1.7 degrees higher temperature of water surface in pan above bay water—0.935.
[6] Correction factor for 2.2 degrees higher temperature—0.91.

TABLE C-22

PER CENT VARIATION OF COMPUTED FROM MEASURED EVAPORATION FOR LARGE FRESH-WATER SURFACES IN VICINITY OF A SALT WATER BARRIER

Based upon values shown in Table C-21

Month	Alvarado	Lake Chabot	Upper San Leandro Reservoir	San Pablo Reservoir (at dam)	Berkeley, University of California Campus	Davis, University of California Campus	Suisun Bay deep water	Reclamation District No. 999	Oakdale
January	0.0	−36.1	−27.7	+10.5	+34.2	+37.5	----	----	0.0
February	0.0	+23.1	−5.2	+37.9	+56.3	+3.4	----	----	0.0
March	0.0	+38.4	−9.7	+5.9	+67.4	+16.7	----	----	0.0
April	0.0	+43.6	+15.4	+5.6	+37.2	+3.3	----	----	0.0
May	0.0	+44.0	+45.1	+18.6	+3.6	+20.8	0.0	−10.2	0.0
June	0.0	+25.7	−1.3	+1.9	−7.4	+42.0	0.0	−4.5	0.0
July	0.0	+5.5	−2.0	−4.4	+14.3	+26.8	+8.0	+6.7	0.0
August	0.0	−2.5	−7.2	−7.1	+0.8	+27.4	----	+21.7	0.0
September	0.0	−7.5	−5.8	−6.5	−4.0	+25.2	----	+17.6	0.0
October	0.0	−25.4	+1.5	−3.1	−30.2	+23.8	----	−7.0	0.0
November	0.0	−33.8	−7.9	−22.2	−17.6	+10.7	----	----	0.0
December	0.0	−25.4	−18.3	−25.9	−1.0	−1.0	----	----	0.0
Year	0.0	+5.2	+0.5	−0.2	+5.6	+23.9	----	----	0.0

TABLE C-23

ESTIMATED MONTHLY DEPTH OF EVAPORATION FROM LARGE FRESH-WATER SURFACES FOR DISTINCTIVE METEOROLOGICAL AREAS ABOVE A SALT WATER BARRIER

Month	San Pablo Bay, San Pablo to Dillon Point barrier sites		Carquinez Strait, Dillon Point to Army Point barrier sites		Suisun Bay, Army Point to Chipps Island barrier sites		River Delta, above Chipps Island barrier site	
	[1]Average air temperature in degrees Fahrenheit	[2]Depth of evaporation in inches	[1]Average air temperature in degrees Fahrenheit	[2]Depth of evaporation in inches	[1]Average air temperature in degrees Fahrenheit	[2]Depth of evaporation in inches	[1]Average air temperature in degrees Fahrenheit	[2]Depth of evaporation in inches
January	47.8	0.98	47.5	0.96	47.1	0.93	46.5	0.90
February	51.5	1.70	51.0	1.65	51.0	1.65	50.5	1.60
March	53.5	2.53	53.7	2.55	54.9	2.81	54.7	2.75
April	56.4	3.58	57.5	3.82	57.5	3.82	58.8	4.12
May	59.0	5.00	61.0	5.80	62.0	6.15	64.8	7.25
June	61.0	5.00	65.0	6.55	66.5	7.10	71.8	9.10
July	64.0	5.75	67.5	7.10	69.0	7.60	75.7	10.10
August	64.0	5.35	66.6	6.25	68.5	6.90	74.75	9.35
September	63.7	4.70	65.0	5.25	66.5	5.90	69.5	7.15
October	61.0	3.40	62.0	3.80	62.2	3.85	62.5	4.00
November	55.0	1.60	55.0	1.60	55.0	1.60	53.75	1.65
December	47.8	1.02	48.0	1.02	48.0	1.02	47.0	1.01
Totals	57.1	40.61	58.3	46.35	59.0	49.33	60.9	58.98

[1] Data from Isothermic Maps, Plate C-I.
[2] Data from temperature—evaporation graphs for large water surfaces, Plate C-VII.

TABLE C-24

LIST OF EVAPORATION AND TRANSPIRATION RECORDS FOR NATURAL FRESH-WATER VEGETATION GROWING IN AREA ABOVE A SALT WATER BARRIER

Type of vegetation	Location	Authority	Reference	Length of record	Tank equipment		Observed annual depth of transpiration and evaporation in feet	Coefficient for adjustment to large area	Adjusted annual depth of evaporation, transpiration in feet
					Size	Setting			
Tule	Santa Ana	U. S. Department of Agriculture.	Correspondence	1 year	1 tank 25 inches in diameter, 3 feet deep.	In ground[1]	17.79	0.56	9.96
Tule	Temescal	U. S. Department of Agriculture.	Preliminary report, Bulletin No. 33.	8 months	1 tank 24 inches in diameter, 30 inches deep.	In ground[2]	----------	----------	----------
Tule and cat-tail	Clarksburg	U. S. Department of Agriculture.	Correspondence	1 year	11 tanks 24 inches in diameter, 5 feet deep.	In ground, waterjacketed[1]	19.27	9.63	9.63
Tule	Mud Lake, Idaho	U. S. Geological Survey	Water Supply Paper 560-D.	3 summers	1 tank 4 feet in diameter, 4 feet deep.	In mud 44 inches.[1]	----------	----------	----------
Salt grass	Independence	U. S. Geological Survey and city of Los Angeles.	Trans. Am. Soc. C. E., Vol. 78, page 192, figure 10.*	2 years	7 feet 5 inches in diameter, 9 feet 9 inches deep.	In ground, flush with surface.	[3]4.5 [4]3.8 [5]3.2	1.0 1.0 1.0	4.5 3.8 3.2
Salt grass	Santa Ana	U. S. Department of Agriculture.	Preliminary report Bulletin No. 33.	1 year	23 inches in diameter, 6 feet deep.	In ground, flush with surface.	[4]2.94 [6]1.12	1.0 1.0	2.94 1.12

*Transactions, American Society of Civil Engineers.
[1] Surface of soil in tank below rim two to three inches, plants transplanted full size with soil; water added once a week and soil surface not continuously flooded; tanks isolated.
[2] Tank in river bottom.
[3] Water table at one foot depth.
[4] Water table at two foot depth.
[5] Water table at three foot depth.
[6] Water table at four foot depth.

TABLE C-25

RECORDS OF MONTHLY EVAPORATION AND TRANSPIRATION FROM TULE AND CAT-TAIL

(For description of records see Table C-24).

Month	U. S. Department of Agriculture experiment plot near Santa Ana, Tank No. 19		U. S. Department of Agriculture experiment plot in Temescal Canyon, Tank A		[7]U. S. Department of Agriculture experiment plot near Clarksburg, average of 11 tanks		U. S. Geological Survey pan at Mud Lake, Idaho		
	1929	1930	1929	1930	1929	1930	1921	1922	1923
	In feet	In feet	In feet	In feet	In feet	In feet	In feet	In feet	In feet
January	----------	0.15	----------	0.33	----------	0.33	----------	----------	----------
February	----------	0.30	----------	0.23	----------	0.18	----------	----------	----------
March	----------	0.50	----------	0.40	----------	0.60	----------	----------	----------
April	----------	1.47	----------	0.96	----------	1.48	----------	----------	----------
May	----------	1.88	----------	1.19	----------	2.20	----------	[3]0.08	----------
June	----------	1.92	----------	----------	----------	2.55	[1]0.74	1.12	[4]0.48
July	----------	2.38	----------	----------	2.34	3.06	1.58	1.78	0.98
August	1.95	----------	----------	----------	2.65	[6]0.85	1.50	1.44	1.12
September	1.98	----------	----------	----------	2.36	----------	[2]0.46	0.86	0.92
October	2.37	----------	1.40	----------	1.97	----------	----------	----------	[5]0.08
November	1.95	----------	0.76	----------	1.18	----------	----------	----------	----------
December	0.94	----------	0.40	----------	0.71	----------	----------	----------	----------
Subtotal	9.19	8.60	2.56	3.11	11.21	11.25	4.28	5.28	3.58
Year, August 1 to July 31	----------	17.79	----------	----------	----------	19.27	----------	----------	----------

[1] June 13 to 30.
[2] September 1 to 23.
[3] May 24 to 30.
[4] June 13 to 30.
[5] October 1 to 16.
[6] August 1 to 9.
[7] Average for five ca -tail and six tule tanks.

TABLE C-26

RECORDS OF MONTHLY EVAPORATION AND TRANSPIRATION FROM SALT GRASS

(For description of records see Table C-24)

Month	U. S. Department of Agriculture experimental plot near Santa Ana[1]				U. S. Geological Survey experimental plot near Independence[2]			
	Depth to water table two feet		Depth to water table four feet		Depth to water table one foot	Depth to water table two feet	Depth to water table three feet	Depth to water table four feet
	1929	1930	1929	1930				
	In inches	In inches	In inches	In inches	In inches	In inches	In inches	In inches
January	---------	0.72	---------	0.31	0.54	0.46	0.38	0.30
February	---------	0.92	---------	0.33	0.54	0.46	0.38	0.30
March	---------	1.40	---------	0.44	1.08	0.92	0.76	0.30
April	---------	2.90	---------	1.01	3.24	2.76	2.28	0.60
May	2.45	---------	0.33	---------	6.75	5.75	4.75	2.40
June	4.40	---------	0.79	---------	8.10	6.90	5.70	4.20
July	5.64	---------	2.43	---------	10.52	8.96	7.42	6.00
August	5.53	---------	2.96	---------	10.85	9.20	7.61	7.81
September	3.54	---------	1.70	---------	7.29	6.20	5.14	5.40
October	3.52	---------	1.67	---------	3.24	2.76	2.28	1.80
November	2.66	---------	0.77	---------	1.35	1.15	0.95	0.60
December	1.64	---------	0.63	---------	0.50	0.46	0.38	0.38
Subtotal	29.38	5.94	11.28	2.09	---------	---------	---------	---------
Year	---------	35.32	---------	13.37	54.00	46.00	38.00	30.00

[1] Values are average for three tanks as measured. Tanks installed February, 1929.
[2] Totals from Transactions, American Society Civil Engineers, Volumne 78, page 192, Figure 10, 1911 curve, and monthly distribution in accordance with average percentages as computed from Tables 2 to 7; tanks installed April, 1909.

TABLE C-27

AMOUNT OF WATER TRANSPIRED BY DIFFERENT FOREST TREES IN CENTRAL EUROPE PER POUND OF DRY LEAF SUBSTANCE[1]

No.	Variety of tree	Pounds of water transpired per pound of dry leaf			
		1878	1879	1880	Average for 1879 and 1880
1	Ash	566.89	983.05	1,018.50	1,000.78
2	Aspen	-------------	-------------	959.70	959.70
3	Alder	-------------	-------------	933.00	933.00
4	Birch	679.87	845.13	918.00	881.57
5	Beech	472.46	859.50	913.80	886.65
6	Hornbeam	562.51	759.01	871.70	815.36
7	Linden	-------------	-------------	883.40	883.40
8	Elm	407.31	555.00	822.80	688.90
9	Maple (A. campestic)	435.77	618.30	703.80	661.05
10	Norway Maple	462.87	517.22	611.80	564.51
11	Oak (Q. robor)	283.45	622.21	691.50	656.86
12	Oak (Q. cerris)	253.33	614.22	492.20	553.21
13	Norway Spruce	58.47	206.36	140.20	173.28
14	Scotch Pine	58.02	103.72	121.05	112.39
15	Fir	44.02	77.54	93.80	85.67
16	Austrian Pine	32.07	99.92	70.05	84.99
Average for broadleaf deciduous trees with normal occurrence on stream borders or in moist soil, Nos. 1 to 5				948.6	932.54
Average for deciduous trees with normal occurrence away from streams in well drained soils and on hillsides, Nos. 6 to 12				725.3	689.04
Average for evergreen conifers Nos. 13 to 16				106.2	114.08

[1] Compiled from experimental data obtained by F. R. Hohnel at Austrian Forest Experiment Station. Origina data in "Forschungen auf dem Gebiete der Agrikulten-Physik," Bd. 4, pages 435 to 445.

NOTE.—Observations during vegetative season April 1 to October 30. Atmospheric and experimental conditions in 1880 favorable to maximum water consumption, and in 1878 were such that results show the minimum water requirement under the local conditions.

TABLE C-28

ESTIMATED MONTHLY DEPTH OF EVAPORATION AND TRANSPIRATION FROM NATURAL FRESH-WATER VEGETATION GROWING IN AREA ABOVE A SALT WATER BARRIER

Month	Tule and cat-tail	Salt grass[1]	Willows	
			In large groves	Isolated trees
	In feet	In feet	In feet	In feet
January	0.16	0.06	0.04	0.09
February	0.09	0.08	0.03	0.05
March	0.30	0.12	0.08	0.16
April	0.74	0.24	0.20	0.41
May	1.10	0.36	0.30	0.60
June	1.28	0.43	0.35	0.70
July	1.53	0.56	0.42	0.84
August	1.32	0.58	0.36	0.73
September	1.18	0.39	0.33	0.65
October	0.98	0.29	0.27	0.54
November	0.59	0.22	0.16	0.32
December	0.36	0.14	0.10	0.20
Year	9.63	3.47	2.64	5.29

[1] Values for average annual depth to water table of two feet.

APPENDIX D

GEOLOGY OF UPPER SAN FRANCISCO BAY REGION

With Special Reference to a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

by

C. F. Tolman

RELIEF MODEL OF CALIFORNIA

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CHAPTER VIII

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LETTER OF TRANSMITTAL

Mr. Edward Hyatt,
State Engineer,
Sacramento, California.

Dear Sir: I transmit herewith a report on the "Geology of Upper San Francisco Bay Region With Special Reference to a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."

The geology of the region closely adjacent to the salt water barrier sites has been worked out in great detail, and the surrounding region has been studied in less detail. On account of the seismic history of the region, all known faults, possible faults and faults suggested by other writers have been investigated in detail.

Two sites have been reported on adversely, namely, the original site at Benicia (site D on the geological map) and the site at Vallejo Junction (site F on the map). The unfavorable foundation features are emphasized for the site opposite Crockett (F′) and also for the sites (A and B) near the confluence of the Sacramento and San Joaquin rivers. Two alternate additional sites have been suggested in place of the original site (D) at Benicia. These are shown on the geological map as sites D′ and D″. Alternate sites C′ and C″ are suggested for site C at Army Point.

Attention has been called to the seismic history of the region and on account of past seismic activity it is concluded that no site should be selected across a known fault, especially an active fault. Sites should be parallel to the faults. Barriers should be designed to withstand earthquake shocks of intensity of X, Rossi-Forel scale.

Respectfully,

Professor of Economic Geology,
Stanford University.

Stanford University, California,
August 22, 1930.

ACKNOWLEDGEMENT

This region has been studied by several geologists, but because of the complexity of the geology, especially the geological structure, there is considerable diversity in the geological maps and the interpretation of the structure as advanced by these geologists. For this reason the area adjacent to the river was mapped independently and in detail, and the geological maps of adjacent areas, especially those of Andrew C. Lawson and C. E. Weaver, were checked and modifications and additions made where checking necessitated them.

The detailed study of the faulting indicated that some of the faults depicted on the various geological maps did not exist; others were noted that were not shown on the existing maps. Andrew C. Lawson's* map of the Concord and San Francisco quadrangles was used to good advantage, although only the San Pablo and San Pedro barrier sites lie within the area mapped by him. Most of the remaining area has been mapped in detail by C. E. Weaver. A copy of his map appears in Bulletin No. 22 of the Division of Water Rescources, "Report on Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers," volume 2, plate 3-2. Advantage was had of a more detailed copy of Weaver's map. Weaver has spent most of his field seasons since 1916 mapping the area lying north of Carquinez Strait. His map is excellent, and without it the area could not have been covered in the allotted time. A field trip was made with Weaver, the differences in mapping and interpretation were discussed with him, and a general agreement was reached in regard to the mooted questions.

Bruce Clark loaned a copy of his geological map of Mt. Diablo, which lies just south of the area studied in detail. He also made a trip in the field and discussed and assisted with his detailed paleontological and stratigraphic studies on the southwest border of the Carquinez Strait. He also made paleontological correlations of the formations exposed on Mare Island.

Other geological maps which were made available are those of Grant Corby, who made studies for the Marland Oil Company; Jas. M. Kirby, who is now mapping the region for the Standard Oil Company of California; H. J. Hawley and W. H. Corey, who have made a detailed geological map of the San Pablo Peninsula; A. R. Whitman, who mapped a portion of the region for the Division of Water Resources; L. N. Waterfalls, who mapped in detail the eastern portion of the Carquinez Strait area under Andrew C. Lawson. This map formed the geological basis for reports by Andrew C. Lawson and Bailey Willis on the Martinez Bridge, now being built by the Southern Pacific Company.

* The San Francisco Folio, No. 193, published by the United States Geological Survey.

A report criticizing the conclusions of Lawson and Willis on the so-called Martinez fault as mapped by Waterfalls, was made by J. A. Taff and G. D. Hanna. Copies of the reports dealing with the Carquinez Bridge area were made available by the courtesy of C. R. Harding, assistant to the president of the Southern Pacific Company.

Frank Tolman made trips in the field and micro-paleontological studies which assisted in the correlation of the strata on the two sides of the western portion of Carquinez Strait.

H. A. Sedelmeyer kindly gave permission to use a photograph of his recently constructed relief model of California, which is reproduced as Plate D-I.

CHAPTER I

SUMMARY AND CONCLUSIONS

This report presents the results of a detailed geological study in the vicinity of the salt water barrier sites from below the confluence of the Sacramento and San Joaquin rivers to, and including, the San Pablo Peninsula at Richmond and the San Pedro Peninsula north of San Rafael, and also the results of such general geological studies of the adjacent region as were deemed necessary to work out the general geologic structure.

These studies have been carried on since April, 1930. Approximately thirty days were spent in field work, and a somewhat longer period in laboratory and office work, including examination of the drill cores collected during the cooperative investigations for a salt water barrier carried on during 1924 and 1925 by the Federal Government and the State of California.

No detailed study of construction materials available at each site was made. There is abundant material of two kinds, namely the Franciscan and the Chico sandstones. Information as to the former can be obtained from the numerous quarries on the San Pablo Peninsula and Point San Pedro. The latter is well exposed in the cliffs adjacent to Carquinez Strait. Detailed estimates of the cost of material at each site is an engineering undertaking.

No studies were made on the effect of a completed barrier on the ground water conditions in the vicinity, although this is an important phase of the general problem of such a project.

The results of the geological investigations are applied merely to determine the suitability of the foundation rock to support the proposed structure, and to evaluate the earthquake hazard and the probable intensity of the future earthquakes that may occur in the region. This involved a general geological study and mapping of the entire region and a detailed investigation of all known or supposed faults. It also involved a study of the seismic record and an interpretation of the distribution of earthquake intensities in relation to the faults as mapped.

Fault Movements and Earthquakes.

A fault is a fracture along which movement of the rocks has occurred on either or both sides. A sudden displacement along a fault produces an earthquake or earth tremor. This vibration, set up at the point of slipping on the fault plane, moves outward in all directions. The destructive effect of this earth wave is developed only at the surface where loose objects, such as soils, delta clays and artificial structures, are set in motion.

There are two different disturbances which must be considered in studying the earthquake hazard affecting a contemplated structure.

First, the bodily displacement of the soil and underlying rock along the earthquake fault; and second, the vibrational wave traveling through the rocky framework of the earth.

Bedrock Displacements Along Faults.

Horizontal displacements up to a maximum of 21 feet were observed along the San Andreas fault during the earthquake of 1906, and combined horizontal displacement of ten feet and vertical displacement of 25 feet along the Lone Pine fault zone in Owens Valley during the earthquake of 1872. It is evident, therefore, that any structure built across an earthquake fault will be broken and displaced by the movement occurring at that locality.

This situation may be met (1) by building either a rock fill or earth fill structure of sufficient size to take up the foundation movement without severing the broken sides of the structure, or (2) far better, by not building across a known fault, especially in a region of high seismic activity. The second alternative is recommended in this report.

The Earth Wave.

The vibrational wave generated by movement on a fault can not be avoided and structures should be designed to withstand earthquakes at least equal to the strongest shock recorded in the region.

Theoretically the shock should be most intense a short distance on each side of, and should diminish in intensity away from, the fault. As a matter of fact, however, the character of foundation material may be more important in determining intensity of shock than close proximity to the fault. Soft alluvial fill is notoriously poor foundation material and greatly magnifies the destructive effect of an earthquake. The three disastrous shocks suffered by Antioch may be due, in part, to the delta clays on which a portion of the town is built.

A second factor affecting the distribution of intensities is brought out by the study of the earthquake record. The record often shows disastrous effects along a well known active fault, and also a marked intensification of the earthquake shock in the vicinity of a ''contributory fault,'' which may be many miles away from the one chiefly responsible for the shock.

The above suggests that building across, or in close proximity to, any known major fault should be avoided if possible, even if the earthquake record does not indicate increased seismic activity in that vicinity.

Earthquake Intensity Scales.

No scale of earthquake intensity has been devised that is thoroughly satisfactory from either the scientific or the engineering viewpoints.

The earth wave, like all other waves, has measureable amplitude, period, velocity and acceleration. The destructive effect depends not only on all the above, but also on the type and vibration period of the structure. The character of the wave is greatly modified by passage through the material on which the structure rests.

Many scales of earthquake intensity have been suggested, some of which use the disturbance caused to structures, surface rock and soil and the effect on the senses of men and animals to measure the shock, and some classify intensities according to the acceleration of the wave.

Because of the difference of opinion regarding classification of intensities, the simplest and most generally used scale (the Rossi-Forel scale) is adopted in the following discussion. The deficiencies of this scale are recognized, but, notwithstanding, it is believed to be sufficient for the general discussion of the foundation sites.

Engineers are beginning to appreciate the importance of a better understanding of the principals of designing rigid structures to withstand earthquake shocks. The effect of vibration on structures and on foundation material is now being investigated at the vibration laboratory at Stanford University.*

Because of the seismic history of the region, all plans should be reviewed by one who has followed the recent studies of vibration effects, especially the work of Professor L. S. Jacobsen of Stanford University, before any structure receives final approval by the investigating committee.

Rossi-Forel Scale of Earthquake Intensities.

The Rossi-Forel scale for classifying earth-shock intensities is as follows:

I. Microseismic shock: Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. Extremely feeble shock: Recorded by several seismographs of different kinds; felt by a small number of persons at rest; some startled persons leave their dwellings.

III. Very feeble shock: Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. Feeble shock: Felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. Shock of moderate intensity: Felt generally by everyone; disturbance of furniture, beds, etc.; ringing of swinging bells.

VI. Fairly strong shock: General awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. Strong shock: Overthrow of moveable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. Very strong shock: Fall of chimneys; cracks in walls of buildings.

IX. Extremely strong shock: Partial or total destruction of some buildings.

X. Shock of extreme intensity: Great disaster; buildings ruined; disturbance of the strata; fissures in the ground; rock falls from mountains.

* Progress Report on Vibration Research at Stanford University, Bulletin Seismological Sociey of America, Vol. 20, pp.113–237, September, 1930.

The destructive intensities of the "Rossi-Forel scale," compared with the "Omori scale," the "San Francisco scale" and the "Acceleration scale" are shown in the following chart:*

COMPARISON OF EARTHQUAKE INTENSITY SCALES

<table>
<tr><th>Rossi-Forel scale</th><th>Omori scale</th><th>San Francisco scale</th><th>Acceleration mm. per sec. per sec.</th></tr>
<tr><td rowspan="6">10</td><td>No. 7</td><td rowspan="2">Grade A</td><td></td></tr>
<tr><td rowspan="3">No. 6</td><td>4,000</td></tr>
<tr><td rowspan="6">Grade B</td><td>3,000</td></tr>
<tr><td>2,500</td></tr>
<tr><td>No. 5</td><td></td></tr>
<tr><td rowspan="3">No. 4</td><td></td></tr>
<tr><td>9</td><td>2,000</td></tr>
<tr><td rowspan="5">8</td><td></td></tr>
<tr><td rowspan="2">No. 3</td><td rowspan="3">Grade C</td><td>1,200</td></tr>
<tr><td>900</td></tr>
<tr><td rowspan="4">No. 2</td><td></td></tr>
<tr><td rowspan="4">Grade D</td><td>800</td></tr>
<tr><td rowspan="4">7</td><td></td></tr>
<tr><td>300</td></tr>
<tr><td rowspan="2">No. 1</td><td></td></tr>
<tr><td>Grade E</td><td>200</td></tr>
</table>

* Report California Earthquake Commission; Vol. 1, pages 222–227.

Earthquake Hazard in This Region.

A study of the earthquake record indicates this region is of high seismicity. Since 1854, the date of the first recorded earthquake, 58 shocks, the majority of which were strong to severe and no less than four of which were of catastrophic intensity (X, Rossi–Forel Scale), have affected the region. These were the earthquakes of:

October 21, 1868—(Intensity X, Rossi-Forel Scale) at Haywards.

April 3, 1872—(Intensity X, Rossi-Forel Scale) at Antioch.

March 30, 1898—(Intensity X, Rossi-Forel Scale) at Mare Island.

April 18, 1906—(Intensity X, Rossi-Forel Scale) in San Francisco, Santa Clara and Marin counties.

The shocks affecting the region have originated along the San Andreas, the Haywards and the Sunol-Southampton faults, and possibly along the Mare Island fault, the latter of which is shown on Plate D-III, and probably on a "covered fault" near the vicinity of Antioch (see geologic maps). This was determined by a study of the distribution of earthquake intensities in respect to the known faults of the region. These are therefore the "active faults" of the region, as determined by the earthquake record.

Of course interpretation of the seismic record is often difficult and uncertain. A great earthquake may be felt over a large area and intensities may be distorted by the materials on which the buildings rest. Also really accurate knowledge of the faults is limited to regions where exposures are good and where detailed geologic study has been carried on. In the tabulation of earthquake shocks appearing in this report are indicated the faults probably responsible for the recorded shocks wherever the information justified the conclusion.

An interesting result of the study is the clear indication of a cyclic distribution of earthquakes, and also that the region is now showing unusually low seismic activity. From 1854 to 1864 five earthquakes, or one in two years, suggest low seismic activity for this region. This may have been due in part to the thinly settled character of the region. Then followed high seismic activity—six shocks in 1866 and the great Haywards earthquake in 1868. There also was one shock in 1869, two in 1870, one in 1871 and two in 1872, including the great earthquake at Antioch. Then low seismic activity again prevailed, for no shocks are reported for the nine years up to 1881. Then came a period of increasing activity, with one or more shocks a year, with few exceptions, from 1881 to 1892, including a severe earthquake at Antioch in 1889, which culminated in three days of heavy shocks affecting all the area in 1892. These shocks were followed by reduced seismicity, as shown by earthquake records, only one shock every two years up to 1898, when higher seismic activity is indicated by the intense, but local, shock at Mare Island. Five shocks in 1899 and four shocks in 1900 all were at Mare Island or Vallejo, and clearly were after-effects of the movements on the Mare Island fault zone. This high seismic activity was closed by the San Francisco earthquake in 1906. Since that time only one moderate shock, 1911, and two light shocks, 1914 and 1916, have been recorded. It perhaps is not necessary to suggest that the 24 years of reduced seismic activity of the region might cause builders and engineers to overlook the history of high earthquake activity in the past.

Sites Grouped According to Geological Environment.

The barrier sites are situated in three areas, each of which is a unit geologically, and each area differs from the others in respect to all essential geological features. Therefore, the foundation problems of the sites in different areas are wholly dissimilar, but those sites in any one area are quite similar.

The sites may be grouped according to the geological environment as follows:

(1) The sites near the confluence of the Sacramento and San Joaquin rivers.

(2) The sites in the Carquinez Strait.

(3) The San Pablo sites.

Geology of Area Near Confluence of Sacramento and San Joaquin Rivers.

Any barrier site near the confluence of the two rivers must cross the clays and tule muds of the delta region. Underlying these soft alluvial deposits are friable and soft clayey sandstones. This formation is well exposed in cuts along the state highway in the Antioch quadrangle. The material is yellowish-brown clayey sandstone or clay-cemented sand and fine silt. This formation is interfingered with sands and gravels brought down from the neighboring mountains by the temporary streams.

This rather incoherent, clayey, fine sandstone or clayey sand may be considered the bedrock of the Suisun Bay and the lower Sacramento River, in so far as any barrier structure is concerned. It will support piles satisfactorily and will not heave underneath an artificial embankment if one is placed upon it.

Fairly hard sand and gravel, overlain by clay and mud, is found in the river channel proper. These sands and gravels are believed to have been deposited after the ancient Sacramento River excavated its deepest channel, and constitute the first material deposited therein. The channel in this locality is cut in the soft clayey standstone described above. These sands and gravels (basal portion of the "recent alluvium" shown on the geological maps) would support satisfactorily a structure erected on piles.

The soft slippery clays, tule-bearing muds and "muck" fill not only the deep river channel, but also the adjacent "drowned area" of the delta region of the lower Sacramento River. They are the upper members of the "recent alluvium" of the delta area. The deposit varies in thickness from 100 to 150 feet. Pockets of "muck" occur, and in several instances well casing has penetrated 60 feet under its own weight. The soft clayey portion of this formation will flow out from under the load of an overlying embankment. The entire body of this material will be greatly disturbed by earthquake waves. Piles supporting any large structure should be driven through the treacherous "muck" and clay to either the sand and gravel in the river channel or the sandstone (Pittsburg formation) underlying the recent alluvium.

Suitability of Barrier Sites Between Suisun Bay and Confluence of Sacramento and San Joaquin Rivers.

Only meager data are available regarding the Chipps Island site, or any other site in this area. The bore holes put down to explore the contemplated bridge site of the Sacramento Northern Railroad did not go through the clay fill. These drill holes explored the river channel only. Well data regarding the thickness and character of the "recent alluvium" of the delta area adjacent to the river channel are insufficient and unreliable. From this unsatisfactory data it seems probable that piles would have to be at least 150 feet long to pass through the "muck" and soft clay.

Any structure would have to be designed to withstand earthquake shocks of an intensity of X Rossi-Forel scale. It is quite possible engineers could design a satisfactory pile-supported structure in spite of the unfavorable conditions. Until further explorations by boring are made in this locality no final approval of the site can be made.

Geology of Carquinez Strait Region.

The ancient Sacramento River flowed westward towards the ocean before the Berkeley hills were elevated. It held its course and deepened its channel as the rock formations of the Berkeley hills were folded and uplifted. The sides of the strait afford excellent exposures of the formations. The folding and faulting of the strata is easily viewed and can be mapped in detail.

The bedrock group of rocks consists of a thick series of firmly to weakly cemented sandstones, weak sandy and clayey shales and a formation composed largely of volcanic ash. These rocks belong to the great series of Cretaceous and Tertiary formations so well developed in the Coast Ranges of California.

The bedrock of the barrier sites, except site C, on the Carquinez Strait belongs to the second oldest member of this group, namely the Chico formation of Cretaceous age. The Chico sandstones are fairly well cemented. The sandy shale is not so strong. The bulk of the formation is made up of ledges of sandstone, varying in thickness from a few inches to 20 feet and alternating with bands of shale. These are shown in Plates D-V and D-VI.

In the Carquinez Strait region the formations have suffered folding of various degrees of intensity. Some of the folds are broad and open, some are closely appressed and some are overturned. Close folding, crushing and buckling has taken place, especially along the course of the major faults which cut this region. These faults are discussed in the paragraph on earthquake hazard. At the barrier sites, however, the strata dip uniformly westerly and southwesterly at steep angles of from 40 to 90 degrees.

Suitability of the Carquinez Strait Sites.

Army Point Site—The original Army Point site lies approximately in the position of the new Southern Pacific bridge at Martinez. This necessitates moving the site either up or down stream. Two alternative sites are shown on the geological map, Plate D-IX. Both sites are parallel to the strike of the formation which dip at steep angles of 60 to 70 degrees down stream. The upper site, C″, lies along a massive bed of sandstone in the sandstone-shale Chico formation. The lower site, C′, lies on the massive sandstone at the base of the Martinez formation, shown in Plate D-VII. Neither crosses any known fault and both are satisfactory from the geological standpoint.

Benicia Site—This site, D on the map, crosses the Sunol-Southampton fault and is not approved. Two alternate sites, D′ and D″ are suggested. The formation is the interbedded sandstone and shale of the Chico formation. The beds dip steeply at each end of the site, but the dip decreases to a horizontal attitude under the strait where the axis of the Martinez syncline is crossed. Both alternate sites are fairly close to the Sunol-Southampton fault, but otherwise are satisfactory.

Dillon Point Site—The Dillon Point site crosses the narrowest part of Carquinez Strait. A barrier at this site would be the shortest of those suggested. The unsatisfactory features are the lack of room for adequate spillways and for locks.

The bedrock is the alternate thin-bedded sandstone and shale, with occasional thick beds of sandstone of the Chico formation. On the north bank of the strait one massive bed of sandstone forms a good landing place for the structure.

The strata dip southwesterly at angles of 40 to 50 degrees and strike at an angle of 30 degrees to the direction of the site. The foundation site is satisfactory. It lies one-half mile west of the active Sunol-Southampton fault. This is closer than is desirable and would call for careful designing if concrete were used in any part of a structure.

Sites Near the Carquinez Bridge—Two sites, one above and one below the Carquinez bridge, are mentioned in Bulletin No. 22, but were not given detailed study. They are decidedly inferior to the sites described, with the exception of the original Benicia site. The upper site from near Semple Point to Crockett is approximately parallel to the structural trend of the region. It lies on the closely folded weak shales with minor thin-bedded sandstone. This is the weak portion of the Chico formation. It also is fairly close to the Mare Island fault system.

The lower site, from near Tower Hill to a point between Valona and Vallejo Junction, has the same weak foundation rock as the upper site, crosses the geological structure lines at an acute angle and is anchored on the south close to the Mare Island fault zone. Next to the original Benicia site it would be the least satisfactory site in so far as foundation conditions are concerned.

Summary and Conclusions—Topographic and geologic studies indicate that the Haywards fault and the Sunol-Southampton fault are active. The earthquake record also indicates they are active, as is also Mare Island fault system.

The foundation rock of all the sites in the Carquinez Strait is satisfactory except for the earthquake hazard. Because of this hazard no barrier should be built across a major fault. This would eliminate the original Benicia site and the site extending southwest from Semple Point. Alternative sites at Benicia, approximately parallel to the Southampton fault and one to two miles distant therefrom, are suggested.

All sites should be parallel to the direction of the major faults. These faults are all approximately parallel at the Carquinez Strait, and their average strike is approximately north 40 degrees west. Experience during the San Francisco earthquake showed that structures parallel to the fault were much less affected than those at right angles to it.

Shocks of an intensity of X, Rossi-Forel scale, have occurred four times in four different places in the region. Therefore, structures should be designed to resist a shock of this intensity.

Rock fill and earth fill structures properly designed should withstand such shocks. An earthquake-proof concrete structure would be more difficult to construct because of the non-elastic and heterogeneous character of the foundation sites. In spite of these difficulties, however, concrete structures such as were designed in Bulletin No. 22 probably could be built.

Moderate seismic water waves, often referred to as tidal waves, should be provided for in the plans. A sharp change in the level of Suisun or San Pablo bays, due to earthquakes, would cause such a wave.

Geology of the San Pablo Region.

The San Pablo and San Pedro peninsulas constitute a long, narrow, partly drowned mountain range projecting above the waters of the adjacent San Francisco and San Pablo bays. Here is located the most westerly of the barrier sites investigated.

The bed rock formation consists of much older and much harder sedimentary rocks than those exposed at the Carquinez Strait. The rocks are hard sandstone, commonly called quartzite, and black shale, in places approaching slate in hardness. This group of rocks is known as the Franciscan formation of Jurassic age. This formation is the bed rock of the city of San Francisco, hence the name, and many will be familiar with its characteristics. It can be viewed and studied by engineers in the numerous quarries on both the San Pablo and San Pedro peninsulas. As exposed in these quarries it contains massive sandstone beds, up to 50 feet in thickness, which are quarried for crushed rock. The sandstone beds are interstratified with shale, which, of course, is the weak and yielding portion of the formation. The member containing the massive sandstone is both overlain and underlain by alternate thin-bedded sandstone and shale. There are horizons composed wholly of thin-bedded shales, a few horizons of cherts and a few small intrusive masses of serpentine.

The geological structure of the region is complicated. Faulting, shearing, jointing and crumpling of shale members occur. No single "key bed" was recognized throughout the area and no fossils occur in the rocks. Hence it is difficult to determine the amount of movement along either major or minor dislocations.

The San Pablo-San Pedro fault is probably a major fault. In the absence of data proving activity it may be assumed inert, as explained in the more detailed discussion of the geology of the San Pablo Peninsula in a later portion of the report. The possible San Rafael and Corte Madera faults were suggested by a reconnaissance trip, but not studied in detail. The cross faults of the San Pedro region are accompanied by close crumpling of the shale beds. They are probably of minor importance.

None of the above described faultings cross the San Pablo site. The main San Pablo-San Pedro fault lies one-half to one mile east of the site. The major flaw of the foundation site is the general crushed conditions of the rocks of the peninsulas. The massive sandstone beds are aggregates of joint blocks rather than beds. Joint planes are more prominent than bedding planes. The shales are intricately folded and faulted.

The site crosses obliquely the general strike of the formations. As shown by drill holes, a barrier would rest in part on massive sandstone and in part on contorted shale. Because of the cross faulting of the formations it would be impossible to set a barrier on a single continuous bed of sandstone. However, if the site were given further consideration, detailed geological studies should be made to locate the most favorable beds for the foundation of a barrier.

Suitability of San Pablo Site.

The crushed condition of the foundation rock will intensify the effects of earthquake shocks originating in the San Andreas, Haywards, or Sunol faults, or any other active fault of the San Francisco Bay region.

The great difference in strength between the sandstone and shale would add further difficulties to the building of a safe concrete structure. On the San Pablo peninsula excavations in steeply dipping shale overlain by sandstone have been unstable and subject to landsliding.

The sandstone (quartzite) is of ample strength to support any ordinary man-built structure, but if shear zones or crushed zones should be encountered they would require careful engineering treatment. The site would appear more suitable for a rock-fill structure than for an extensive concrete structure. The latter would call for further detailed foundation study and careful designing of a structure which would rest on a foundation composed of strong rocks, alternating with weak rocks, and cut by serious cross flaws (shear zones and minor faults).

CHAPTER II

SCOPE OF INVESTIGATION

Purpose of Geological Studies in Connection with Foundation Sites.

It appears advisable to discuss at the outset the possible applications of the results of a detailed geological investigation to the evaluation of the suitability of natural foundations for man-made structures.

The geological investigation of the natural foundation of a proposed structure deals chiefly with bed rock. It is desirable to determine the kind of foundation rock—*i. e.*, whether igneous, metamorphic, or sedimentary; its character, whether crystalline, firmly cemented or weakly cemented; whether massive, thick bedded, thin bedded, or alternately bedded shale and sandstone; whether the rock is soluble or insoluble; whether fresh or weakened by weathering; and finally its strength, as determined by microscopic examination and crushing tests.

If the above information were all that were desired, an examination of the drill cores should furnish much of the data. Drill holes usually give information regarding the depth to bed rock, thickness of the covering formation, usually alluvial sands and clay, and afford specimens of the rock penetrated by the drill. If the holes are carried down into the bed rock, some notion of the geological structure may be obtained. For example, the amount of dip of the strata, if sedimentary, may be shown in the core recovered, but the direction of the dip can not be determined without special methods of determining the orientation of the cores before they are broken off. However, drilling is often discontinued when the bed rock is reached, and in that case the only information to be obtained therefrom is the character of the foundation rock immediately underlying the softer covering formations. Unless the drilling is done under the observation of a geologist much of its potential value may be lost.

Usually a geological examination and mapping of the region is necessary to determine the structure of the foundation rock, *i.e.*, its dip, its stratification and especially the faulting and folding it has undergone. The folds may be determined by detailed observation at the locality, but the faults are often obscure. Minor fractures may be well exposed, but the main dislocation may not be disclosed anywhere and its existence and position can be deduced only from a general geological study of the region. Therefore, a study of the faults, especially an evaluation of the earthquake hazard furnished by the various faults, usually involves the study of a large area adjacent to the locality where a structure is to be placed, as well as a detailed investigation of the seismic history of the region.

Of course the need for detailed and comprehensive geological information depends largely upon the type of structure proposed and the locality in which it is to be built. Some concrete structures call for a homogeneous, strong and elastic foundation, and their importance may justify searching geological investigation of the foundation rock. Rock fill and earth fill structures demand merely that the foundation will not yield unduly under the weight of the fill. Such structures also are believed to be less liable to serious injury from earthquakes than those of concrete. Structures supported on piles can be built over clays and muds. A floating or semifloating barrier would not rest on bed rock.

All structures, however, would be affected by earthquake disturbances. Therefore, in a region of seismic activity, such as this in which the barrier sites are located, all data regarding faults, and the activity thereof, are pertinent.

The question of safety has two phases, namely, that of a structure itself, and the effect failure would have on the neighboring life and property. The latter is by far the more important. Fortunately a salt water barrier would raise the water back of it but a few feet above mean tide level, and hence there would be no such serious problem of safeguarding life and property as must be solved before the building of a dam to impound water above a city or inhabited region.

The region is one of high seismic activity and a number of faults cut the formations in the vicinity of the barrier sites. The investigation has resolved itself, therefore, chiefly into a study of these faults. All seismic records available have been studied. An attempt has been made to evaluate the relative earthquake activity of these faults in order to determine the most satisfactory location for a barrier in respect to structure and faulting.

Locality Investigated in Study of Barrier Sites.

These studies covered an area extending along the Sacramento River and Suisun and San Pablo bays from the confluence of the Sacramento and San Joaquin rivers to the peninsulas of San Pedro and San Pablo, which bound San Pablo Bay on the west.

The area investigated is shown on the geological map, Plate D-IX. It covers a strip of about eight miles wide along the southern portion of the Antioch, Carquinez and Mare Island quadrangles, and a longer strip along the neighboring Mount Diablo, Concord and San Francisco quadrangles, as published by the United States Geological Survey.

In addition to the topographical maps, aerial photographic maps made for the U. S. Engineers were made available through the courtesy of Lieut. Col. Thomas M. Robins. These were found to be of great assistance in the detailed mapping of the region.

The area of this region is about 600 square miles. Detailed mapping, however, covered only a narrow strip two or three miles wide along the river. The geological map, Plate D-IX, includes both detailed work by the author and that corrected after the geological maps of Lawson and Weaver.

CHAPTER III

TOPOGRAPHY

General Description.

The region under investigation is embraced chiefly within the basins of Suisun and San Pablo bays and the intervening Carquinez Strait, through which the combined Sacramento and San Joaquin rivers traverse the Coast Ranges on their journey to the Pacific Ocean. To the west of the peninsulas of San Pedro and San Pablo lies San Francisco Bay, which is connected with the ocean by a lower strait known as the Golden Gate.

The salient features of the topography of central California, shown by the frontispiece photograph of the relief map of California (Plate D-I), are the westerly sloping Sierra Nevada, the Great Central Valley of California, with its fertile delta lands lying along the course of the lower San Joaquin and Sacramento rivers and extending in the region under discussion to Suisun Bay, and the Coast Ranges, which form the barrier between the Pacific Ocean and the Great Central Valley of California.

The Coast Ranges are a complex of nearly parallel individual ranges, which trend more westerly than the course of the composite range, and therefore extend *en échelon* into the Pacific Ocean. The ranges are not due primarily to erosion, but to uplift of the individual ranges and the down faulting or down folding of the adjacent valleys or troughs.*

The antecedent Sacramento River maintained the course it occupied before the Coast Ranges were formed, cut the rising ridges of the growing Coast Ranges at Carquinez Strait and the Golden Gate and flooded the adjacent down-warped valleys which now form Suisun, San Pablo and San Francisco bays.

Topographic Divisions of the Region.

The area studied falls naturally into three topographic divisions, namely, the lower Sacramento River and Suisun Bay area, the Carquinez Strait area, and the San Pablo Bay area.

Lower Sacramento River and Suisun Bay Area—Here the delta area merges into that of Suisun Bay, or in other words Suisun Bay is a completely drowned delta. Surrounding the delta are the low flat plains which slope up gently to the high hills and low mountains surrounding the bay.

In the delta, islands rise a few feet above a maze of interconnecting channels or river sloughs. These islands are now reclaimed by dykes. The surface formations of the islands and sloughs consist of incoherent and treacherous clays, muds and sands deposited by the river, and, in some cases, peat and muck resulting from decayed vegetation.

* W. M. Davis is very insistent that the term valley should be applied only to a depression carved by a river. He would designate a structural depression produced by folding or faulting as a trough.

This central flat and flooded area extends up to the level of high tide, above which are the gentle piedmont slopes, and is floored by sandy formations on the south. On the north there is an old eroded terrace made up of like material, which rises 100 to 200 feet or more above the bay. This is called the Montezuma Hills.

The mountains rise abruptly on the south of the bay, and, on the north, individual hills and short ranges protrude through the alluvial fill of the delta. These drowned hills are Means Hill, Kirby Hill, Bradtmoor Island and Potrero Hills. On the northwest the region is bounded by the steep Sulphur Springs Range.

Topography of Carquinez Strait Region—The salient feature of this region is a great river channel, which is 300 feet deep from the top of the cut to tide level and which extends 100 to 200 feet below tide level to the bottom of the rocky gorge, as shown by drilling. This gorge has great natural scenic attractions, but, being occupied by factories, oil refineries and other commercial establishments, its utilization as a suburban district has been postponed indefinitely.

Distinct terraces along the river are exposed at Benicia, Antioch, Suisun Point and elsewhere. These lie at various levels up to about 100 feet above the present high-tide level. They show a filling of the gorge subsequent to its excavation to a height of at least 100 feet above present tide level, and that reexcavation has since taken place.

Topography of San Pablo Bay Area—San Pablo Bay is a circular body of water bordered on the north by an area of dead sloughs, which extends into the embayed highland region of Sonoma and Marin counties.

On the southeast the Berkeley Hills plunge under the waters of the bay and the attractive scenery of the Carquinez Strait continues in this direction. To the south of the bay and west of the Berkeley Hills is a low platform, here denominated as the Richmond Platform, on which the towns of San Pablo, Richmond, Berkeley and Oakland are situated. To the northwest of this platform rises the range of Potrero de San Pablo, or the San Pablo Peninsula. This peninsula juts far out into the bay towards San Pedro Point, separating San Pablo Bay from San Francisco Bay, and here is the most westerly of the barrier sites.

Fig. A. GENERAL PANORAMA OF CARQUINEZ STRAIT

Fig. B. SOUTHAMPTON FAULT, SOUTH OF CARQUINEZ STRAIT

CHAPTER IV

GEOLOGIC AND PHYSIOGRAPHIC HISTORY OF THE REGION

The present topography is but the last of an endless succession of past landscapes that have merged, one into the other, under the play of the geological processes of earth movement, erosion and deposition.

It is not proposed here to describe technically the ancient topography of this region, or sketch the gradual development of the topography of today. There will be considered merely the three main episodes in the development of present day topography, which are:

1. An epoch of intense folding and faulting;
2. An epoch of erosion, which uncovered the folded strata and cut the region down to a gently rolling surface of subdued relief; and
3. A general warping of the erosion surface thus formed, accompanied by dislocation of this surface by continued fault movement.

A brief summary of these events may assist in the understanding of the subsequent discussion of the structure of the region, and especially of the faulting.

Epoch of Intense Folding and Faulting.

All the formations of this region, except the undisturbed Pleistocene sands, terrace gravels and recent alluvial deposits, have undergone intense folding and faulting. As the youngest formation affected by this disturbance is of Pliocene age, this epoch may be dated as late Pliocene or early Pleistocene. It is as of yesterday, geologically speaking.

In places the folding was gentle and the arches of considerable extent. In other localities close folding, collapsing of rocks under compression and even overturning of folds took place. The lines of most intense disturbance developed along the major faults, for folding and faulting in this region are the result of one and the same set of stresses of compressive nature.

Folding of this character could not take place at the earth's surface. The strata involved are, in general, incompetent, *i.e.,* they would break rather than fold, unless overlain by considerable weight. The oldest formation (the Franciscan) is brittle. The youngest formations are a heterogeneous group of flexible shales, massive sandstones, thin bedded weak sandstones and layers of volcanic ash. The depth at which this heterogeneous assemblage of rocks could be regularly folded is probably from several hundred to several thousand feet. Therefore, to expose these rocks a like thickness of material was removed in the subsequent epoch of erosion.

Epoch of Pleistocene Erosion.

Erosion continued long enough to reduce the newly elevated Berkeley Hills to a plain of low relief. If one climbs the hills and stands on top of the ridges, he finds that the top of the range is gently rolling. If in

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Epoch of Pleistocene Erosion.

Erosion continued long enough to reduce the newly elevated Berkeley Hills to a plain of low relief. If one climbs the hills and stands on top of the ridges, he finds that the top of the range is gently rolling. If in imagination he fills in the recent gullies, he finds that the surface thus reconstructed is gently domed, with a gentle slope or tilt to the north and a steeper slope southwest.

A warped surface of this type could not be developed by erosion alone. The final result of the erosion processes is to produce a flat or gently sloping plane. A steep slope is first dissected by innumerable gullies, and only becomes flat when erosion has reached a base level.

We may assume, therefore, that the old erosion surface, imperfectly shown on the ridges on either side of Carquinez Strait, records the nearly complete planation of the first Berkeley Hills range by erosion.

A second epoch of earth movement gently arched and faulted the range and produced the second or present range. Such deformation is shown most strikingly on the southwestern face of the Berkeley Hills, north of Berkeley, where the upwarping of the old topographic surface along the Haywards fault is most striking.

Present Day Surface.

The deformation that warped and faulted the Pleistocene erosion surface was extremely slow. We must not imagine that the three epochs mentioned above are distinct, that all intense folding was completed in the first epoch, that complete base leveling took place without movement, or that folding and tilting occurred only after the base level was completed. These epochs overlapped, and the epoch of erosion was terminated before its work was completed.

Present day erosion has attacked ridges, which are largely of an anticlinal nature due to upwarping, and deposited much of the debris obtained therefrom in the bordering valleys, which are largely synclinal. As yet it has not proceeded beyond the stage of topographic youth. The old erosion surfaee still occupies a large portion of the upper parts of the ridges.

In addition to the gully system cut by the ordinary process of erosion, faulting has left its mark on the topography. One of the best known active faults of California is the Haywards rift. Along the line of this rift, at the extreme northwestern end where the fault approaches San Pablo Bay, the surface is arched rather than faulted. Northeast of Oakland a "fault valley" has been opened up along the line of the faulting. This valley is probably due to the dislocation of the surface by faulting and to the easy erosion of the crushed material along the fault line.

Recent movement along the fault is attested by the fact that youthful stream valleys, which cut across the line of the fault, have been offset by fault movement, the south side of the fault moving to the west along the Haywards rift. We have evidence, therefore, of a topographic nature, indicating recent activity and continued earth movement along the Haywards fault. The seismic record also shows that movements on this fault have caused a number of earthquakes, moderate to severe in character, and that at least one was catastrophic.

The topography of the second active fault of the region, the Sunol-Southampton fault, gives evidence of recent movements, but this evidence, shown in Plate D-II-B, is less easily read than that along the Haywards fault.

MARE ISLAND FAULT, SOUTH OF CARQUINEZ STRAIT

This discussion of the recent dynamic and topographic history postulates an epoch of active and intense earth movement and close folding and faulting; an epoch of relative crustal stability during which erosion cut down and removed the newly upraised range, and an epoch of renewed crustal movement, with gentle folding and pronounced faulting, along the major faults. Of course, the history was not as simple as this, but nevertheless it is believed to be broadly true.

The above outlined history does not mean, however, that the deformation in the earlier epoch is much different in character from the earth movement going on today. A theory, not yet accepted, is that extensive folding is a phenomenon which takes place at some depth. Above this folded zone the surface may be deformed by gentle warping, the folded region rising in a gentle dome with down warps on either side. Faulting, which accompanies the deep seated folding, might be carried through to the surface along the major lines of readjustment. According to this hypothesis, close folding may be taking place today at depth, with gentle doming, fault movements and earthquakes affecting the surface.

CHAPTER V

GEOLOGY

The geological column of the Coast Ranges of California is nearly completely represented by the formations present in the area studied. The oldest rocks belong to the Franciscan formation of Mesozoic age, which, in this region, consist largely of cemented sandstone and quartzite, shale, slate and chert. The youngest rocks are the clay, the tule mud and the sand now depositing in the Sacramento River system and the alluvial deposits of the tributary intermittent streams. The formations of the intervening periods, namely, the Cretaceous, Tertiary and the Quaternary, some of which are of great thickness, are present.

A detailed description of all these formations would encumber the report, which is technical rather than scientific, but a descriptive chart has been prepared for the geological reader. This chart, presented in Addendum III, shows the formations mapped, with equivalent formational names used by other geologists.

Franciscan Formation.

This formation is named after the city of San Francisco, where it is well exposed. It is the principal geologic formation of Tiburon Island and the Marin Peninsula and forms the core of many of the Coast Ranges. In many localities the formation is complex. It consists not only of shales, slates, sandstones, quartzite and cherts, but also contains a great variety of unusual types of schists and of intrusive rocks, the most abundant of which is serpentine.

The Franciscan formation is the bedrock of the Richmond Platform and extends up to the Haywards fault, which separates the Franciscan group from the younger Cretaceous and Tertiary rocks. Here the complex schists and intrusive rocks are lacking and the formation consists largely of quartzite, cemented sandstone and shale.

In the San Pablo and San Pedro region, massive layers of sandstone are well exposed in the quarries, but the formation generally consists of alternating strong and weak members. The massive sandstone and quartzite is strong; the interlaminated sandstone and shale is weak. Structurally the rocks are very generally crushed and contorted. These will be described more in detail in the paragraphs on structure.

Cretaceous Formations—Knoxville and Chico.

Two formations of Cretaceous age occur in the area. They are known as the Knoxville and the Chico formations.

Throughout California, the Knoxville formation is predominantly shale, although it is locally sandstone and even conglomerate. In this region it is almost wholly shale. The shale is a dark, sandy, clay shale, considerably indurated, and resembles greatly the Franciscan shale. In mapping it was found difficult to differentiate the Knoxville from the Franciscan along certain contacts. The Knoxville occurs north of the area in the eastern portion of the Sulphur Springs Mountains. It does not constitute bedrock at any of the barrier sites, and hence does not need detailed description.

The Chico formation is the most important of the region from the viewpoint of the salt water barrier studies. It is a bedrock of all of the sites, except the San Pablo and the Chipps Island sites. The Chico is a thick formation containing massive yellow sandstone in the upper portion, some of which is markedly concretionary. These massive sandstones are all well exposed at, and west of, the tunnel east of Selby (Plate D-IV), and on the southwest border of Mare Island. Could these be utilized they would form the best foundation rock of the Cretaceous formation.

The bulk of the formation consists of alternating gray sandstone and gray to brown sandy shale, with occasional massive sandstone members to give additional strength to the foundation rock such as is indicated in Plates D-V and D-VI. A zone of several hundred feet in thickness of dense gray shale, practically free from sandstone, occurs especially in the vicinity of Eckley where the shale is used for the manufacture of brick.

The Chico formation is exposed from Vallejo Junction and Mare Island, on the west, to Southampton Bay, on the east. It occurs again at Army Point and Suisun Point. The Southern Pacific bridge at Army Point and the Carquinez bridge at Valona are set on the alternating sandstone and shale phase of the Chico formation indicated in Plate D-VI, and the results of these constructions should give the engineers valuable data as to the strength of this weakest variety of the Chico formation.

The Chico sandstones and sandy shales are weak in weathered surface, but excavations below the water table, especially those of the Army Point bridge, show the unaltered rocks are of considerable strength, ample to sustain a salt water barrier as designed in Bulletin No. 22.

Eocene Formations.

These consist of two formations, namely, the Martinez and the Tejon formations.

The Martinez formation (Plate D-VII) is a massive greenish-brown to gray sandstone with some interbedded shale. The characteristic green color is due to the mineral glauconite, which does not occur in the other formations. It contains calcareous strata and concretions which were used near Benicia for the manufacture of natural cement. The best exposures of this formation are north of Benicia and south and west of Martinez.

Beneath the typical Martinez sandstones there is a zone of very dark, sandy clay shale that resembles the Cretaceous shales. The contact between the Martinez and Cretaceous is often difficult to map because of these gradational shales. The Martinez sandstone weathers easily, due to the instability of the mineral glauconite. However, under water it probably would be a strong rock. None of the barrier sites encounter this formation unless the Army Point barrier should be built west of the Southern Pacific bridge.

Tejon Formation.

Under the designation Tejon formation are grouped several formations that would be separately mapped in detailed scientific work. In the vicinity of Martinez a band of shale, probably of the Oligocene age, is included with the Tejon. In the Antioch quadrangle, rocks of supposed Oligocene age have been included under the Tejon formation. Detailed separations of these formations would have no bearing on barrier problems. The Tejon formation is absent west of Southampton Bay and is not present at any of the barrier sites.

Lower Miocene, Monterey Formation.

The Monterey formation is perhaps the most interesting of all the Tertiary rocks of California. Throughout the state it consists largely of organic silica deposited by microscopic plants known as diatoms. In this region the group has little of the white organic silica, but consists of several bands of standstone and impure gray organic shale. The Monterey formation was subdivided into four groups by Lawson. A fifth sandstone, known as the Briones, was separately mapped by him. All these are included in the Monterey, as mapped in this study. The Monterey does not constitute the bedrock of any of the sites studied.

Upper Miocene, San Pablo Formation.

The San Pablo formation is widely distributed through central California, and is everywhere characterized by a striking blue color. It is best exposed in the region at Oleum where the massive blue sandstone stands in a vertical position on the north limb of the Rodeo syncline. Because of its striking character it is easily mapped, and it was given cartographic representation because its outcrop helps outline the structure of the region.

Pliocene, Pinole Tuff and Orinda Formation.

The Pinole tuff consists largely of white volcanic ash with beds of pumice. It forms striking outcrops at Lone Tree Point and on the highway south of Rodeo. The overlying Orinda formation, of which it constitutes the base, outcrops along the margin of the hills south of Pittsburg and Antioch. These formations are the youngest involved in the deformation of the region.

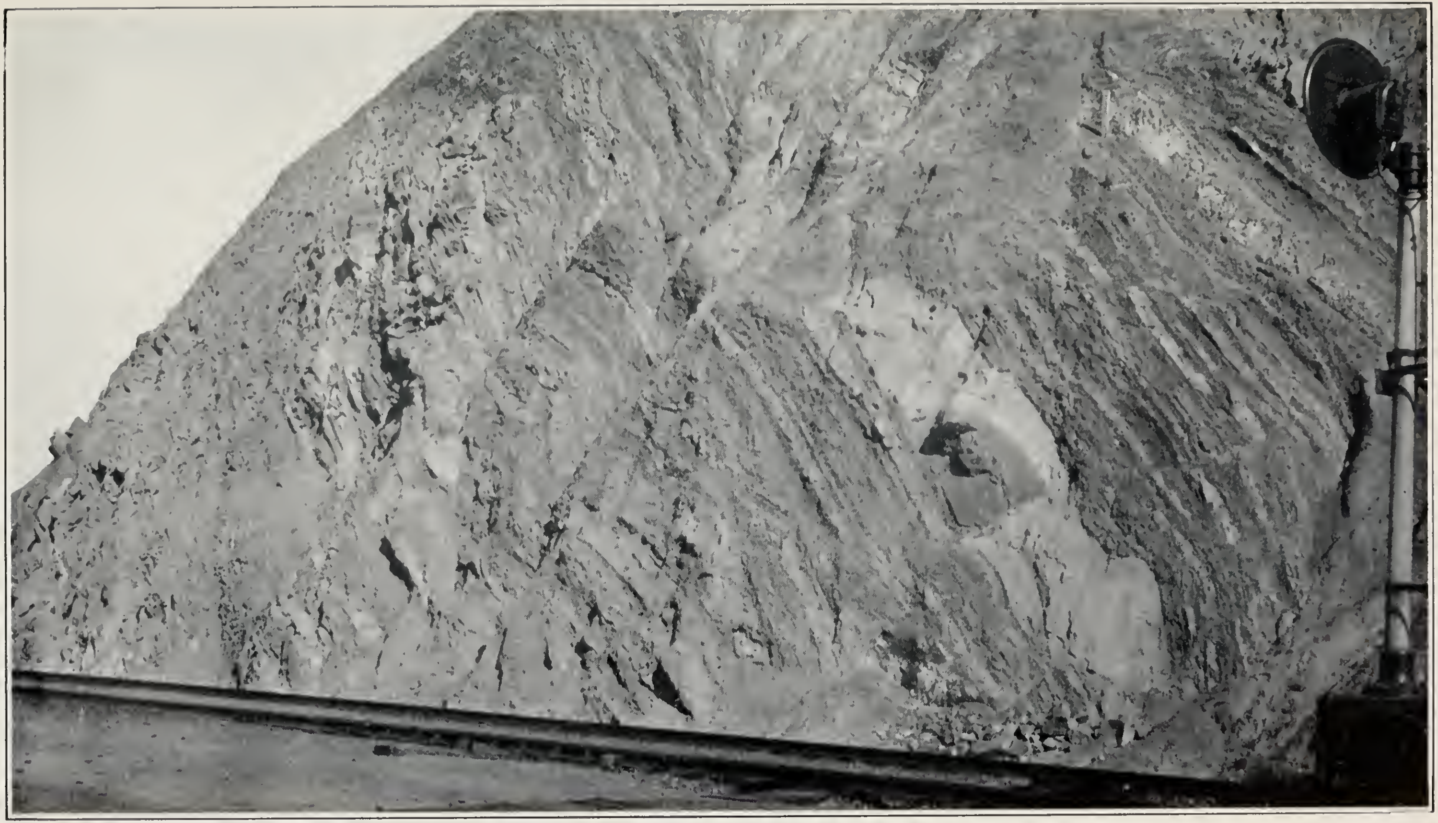
Pleistocene, Pittsburg Sandstone, Terrace Sand and Recent Alluvium.

Subsequent to the epoch of intense folding described above, the Pleistocene formations were deposited, and everywhere show a nearly horizontal attitude. The most extensive of these formations is the Pittsburg sandstone, a soft gray weakly cemented sandstone developed at the foot of the mountains in the Antioch quadrangle. It constitutes the surface formation of the Montezuma Hills, north of the Sacramento River.

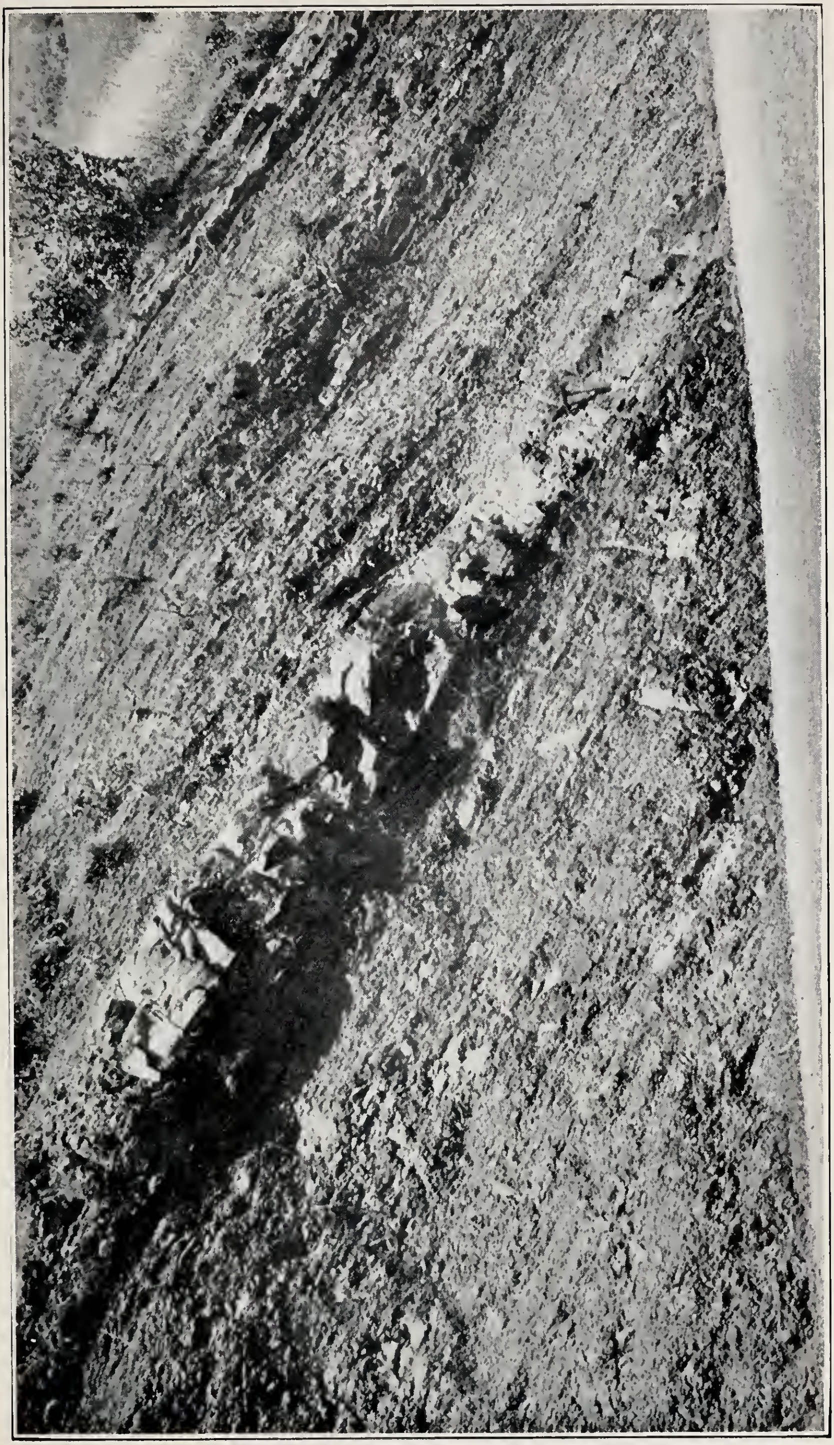
Coarse terrace sands and gravels, probably a phase of this same formation, occur at Antioch, Benicia, Martinez, Army Point and elsewhere.

Recent Alluvium.

The deep alluvial deposits of sand and gravel beneath the incoherent sands and clays of the delta region may well be of Pleistocene age. The

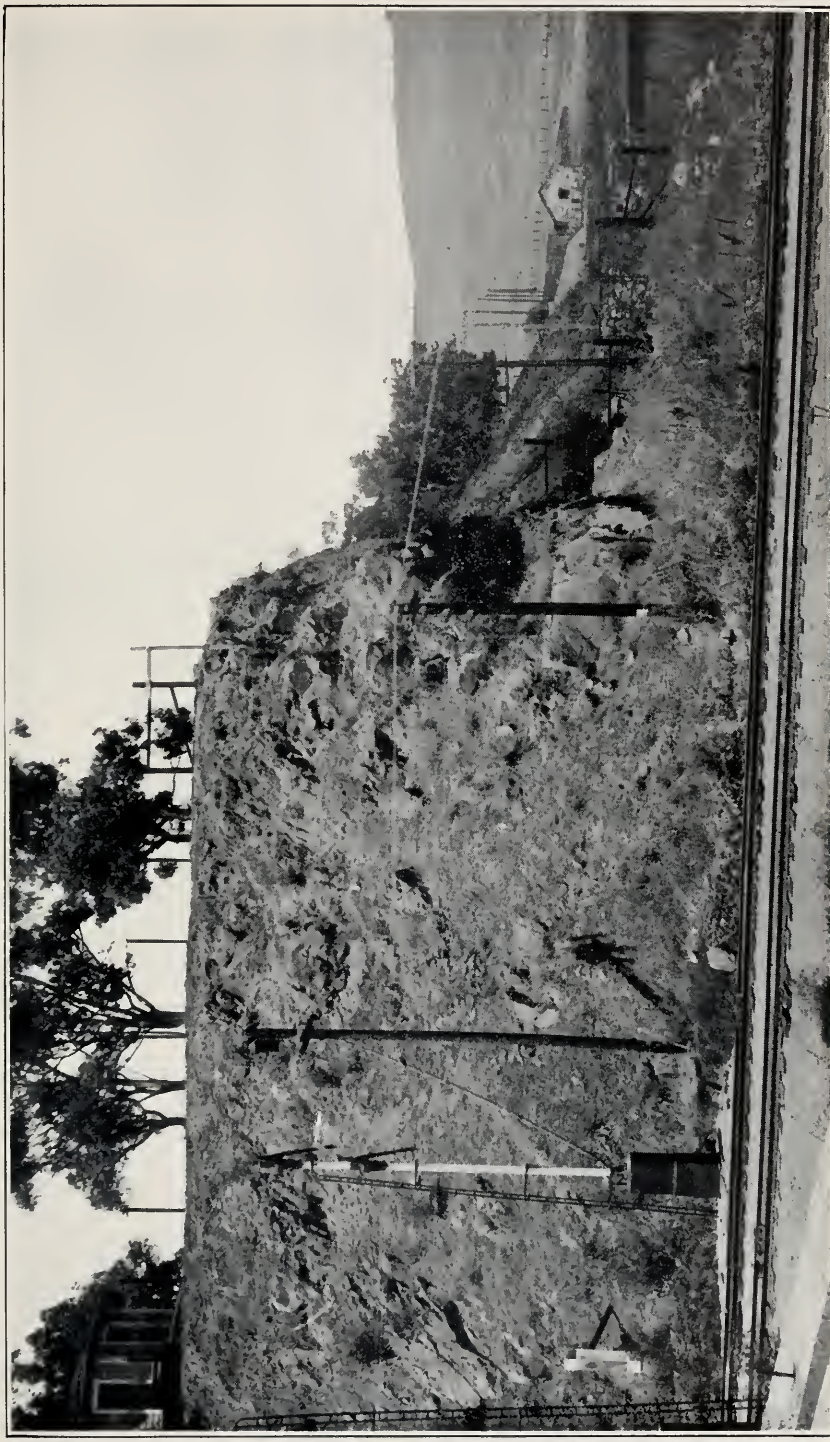


CRETACEOUS SANDSTONE AND SHALE, CRUSHED AND FAULTED, ALONG WEST BRANCH OF MARE ISLAND FAULT



CHARACTERISTIC EXPOSURE OF CRETACEOUS (CHICO) SHALE WITH MINOR LAYERS OF SANDSTONE

CHARACTERISTIC EXPOSURE OF CRETACEOUS (CHICO) MASSIVE SANDSTONE INTERLAYERED WITH SHALE



OUTCROP OF MASSIVE MARTINEZ SANDSTONE

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drill holes along the Sacramento River show cemented sand and gravel, overlain by sticky blue and green clays, black tule clays and sandy clays. These cemented sands and gravels represent the earliest formation laid down in the present bedrock channel of the Sacramento River. The recent alluvial material only is without strength, but the clays are extremely slippery and dykes and embankments built on these may settle for years before equilibrium is obtained. Structures of any importance must be supported on piles.

CHAPTER VI

GEOLOGIC STRUCTURE

The geologic structure is an important item in determining the strength of any foundation site. If the formations dip, it is important that the man-made structure be built if possible to take advantage of the slope of the strata. If alternate strong and weak strata occur, the strong members of the foundation should be selected as foundation rock. If shear zones have cut the foundation area, the zone least affected by shearing should be selected as the site for the structure.

In regions of seismic activity all of the faults should be scrutinized closely, the position of the contemplated structure in respect to the faults should be considered and localities floored with incoherent material, such as clay and sand, should be studied most carefully before a structure supported on piles is undertaken.

The area is divided into three structural regions. This division corresponds closely to that used in the discussion of the topography and structural units are as follows:

1. Antioch-Suisun Bay region.
2. Carquinez Strait region.
3. Richmond Platform, and the peninsulas of San Pedro and San Pablo.

Antioch-Suisun Bay Region.

General Structure and Geological Formations—Suisun Bay is a basin, both topographically and structurally. It is surrounded on the south by the northerly dipping Cretaceous and Tertiary rocks, which plunge under the flat lying Quaternary sands at a steep angle at the margin of the Mount Diablo range (Plates D-VI and D-VIII). On the east the horizontal Pleistocene formations are well exposed in the Montezuma Hills, and northwest of these are the drowned ranges, which are made up of closely folded and upturned Cretaceous and Tertiary rocks, protruding above the recent alluvium of Suisun Bay. The south side of this line of drowned hills exposes southerly dipping sedimentary rocks and forms the north rim of the Suisun basin.

The Franciscan formation and Knoxville shale and lava flows, which belong to the series denominated the Napa andesites, bound the basin on the west. These are folded and faulted, but at the margin of the sloughs, which bound Suisun Bay on the north, the general dip is to the northeast and the strata therefor constitute the southwestern limb of the Suisun syncline.

Faults—The Mount Diablo thrust lies at the western edge of the region. This has been described as a low angle thrust, old geologically compared with the other faults of the region. Clark describes folding and faulting of this old thrust plane. It is probably not active.

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PANORAMA SHOWING GENERAL GEOLOGIC STRUCTURE AND FORMATIONS OF HILLS SOUTH OF SUISUN BAY

No other fault is exposed in the area. However, the east end of the Potrero hills is cut by a fault and a second parallel fault is known in Vaca Valley. These, projected, would pass a mile or so east of Antioch. The cover of alluvium and Pleistocene deposits hide these faults, if they exist. Antioch has suffered from numerous and heavy earthquake shocks due, possibly, to the covered faults.

Data Available Regarding Quaternary and Recent Formations of Antioch-Suisun Bay Region—The Quaternary soft sandstones and silts, terraced gravels and sands and the recent sands, clays and muck of the river channel and delta area are the important formations, in so far as the barrier studies are concerned. The data regarding these formations are meager. Little is learned from surface examination as the delta region is an expanse of swamp and water.

The following data were made available regarding the materials of the river channel and adjacent delta lands in the general vicinity of the Chipps Island site:

1. Test borings in the vicinity of New York Slough, opposite Pittsburg, furnished by the U. S. Engineer's Office, Sacramento (June, 1928). These holes were 25 to 40 feet deep and penetrated "soupy peat," dry peat, clay and some fine sand.

2. Chart of borings at the ferry crossing, Chipps Island, furnished by the Engineering Office, Sacramento Northern Railroad. These borings were all 125 feet deep, measured from mean tide level. They record soft mud, blue clay, yellow clay and sands, and below 50 to 75 feet stiff clays and hard sands were encountered in some of the holes. In many of the holes, however, the bottom formations were blue clay and sand. The data were not sufficient to assure a hard clay or sand bottom across the channel at the depth of 125 feet and the tentative conclusion was drawn that at that depth the material is to be classified as "Recent Alluvium" of incoherent clays, muds and sands

3. Only three satisfactory logs of wells in the neighborhood of Chipps Island site were obtained in the data collected on water wells. Two of these wells are on Van Sickle Island and one at Duttons Landing. These furnish an indication only of the character of the alluvial fill of the delta area.

The well at Duttons Landing records:

0 to 6 feet, peat.
6 to 26 feet, blue mud and quicksand.
26 to 200 feet, blue clay and gray clay in alternating layers.
200 feet plus, hard. dry clay, brown sand, hardpan, etc. (probably the Pittsburgh formation).

The well three-fourths of a mile west of the drawbridge over Montezuma Slough is critical in the study of the Chipps Island site. It records 107 feet of peat, blue mud, fine blue sand and blue clay, and from 107 to 141.5 feet, alternate yellow clay and yellow sand (probably the Pittsburg formation).

Several wells in the delta area report 60 feet of "muck" and well pipe shoved down this distance.

It is concluded from the meager data available that the recent formation of clays, tule muds, silts and "muck" is 125 feet thick, on the average, and in some cases thicker.

No other fault is exposed in the area. However, the east end of the Potrero hills is cut by a fault and a second parallel fault is known in Vaca Valley. These, projected, would pass a mile or so east of Antioch. The cover of alluvium and Pleistocene deposits hide these faults, if they exist. Antioch has suffered from numerous and heavy earthquake shocks due, possibly, to the covered faults.

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Carquinez Strait Region.

Considered as a structural unit, the region extends beyond the mouth of the strait at the promontory of Oleum and includes all of the Berkeley Hills fronting San Pablo Bay up to Pinole Point. This block includes complexly folded and faulted Cretaceous and Tertiary rocks, up to the Haywards fault which separates this area from the Richmond Platform of Franciscan rocks, covered by recent alluvium.

The structures extend across Carquinez Strait, for the ancient river cut its channel without regard to geological structure or rock formation, and on the walls of the canyon thus carved is depicted the geology of the folded, faulted and upwarped Berkeley range.

General Description of Folded Structures—The salient structural features of this region are the Martinez syncline and the Rodeo syncline. These synclines are separated by a folded anticline, the parallel folds of which are well exposed in the town of Crockett. The folding is complex and intense. The northeast limb of the Rodeo syncline is overturned, as is the west limb of the Martinez syncline. The folded structures are cut by faults described below. Along these faults the most intense folding and overturning has taken place.

Along the Southampton fault, exposures on the banks of the strait show crumpling, close folding and overturning of the strata. Between the two branches of the Franklin Canyon-Mare Island fault zone, the most intense folding has taken place. On the south coast of Mare Island some five closely oppressed folds are exposed within a distance of about a mile.

The folded structures, so well exposed along Carquinez Strait, continue along the southeastern boundary of San Pablo Bay to Pinole Point. The southern limb of the Rodeo syncline exposes an even greater thickness of Tertiary rocks than the northern limb. The syncline is cut by the Pinole fault at Pinole, and some complex folding brings up the youngest of the Teritiary rocks, the Orinda formation, at Pinole Point. Then comes the Haywards Rift, which separates the faulted Tertiary block of the Berkeley Hills from the Richmond Platform, made up of the Franciscan formation.

Faults—The first fault that crosses in the neighborhood of Army Point is the well known Mount Diablo thrust. This fault has been mapped in detail in the Mount Diablo region by Bruce Clark, and in the Carquinez area and the region to the northwest by Dr. Weaver. As previously stated, it is believed to be an old geological feature and since it has undergone later cross-faulting and folding it could not remain a plane of weakness along which recent movement and earthquakes could take place. Therefore it is not considered an active fault. Its position is shown on the accompanying geological map.

The next important fault is designated as the Sulphur Springs Mountain fault zone. Its existence is clearly shown east of Sulphur Springs Mountain, where the Franciscan formation lies against the Knoxville shales. The fault has been encountered in a mine tunnel passing through the Knoxville shale into the Franciscan formation. The exposed fault plane dips 50 degrees northeast.

The western branch of the fault occurs along an outcrop of Cretaceous shale, which lies against the Franciscan formation, and the combined faults continue down the Sulphur Springs canyon. This fault probably crosses between Vine Hill and the ridges on which the Shell Oil Company refinery is situated. It lies about a mile east from the Army Point barrier site and is approximately parallel to the direction of the site. No physiographic evidence of recent movement was noted in the study of this fault.

The third fault is the Southampton Bay fault, probably the most interesting geological feature of the region. It is believed to be the continuation of the well known Calaveras or Sunol fault. This fault is characterized by intense disturbance of the strata in the vicinity of Port Costa. This is shown by the attitude of the dips plotted in the geological maps. There also is evidence in the topography of fairly recent movement. The general topographic surface of the hills is decidedly higher on the southwestern side than on the northeastern side of the fault. Also, the fault passes through certain topographic draws that may be the result either of erosion, because of the softness of rock weakened by it, or may actually be due to fault movement. Study of the seismic records of the region proves the fault zone to be active.

One barrier site has been suggested from Benicia across the strait in a southwesterly direction. This site lies across this fault, and the site is not approved.

All the other barrier sites are approximately parallel in direction to the main faults, and it is believed this is the most satisfactory orientation for such a structure. It would not be advisable to build a barrier across a known fault, when a satisfactory location, which does not cross the fault, can be had. The Dillon Point barrier site lies about half a mile west of the Southampton fault and while this is fairly close, it is believed a rock fill or earth fill structure, built on a good foundation, would be safe at that distance.

The Franklin Canyon-Mare Island fault system cuts off the folded anticlinal structures, or anticlinorium, lying between the Rodeo and Martinez synclines. The extraordinary folding on Mare Island, between the two branches of these faults, has been described. South of this area Lawson mapped this fault as a relatively low angle thrust, and described the Cretaceous formation as thrust over and resting upon the Tertiary rocks. His mapping and interpretation were verified by these studies. However, at the point where the faults branch, the fault planes appear to steepen up and the block between the planes has been greatly compressed, as if the thrusting movement was taken up by folding of the strata at the point where the attitude of the planes becomes steeper. The relations suggest strongly the close connection between folding and faulting in the highly deformed incompetent strata of the region. No topographic evidence definitely indicative of recent movement along the fault was observed. The gullies along the two branches of the fault may be explained as due to the erosion of soft and crushed shale.

The severe earthquake at Mare Island on March 30, 1898, followed by seven minor shocks in 1899 and 1900, has been attributed to the Haywards fault, but it is quite probable the shock generating movement occurred along the Mare Island fault. This fault is therefore classified as probably active.

The next important fault to the southwest is the Pinole fault. This fault separates the Pinole syncline from a highly-folded area to the west. It is too far away to have any direct bearing on a barrier site in Carquinez Strait.

Haywards Fault.

This fault separates two very different geological units—the Richmond Platform of bevelled Franciscan rock and the Berkeley Hills area of folded Cretaceous and Tertiary rock. Next to the San Andreas fault it has displayed the highest seismic activity of any fault in central California. The topographic evidence of recent movements are most striking.

An interesting feature along this fault is that evidence of actual dislocation begins opposite Berkeley and extends southward in the Haywards and Pleasanton quadrangles. Offset stream channels are described by Buwalda* and Russell†, and the rift valley and fresh fault scarps are striking. North of Berkeley the fault degenerates rapidly into a fold which decreases towards the north into a scarp of less than 100 feet in the vicinity of the town of San Pablo. This is in contrast to a vertical movement of 1500 feet opposite Berkeley and Piedmont.

As far as surface indications go, the fault dies out north of Berkeley and the fold is nearly gone at San Pablo. The Orinda formation is draped over the line of the fault in the northern portion; hence it is concluded that since Orinda times (Pliocene) there has been no rupture along the fault from Berkeley to San Pablo Bay. This may be interpreted as indicating the fault is innocuous in the vicinity of the bay and also that earth stresses find relief along this line from Berkeley south, while to the north they find relief along the Sunol fault system and possibly the Pinole fault, the Mare Island fault and faults farther east.

Richmond Platform and San Pablo and San Pedro Peninsulas.

The structure of the Richmond Platform is largely unknown. Possibly a complete study of the logs of the wells dug in that region might furnish the critical data needed, but this line of investigation was not taken up.

The Richmond Platform is composed exclusively of the Franciscan rocks. These rocks were bevelled by the erosion and hard and soft members were cut to a peneplain. Bounding this platform on the west is the peninsula of San Pablo. This mountain range rises approximately one thousand feet above the Richmond Platform. It is some five miles long and averages less than half a mile in width. The range is continued another mile by Brookes Island on the southeast. The San Pedro Peninsula on the northwest is exactly on a line with the San Pablo Peninsula.

The alluvial cover hides the geological relations of the San Pablo range to the Richmond Platform, but the detailed study by H. J. Hawley and W. H. Corey of well logs northeast of the San Pablo ridge indicates an important fault bounding the peninsula on that side;

* John P. Buwalda—Nature of the Late Movements on the Haywards Rift, Central California. Bulletin Seismological Society of America, Vol. 19, pp. 187–199, (1929).

† J. R. Russell—Recent Horizontal Offsets Along the Haywards Fault. Journal of Geology, Vol. 39, pp. 507–511, (1926).

also the faulting, which brings chert and volcanic breccia against Franciscan sandstone and shale at the point approximately one mile east of Point San Pablo, is interpreted as a part of this same fault zone. The fault probably bounds the San Pedro Peninsula on the northeast and lines up with the known fault east of the Dumbarton Hills, 30 miles to the southeast. This fault is referred to herein as the San Pablo-San Pedro fault.

The other faults tentatively located on the brief reconnaissance of the region are the Corte Madera fault and the San Rafael fault, striking northwesterly, and the northeasterly McNear and Stetson faults. A north-south fault, with strong horizontal striae on the face, was located west of the swamp land in the embayment north of San Pedro Peninsula. None of these faults are known to be active, nor were any data noted indicating seismic activity.

As indicated above, no detailed mapping was done in either the San Pablo or San Pedro regions. The lines of crushing and disturbed dips, taken to indicate faults, may not indicate major faults. The San Pablo-San Pedro fault is the only one established with fair degree of certainty.

The reconnaissance work and the geological map, by Hawley and Corey, of the San Pablo Peninsula were sufficient to show the main structural features of the region. It would be inferred from Dr. Lawson's map, on which the half-dozen dips shown are parallel to the direction of the range, that the San Pablo ridge is a strike ridge developed along the strike of the harder strata. This is not the case. The massive beds strike at an angle of about 30 degrees to the direction of the peninsula. The shape of the ridge is controlled by faulting on the northeast, and minor faulting and shearing, which truncates the massive sandstone beds, on the southwest side.

Both peninsulas are cut into blocks by innumerable minor faults, shears and joints. The massive standstone members are jointed and sheared; the shale members are intricately contorted.

CHAPTER VII

SUMMARY OF GEOLOGY AND STRUCTURAL FEATURES OF BEDROCK BEARING ON SUITABILITY OF BARRIER SITES

Chipps Island Site.

The Chipps Island site, shown in Plate D-IX, "Geology of Upper San Francisco Bay Region in relation to Salt Water Barrier Sites," crosses the Sacramento River to Chipps Island, west of Pittsburg.

The geological formations of importance here are:

1. The Pittsburg sandstone of Pleistocene age.
2. The sands and gravels of the older Sacramento River fill.
3. The recent fill of slippery clays and tule mud.

The Pittsburg sandstone is probably a flood plain deposit laid down as the river was struggling to maintain its course across the rising barrier of Berkeley Hills. The sands and gravels of the older fill were deposited after the channel was cut to its maximum depth and are encountered in all the borings in the Carquinez Strait.

The recent alluvium is the fill of the island or delta region. It is almost wholly made up of clays. The present channel of the river contains sand bars that are believed by some to have been brought down since hydraulic mining was started in California.

No boring has been made of this site, and the only data available are the logs and bore holes made by the Sacramento Northern Railroad to explore for a contemplated bridge across the river, shallow holes to explore for river improvements, and unsatisfactory water well data.

The bore holes crossing the river apparently penetrated, but did not go through, the treacherous clay fill, and no borings were made in the slough area north of the river, where continuous maintenance trouble has affected the railroad embankment of the Sacramento Northern Railroad.

The data on wells is unsatisfactory as it is merely the recollection of the drillers and not based on recorded logs. It suggests a depth of 150 feet for the sticky clays.

If the advantages of this site, especially elimination of the evaporation loss from Suisun Bay which would occur if any of the other sites were to be utilized, make further consideration of this site advisable, it should be drilled. The depth to the older alluvial sand and gravel and to the Pittsburg sandstone should be determined.

A structure supported on piles driven into, but not through, the recent clays would be subject to slow settlement and might be seriously disturbed by earthquake. Incoherent alluvial deposits magnify the effect of earthquake waves, even at a long distance from the parent active fault.

Bedrock is exposed in the line of drowned hills mentioned above. This line continued would cross the river not far from the site. It is probable the bedrock ridge continues in this direction, but of course is covered by the recent delta clays. The extent of this ridge and the depth of the cover can only be determined by drilling.

Carquinez Strait Sites.

The Army Point site has been drilled and further information gained by the construction of the Southern Pacific Bridge. The results of examination of drill cores and data obtained from the Southern Pacific Company has made it possible to determine the geological structure under the river. The bridge building operations have proved the absence of any important fault cutting the line of the bridge. The drilling of the U. S. Bureau of Reclamation shows a second "basining" of the Martinez syncline under the strait, as shown on the geological map.

If a barrier were to be built northeast of the line of contact between the Martinez formation and the Chico formation, as shown on the geological map, it would rest on the inner-layered sandstone and shale of the Chico formation shown in Plate D-VI; if southwest of the contact it would rest on the Martinez formation of thick-bedded sandstone and minor shale shown in Plate D-VII.

The Chico formation has two zones of massive, thick-bedded sandstone which could be utilized as the central rib of the foundation, as the structure could be built parallel to the strike of the formations. The location C″ is suggested as a site of a barrier to take advantage of the massive Chico sandstone east of the Southern Pacific Martinez bridge.

There is a very massive bed of Martinez sandstone at the contact as mapped, Plate D-VII, and this probably would constitute the best barrier site. The dip of the beds is uniformly about 60 degrees down stream. Location C′ is the suggested position of a barrier to take advantage of the massive sandstone ledge at the base of the Martinez formation. There is a sheer plane or minor fault exposed in the railroad cut 600 feet northeast of the bridge head. This minor foundation flaw is not serious. The site is respectively three miles and two and one-half miles distant from the Southampton Bay fault and the Sulphur Springs Mountain fault. The site is satisfactory for structures as planned in Bulletin No. 22.

The Benicia site extends from Benicia Point southwesterly across the strait. It was very properly dismissed from detailed consideration because it crosses the Southampton fault, and because it lies at right angles to the trend of the faults. It is well established that, because of the horizontal shift that commonly occurs along the California faults, structures parallel to the fault lines are less disturbed than those normal thereto.

There is no reason, however, why a structure could not be built southeasterly from Point Benicia. The structure would then be parallel to the Southampton fault and nearly a mile distant therefrom. It would cross the Martinez syncline and therefore rest on flat strata for a portion of its length. This would be more satisfactory than steeply dipping strata. The two positions tentatively suggested are indicated on the geological map, Plate D-IX, as D′ and D″.

The Dillon Point site crosses the narrowest part of Carquinez Strait. The rock formations are alternating thin-bedded sandstone and shale, with occasional thick beds of sandstone of the Chico formation. One massive bed of sandstone occurs at the point and would furnish a satisfactory landing place for the structure. The strata dip southwesterly and strike at an angle of 30 degrees to the orientation of a barrier. The foundation rock is satisfactory. The structure would lie one-half mile west of the active Southampton fault and since it would not cross the fault it probably could be built to withstand the earthquake shocks.

Two sites on either side of Carquinez Bridge have been suggested, but apparently not considered seriously. The easterly one, from near Semple Point to Crockett, has a northwesterly trend parallel to the faults. The bed rock is the Chico shales, which have been closely folded south of the barrier site landing at Crockett. The westerly site, from the old Tower Hill to a point between Valona and the now abandoned Vallejo Junction, extends southwesterly to the east branch of the Franklin Canyon-Mare Island fault and ends on the south in broken shale. This site is not recommended.

Point San Pablo Site.

The quartzite and sandstone ledges of the Franciscan formation at San Pedro and San Pablo points are hard and massive. The interstratified shale, however, is weak and causes slipping where the slope is steep. The highly developed jointing and shearing has reduced the foundation strength.

A barrier here would have to be designed to meet the condition of high seismicity and thorough fracturing of the foundation beds. A study of the quarries will show the conditions to be met in constructing a barrier here.

CHAPTER VIII

EARTHQUAKE RECORD

A list of earthquakes in central California, especially in the San Francisco Bay, San Pablo Bay, Carquinez Strait and Suisun Bay regions, follows.* The Roman numerals in the second column of the tabulation are the earthquake intensities on the Rossi-Forel scale. (See Chapter I.)

DATA ON EARTHQUAKES IN CENTRAL CALIFORNIA

	Date	*Location and intensities*	*References*	*Faults causing earthquakes*†
1854.	October	Benicia, V. Smart. (Also felt in San Francisco, followed by a sea wave.)	A Catalogue of Earthquakes on the Pacific Coast, by Edward Holden.	San Andreas and Sunol (?).
1857.	January	Martinez and Benicia, III.	Holden.	Sunol fault system.
1860.	September 23	Martinez, IV. Local.	Alta, October 1, 1860.	Sunol fault system, (By Harry O. Wood).
1861.	July 5	Light in San Francisco (IV?) but very heavy near Livermore (IX?). Also felt at Stockton.	Hittell's Resources.	San Andreas (?) and Sunol.
1864.	March	Santa Rosa to Stockton, VI. Severe. Also severe at Visalia, Santa Clara and San Jose.	Holden.	San Andreas or Haywards, (By Harry O. Wood).
1865.	October 8	San Francisco, San Jose, Stockton, Santa Cruz, up to Sacramento. Very severe, VIII. Followed by a continuous vibration lasting ten hours.	San Francisco Bulletin, October 9, 1865.	San Andreas and other faults.
1865.	October 13	Angel Island and San Francisco, V. Also Oakland and Santa Clara.	Holden.	San Andreas and other faults.
1866.	March 26	San Francisco, Stockton, Sacramento, San Jose, etc.	Holden.	San Andreas and Haywards faults.
1866.	May 27	Pacheco, Contra Costa County.	Bancroft's History of California.	Sunol fault system.
1866.	July 14	Sacramento, Contra Costa and Sierra counties. Heavy in Sacramento; light in Contra Costa and San Francisco.	Bancroft.	Haywards fault and possibly faults east.
1866.	December 17	Antioch, local.	Bancroft.	Antioch and Potrero Hills covered faults.
1866.	December 18	Pacheco, local.	Holden.	Sunol fault system.
1866.	December 20	Antioch, local. Two, morning, and 4:15 p.m.	Bancroft.	Antioch and Potrero Hills covered faults.

* Compiled by Beatrice Henderson from data assembled in the office of the Seismological Society of America, August 26, 1930.

DATA ON EARTHQUAKES IN CENTRAL CALIFORNIA—Continued

	Date	*Location and intensities*	*References*	*Faults causing earthquakes*†
1868.	October 21	Martinez, IX. Haywards, IX. Mare Island Navy Yard, VIII. Vallejo, VIII. Antioch, VIII. Pacheco, IX. San Francisco, IX. "Central and northern California. Preceded by a number of shocks in the Kern River country. Martinez courthouse wrecked. Haywards very severe, 22 shocks during the morning; 'not a building that was not damaged or wrecked.' Brick and concrete buildings in Pacheco destroyed. Mare Island Navy Yard, 'Chimneys thrown down and a person walking thrown down.' 'Open crack in Haywards.' "	Holden. Also San Francisco Call, October 25, 1868.	Haywards, with possibly Sunol contributory faults.
1869.	January 22	Haywards, local.	San Francisco Herald, January 23.	Haywards fault.
1870.	February 17	Vallejo, San Rafael, San Francisco Bay region, V. Also Petaluma, Sacramento, San Jose, Santa Cruz. Monterey, III.	Bancroft.	San Andreas fault.
1870.	April 2	Smart shocks Contra Costa County, V. Two smart shocks at San Francisco, V. Berkeley, VI.	Bancroft.	Haywards fault.
1871.	April 2	Contra Costa County, IV. Also at San Francisco.	Bancroft.	Haywards and the Sunol fault system.
1872.	April 3	Antioch, X. "Terrible shock."	Bancroft.	Antioch and Potrero Hills covered faults.
1872.	October 21	Vallejo, San Rafael, III. San Francisco, IV.	Bancroft.	San Andreas fault.
1881.	September 18	Angel Island, III. San Francisco, V.	Holden.	San Andreas fault.
1883.	October	Port Costa, VI. San Francisco, VI. Not felt at Sacramento, but severe at Davisville.	Bancroft.	San Andreas and Sunol faults.
1885.	January 26	Central California, IV, including San Francisco Bay region.	Holden.	San Andreas fault probably.
1885.	December 30	Vallejo, Port Costa, Martinez, V. San Francisco, III. San Jose, III. San Mateo, V. Petaluma and Napa, V.	Holden.	Sunol fault system.
1886.	October 15	Mare Island Lighthouse and Fort Point Lighthouse, local shock.	Holden.	Mare Island fault.
1887.	January 19	Mare Island Lighthouse, local.	Holden.	Mare Island fault.
1887.	October 19	Vallejo, III. Also Napa County, Petaluma and San Francisco.	San Francisco Chronicle, October 5.	Impossible to estimate, because of inaccuracies in times given.
1887.	December 4	Haywards, VI.	San Francisco Chronicle, December 5.	Haywards fault (H. O. Wood).

DATA ON EARTHQUAKES IN CENTRAL CALIFORNIA—Continued

	Date	*Location and intensities*	*References*	*Faults causing earthquakes*†
1888.	February 29	Mare Island Lighthouse, IV. Martinez, VI. San Francisco and Point Reyes, V. Oakland, II. Not felt in Berkeley. Petaluma, VII.	San Francisco Chronicle, February 29 and March 1. Also Alta, and San Francisco Bulletin, same dates.	San Andreas and Sunol system (?).
1889.	May 19	Mare Island, VI, Antioch, VII. Haywards, VII. Stockton, VII. San Francisco, Mills, San Jose, VI. Modesto, Napa, VII. Berkeley, VI. Oakland, VI.	All San Francisco papers of May 20.	Haywards fault, Sunol fault system, and Antioch and Potrero Hills covered faults.
1889.	July 31	Mare Island Lighthouse, VI. Martinez, V. Benicia, V. Felt all through central California, except Sacramento.	Holden.	San Andreas, Sunol contributory.
1890.	April 24	Benicia, VI. Oakland, San Francisco, Salinas, Los Gatos, Brentwood, Gilroy, San Jose, Hollister, VI.	San Francisco Examiner, April 25.	San Andreas fault, with the Sunol system possibly contributory.
1891.	October 11	Suisun, Fairfield, VII. Central portion of state, V and VI.	Holden.	Sunol fault system and possibly Antioch and Potrero Hills covered faults.
1891.	October 14	Suisun, VI. Berkeley, Petaluma, Napa, San Francisco, V or VI.	Holden.	Same as above.
1892.	April 19	Suisun, VII. Martinez, VII. Benicia, VII. Vallejo, VI. All central California region, including Sacramento, Grass Valley, Marysville and Winters. Felt at Reno, Nevada, very slightly.	Holden.	Same as above.
1892.	April 20	Same places given above, but lighter intensities. Martinez, Suisun, Fairfield, IV. Aftershock of April 19.	Holden.	Same as above.
1892.	April 21	Martinez, VII. Benicia, VI. Haywards, VI. Suisun, VIII, and same north-central portion of the state as given above for April 19. Buildings were wrecked in all these cities. Free Library at Martinez cracked so badly it was afterwards unsafe. Some damage done in the State Capitol at Sacramento. Suisun suffered a great deal of property damage.	Holden.	Same as above.
1892.	April 29	All north-central California, VI.	Holden.	Sunol fault system, and possibly Antioch and Potrero Hills covered faults.
1893.	June 30	Vallejo and Mare Island, V or VI? San Rafael, VI. Petaluma and Niles, VI.	Holden.	Mare Island system?
1895.	December 8	Fairfield, VI, local.	Holden.	Antioch and Potrero Hills covered faults.
1896.	July 23	Vallejo, V. "Sharp shock."	Holden.	Vallejo-Mare Island faults.

DATA ON EARTHQUAKES IN CENTRAL CALIFORNIA—Continued

	Date	*Location and intensities*	*References*	*Faults causing earthquakes*†
1898.	March 30	San Francisco Bay region, as far northeast as Stockton and Sacramento. "This earthquake wrought such damage at *Mare Island Navy Yard* that it may properly be known as the Mare Island Earthquake. Fortunately, the loss of life was small, owing to the hour."	Alexander McAdie's "Catalogue of Earthquakes on the Pacific Coast, 1897 to 1906."	Mare Island system with contributory faults.
1899.	May 10	Mare Island, III.	McAdie.	Mare Island fault system.
1899.	June 13	Vallejo, College Park, San Jose, Napa.	McAdie.	Mare Island fault system, with possibly contributory faults of that district.
1899.	June 19	Mare Island, slight.	McAdie.	Same fault.
1899.	June 21	Mare Island, slight, local.	McAdie.	Same fault.
1900.	March 26	Vallejo, Napa, Vacaville.	McAdie.	Mare island fault system with Sunol system contributory.
1900.	June 13	Mare Island, San Francisco, Berkeley, II.	McAdie.	Mare Island fault system.
1900.	June 17	Mare Island, local, slight.	McAdie.	Same fault.
1900.	June 21	Mare Island, local, slight.	McAdie.	Same fault.
1901.	December 15	Antioch, Oakland, San Francisco, San Leandro.	McAdie.	Antioch and Potrero Hills covered fault system.
1902.	May 19	Antioch, Suisun, Vallejo VII. All north-central portion of California had quite heavy shocks on this date.	McAdie.	Chiefly Sunol fault system with contributory faults.
1903.	June 11	Antioch, Haywards, Livermore, Vallejo, and all north-central portion of California.	McAdie.	Sunol fault system with contributory faults, chiefly the Haywards fault.
1906.	April 18	The San Francisco earthquake, X. All the towns in this district suffered from the shocks.	Report of the California Earthquake Commission.	San Andreas fault with contributory faults.
1911.	July 1.	Niles, V. Suisun, IV. Haywards, V. Mare Island.	Bulletin of the Seismological Society of America, March, 1912.	Haywards fault with contributory faults—H. O. Wood. (See article in Bulletin, March, 1912.)
1914.	December 28	Niles, III. Benicia and Martinez, IV.	Bulletin of Seismological Society of America, March, 1915.	San Andreas fault—E. F. Davis. (See Bulletin.)
1916.	August 6	Sausalito, III, slight shock.	Bulletin, Seismological Society of America, March, 1917.	Haywards fault —Andrew Palmer. (See Bulletin.)

† Determination of faults causing earthquakes after Harry O. Wood and C. F. Tolman.

Conclusions from Study of Earthquake Record.

The above tabulated seismic record brings out the following:

1. Prior to the San Francisco earthquake in 1906 the Carquinez Strait and the Suisun Bay area probably exhibited the highest average seismic activity of any region in Central California. This statement is believed to be justified even in view of the incompleteness of the older records and the fact that much of Central California was sparsely inhabited.
2. Since that time the activity has been very slight.
3. The record indicates that five active fault lines generate earthquakes which affect this region. These are:
   (a) The San Andreas fault.
   (b) The Haywards fault.
   (c) The Mare Island fault system.
   (d) The Sunol-Southampton Bay fault system.
   (e) The possible buried fault near Antioch, which may be continued in minor faults of the Eastern Potrero Hills and the Suisun-Fairfield region. This system has not been studied and no accurate information is available.
4. The earth stresses relieved along the Haywards fault, south of Berkeley, are expended farther north along the Sunol-Southampton fault and possibly other faults to the east.
5. A great shock on one fault induces contributory movement on adjacent faults.

The surface geology indicates recent activity along the faults as follows:

The San Andreas fault—highly active throughout its entire length.

Haywards fault—active from Berkeley south, at least as far as opposite San Jose.

The Mare Island system—data inconclusive. Possibly active from the Franklin Canyon Highway north.

The Sunol-Southampton fault—probably active.

No geologic or topographic data observed regarding the other faults indicated recent activity.

Structures contemplated in this region should be designed to withstand a shock of intensity of X, Rossi-Forel scale. No structures should be built across a major fault. The proposed barrier should be aligned parallel with the major faults (average bearing north 40 degrees west). Excessive disturbance is to be expected in the marshland adjacent to the river. Moderate seismic water waves might affect a barrier.

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ADDENDUM I

ERODED FAULT BLOCK CONCEPT OF LAWSON AND OTHERS

The reader familiar with Lawson's discussion of structure in his San Francisco Folio* and Willis' ideas of a great number of fault blocks, crushed against and interacting on each other, will note that the structural provinces of this region are not described here as fault blocks.

Lawson describes three "earth blocks" in the San Francisco region, namely, the Montara block, the San Francisco-Marin block, and the Berkeley Hills block. He describes them as bounded by major faults. The first two have an "asymmetrical outline characteristic of tilted fault blocks." He recognizes the more complicated structure of the Berkeley Hills block, which he states "is bounded on the southwest by a zone of acute deformation."

Willis† states "all of the blocks" (a large number are described in the Berkeley Hills and adjacent regions) "are bounded by faults, that is by planes on which they have been parted from the adjacent masses by shearing. The pattern of the faulting can be seen in the topographic map, since the valleys and gullies have been worked out chiefly on faults."

This simple notion of tilted fault blocks bounded by active faults is easily understood and has been rather widely accepted as the characteristic feature of Coast Range geology. Although tilted blocks exist in the Coast Ranges, it has been found that this is not the dominant type of structure. It is difficult to understand how the great series of weak sedimentary rocks of the Coast Ranges could be faulted and tilted regularly under compressive stress; or if the underlying granitic basement has been faulted and tilted and carried the draping sedimentary rocks with it, how they could be closely folded. It is believed that a thick series of weak sedimentary rock yields irregularly to compressive stresses. The belt of yielding is a belt of close folding and faulting at moderate depth, and doming or bulging near the surface. Tilted fault blocks are developed only where the strong crystalline rocks lie near the surface, covered, if at all, by a relatively thin veneer of sediments. Active faults cut through folded upwarps or downwarps as often as they bound fault blocks. There is little to support the prevalent idea that active faults occur only at the boundary of fault blocks. If this were so, it would be easy to discriminate between "active" and "dead."

In discussing the topographic history of a tilted fault block, Davis has repeatedly explained that the fault face will retreat under erosion and deflating and form the erosion scarp. The old surface will be preserved longest on the top of the ridge and a regular, even sloping ridge will develop between the new gullies, due to deflation and rainwash. In this case the old erosion surface is not deformed, yet the general cross-sectional profile of the range is curved or domed. Usually, however,

* Folio 193, U. S. Geologic Survey (1914).
† Suisun Bridge, Geology and Earthquake Risk. Private report.

as recognized first by Willis, the old surface is actually deformed. This is certainly true of the Berkeley Hills block. The bowing of the old surface north of Berkeley would be classic if it were adequately described.

The notion that the active faults are confined to the margins of structural fault blocks is less true, as a generalization, than that the fault block structure is commonly developed in a thick series of weak sedimentary rocks. The San Andreas fault cuts through Lawson's "Montara Block" and it is believed most California geologists will agree that the San Andreas is an old fault and not a recent feature as described by him. In the vicinity of Carquinez Strait, the Haywards fault does separate regions of unlike geology, but the Mare Island, the Sunol-Southampton, and the Sulphur Springs faults cut closely folded blocks and mark lines of close folding and overturning.

The studies in the Carquinez Strait area have confirmed the belief that folding and faulting may be the result of the application of the same set of compressive stresses and therefore may be contemporaneous; that each block or zone of yielding is characterized by its individual type of failure under compression; that close folding and faulting at depth may be represented by faulting and gentle doming at the surface.

Complicated Topographic History.

The complicated topographical history of this region will be appreciated by one reading Buwalda's recent paper on the Nature of the Late Movements on the Haywards Rift, Central California.* He states:

"The observations set forth in this report are believed to indicate that:

"1. The northeastern part, at least of the San Francisco-Marin Block, formerly stood higher instead of lower, as at present, than the southwestern part of the Berkeley Hills Block; a northeastward-facing fault scarp, instead of one sloping southwest, presumably rose along the approximate site of the present hill front. This means a rather striking reversal of the physiographic and drainage conditions now existing in the Eastbay region.

"2. Reversal in direction of the vertical-component movement along the Haywards fault zone occurred, giving rise to the present topographic relations. This movement was in part warping.

"3. The latest movement has been an essentially horizontal nortwestward displacement, relatively, of the San Francisco-Marin Block, with reference to the Berkeley Hills Block, by at least 1400 feet.

"The late relative movements of the former block, with reference to the latter have therefore been successively upward vertically or obliquely, downward vertically or obliquely, horizontally northwestward."

* John P. Buwalda—Nature of the Late Movements of the Haywards Rift, Central California. Bulletin Seismological Society of America, December, 1929, p. 199.

ADDENDUM II

DISCUSSION OF DETAILS OF AREAL AND STRUCTURAL GEOLOGY AND COMPARISON OF RESULTS OF THIS STUDY WITH THE WORK OF OTHERS

Correlation of Formational Divisions with Those Used by Weaver.

On the Antioch Quadrangle the mapping of Chas. E. Weaver was accepted with only minor changes. For the sake of uniformity in the map of the region, all his divisions between the Monterey formation and the Cretaceous were grouped under the term Tejon. No Martinez formation occurs east of the Mount Diablo thrust.

The formation Weaver designates as Pleistocene terrace was found to include an estuarine or flood plain. Tawny yellow, clayey sandstone here denominated the Pittsburg formation. The sandy alluvial cones of the side streams from the Mount Diablo range interfinger with this deposit, and therefore it grades into material more properly designated as recent alluvium. The dip is not toward the Suisun Basin, as would be the case if it were a wash formation from the hills, but is from two to four and a maximum of ten degrees away from the river. This dip may be explained by a slight earth movement, or a river overflow deposit dipping away from an aggrading stream channel, or both.

Under terrace deposits, this report includes the stream sands and gravels, often strongly crossbedded, which occur as pronounced terraces at various levels up to 100 feet, and are well developed southeast of Antioch and at Suisun Point. They are believed to be a phase of the Antioch formation and represent old river channel deposits rather than estuarine and flood plain deposits.

The Pittsburg formation and interstratified sands and gravels is important in the study of ground water in this region. At Pittsburg there has been considerable contamination of ground water by the salt water in the river.

Mt. Diablo Thrust.

The studies herein described did not cover sufficient area to throw much light on the vexing problem of the Mount Diablo thrust. Just west of Goodyear, a flat-lying fault is exposed on three sides, with folded Tertiary rock lying on top of Knoxville shales. This is undoubtedly an old flat thrust fault. Following Weaver, the fault separating the Napa volcanics from the Knoxville shale, northwest of Goodyear, also is designated as the Mount Diablo thrust. However, the fault appears to dip fairly steeply easterly and may be later than the Mount Diablo thrust and belong to, or lie east of, the Sunol system of faulting.

Contact Between Chico and Martinez Formations.

The complicated geology of the Carquinez Strait area is open to differences of interpretation. Considerable doubt exists as to just what horizon should be taken as the contact between the Chico and the Martinez formations. At Benicia a very massive glauconitic sandstone is underlain by alternating sandstones and shales of Cretaceous lithology. The difficulties in mapping are further increased by the complicated structure.

"Martinez Fault."

The northwest limb of the Martinez syncline is fractured and overturned. This disturbance has been mapped as "the Martinez fault" by several geologists. This is believed to be minor and local and the disturbance has been indicated by a dashed line on the map. There is no faulting along the projection of this line on the Benicia side of the strait, and hence the disturbance dies out, or the fault curves back and joins the main Southampton fault under the bay.

"Martinez Fault" of Lawson and Waterfalls.

The Martinez fault, as mapped by Waterfalls and accepted by Lawson and Willis, is quite different from the Martinez fault of Taff and others as described above. In the ridge northwest of Muir, Waterfalls noted the cutting off of the basal bed of the Martinez formation and projected a fault from this point of cutoff through a draw south of Martinez, along which he mapped an offset of the Martinez formation. This "fault line," projected, cuts the northern end of the Southern Pacific bridge and the three geologists mentioned suggested special engineering precautions in the building of this bridge where it crosses the supposed "fault."

A horizon of shale, which occurs at the contact of the Martinez and Tejon formations, can be followed without dislocation across this "fault." Construction work on the bridge at the draw above-mentioned uncovered no fault. The Martinez syncline is not cut off by the fault at Martinez, but continues under the bay, as shown by samples from the drill holes

This fault, if it exists, would add to the seismic hazard of the Army Point sites. Hence the question of the existence of this fault was investigated in detail. It is fortunate that the bridge construction has verified its nonexistence.

Willis thought the steep cliffs on the north side of the bridge head indicated a fault, since he regarded this cliff to be one due to undermining by erosion of a set of shears or minor faults parallel to the supposed Martinez fault. These minor faults, however, do not offset the strata. One of them is well exposed in the new railroad cut north of the bridge head.

Supposed Earthquake Cracks at Benicia.

A series of three lines of trenches, maximum depth about six feet and length about 800 feet, occur on a small hill just south of and in sight of the highway at the western boundary line of the town of Benicia.

They were described by Lawson and Waterfalls and both classify them as earthquake cracks. Lawson states:

> "On the immediate trace of this fault (Southampton fault), there is no observable evidence of recent movement; but on the east side of Southampton Bay, opposite Dillon Point and about half a mile from the projected position of the fault trace in Southampton Bay, there is an open rupture of the ground which I take to be significant of a recent movement on this fault or on a branch of it. The phenomena are very clear, the rupture of the ground having occurred probably less than 100 years ago, and are sufficient to warrant the view that the Southampton fault is a live fault upon which future movements may be expected."

The trenches resemble somewhat the fault trenches of Owens Valley, which lie directly over the fault planes of the great Owens Valley earthquake fault. However, it appears that they were artificial and that material had been thrown out at the north side of the trenches. Inquiry brought out that they were trenches dug for natural cement rock. T. F. Connolley reports that 50 or 60 years ago his father and others dug these trenches in layers of cement rock. The cement rock was sold to the owners of the Benicia Cement Mill; first, Henry Martin and then James Clyne and J. C. Johnson. Tom Clyne, now at Redwood City, and Charles O. Clyne, sons of James Clyne, verified the information that cement rock was mined in the vicinity at that time.

This question was investigated because of the high standing of those who reported the cracks, and also because an earthquake such as would have affected the solid rock strata on a hill would have resulted in a tremendous disturbance of the clays of the river and Southampton Bay.

Complicated Geology Between Martinez and Southampton Fault.

The geology between the city of Martinez and the Southampton fault is complicated, and the geology, as mapped, is the interpretation favored, but other interpretations are possible.

The difficulty in locating the Martinez-Chico contact has been mentioned. The exact contact can only be located by detailed micropaleontological study of the shales. The Martinez formation fronting the strait is overturned, dipping at steep but variable angles to the south. The Cretaceous also is overturned, dipping to the south in like manner. Farther south the Cretaceous maintains its southerly dip, but the dip is regularly at a moderate angle and then it dips to the north. Ordinarily these dips would indicate a syncline. In this case the older formation (the Cretaceous) would be in the syncline. This of course is impossible.

The interpretation advanced is an overturned anticline in the Cretaceous, just south of the contact between the Martinez and Cretaceous formations. The north limb is overturned and the south limb in normal position. A fault is postulated at the change in dip from north to south. This fault is certainly present in the big gully at the contact of the Cretaceous and the Martinez formation farther west. It is a branch or spur of the main Southampton fault.

The Southampton fault (Sunol fault) has been described in detail in the body of the report. In the preliminary study the evidences of recent movement were not appreciated. More detailed study brought out its affect on topography as shown in Plate II–B. The study of the seismic record leaves little doubt in regard to recent earthquakes originating on this fault.

Mare Island-Franklin Canyon Fault Zone.

This fault was described as a very flat thrust plane by J. C. Merriam when the tunnel of the Santa Fe Railroad between Christie and Glen Frazer was being dug. A. C. Lawson mapped the Chico formation thrust over the Tertiary formations in this vicinity. One branch of the fault was mapped in this study as passing through the contorted Cretaceous shales in the gully back of Vallejo Junction. The second branch separated the massive Cretaceous yellow sandstone from the upper portion of the Martinez formation, which is completely cut out a mile to the south. The eastern branch projected would pass through Mare Island Strait shown in Plate D-III. The geology on the two sides of the strait calls for a fault. The western branch, projected, passes west of the island. The dip of these two planes cannot be flatter than 45 degrees, as shown by the contacts on the steep slope. The close folding on Mare Island has been described.

Fault Assumed by Some to Extend Down the Center of Carquinez Strait as a Branch of the Southampton Fault.

In some of the geological maps of the region, the Sunol fault is turned down along the course of the Carquinez Strait and then northwesterly into San Pablo Bay, past Mare Island. In this region of high seismic activity, the building of a structure across a branch of an active fault would be hazardous. Every effort therefore was made to determine positively whether or not this fault exists.

The data on which this fault was postulated probably were the following:

1. The course of the strait might have been governed by a line of weakness, such as a fault.
2. The important Sunol fault might be expected to register more prominently in the geology north of Southampton Bay.
3. The strike and dip of the Cretaceous formation are quite divergent in places on the two sides of the strait.

As to topographic evidence, the strait was excavated by an antecedent river, regardless of underlying structure. The two sides of the strait show no greater elevation of one side than the other. Topographic evidence is against the existence of a fault in the channel.

Geological study showed that the differences in dip and strike on either side is due to folding of the Cretaceous shales and sandstones and not to faulting.

Positive geologic evidence of absence of faulting was discovered. The massive concretionary sandstone, with alternate shales and shaley sandstone, occurring between the Southern Pacific tunnel at Selby and Vallejo Junction on the south side and at the southeast end of Mare Island were proved to belong to the upper horizon of the Cretaceous by paleontological evidence. The underlying dark gray shales are the same lithologically and contain a similar Cretaceous fauna. These strata therefore extend across the strait on the line of strike without dislocation. Because of the importance of this question, micropaleontological and microlithological studies of the sections on either side of the strait were undertaken by Frank L. Tolman and he correlated identical zones on each side of the strait.

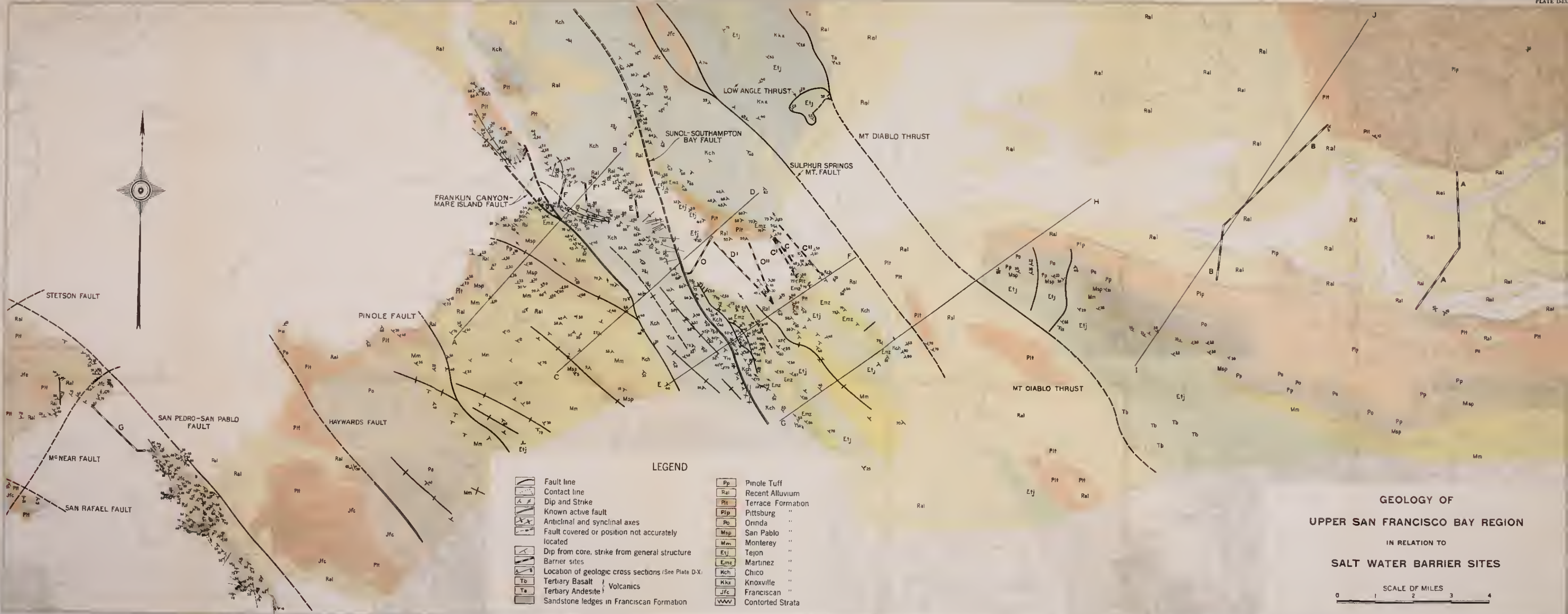
ADDENDUM III

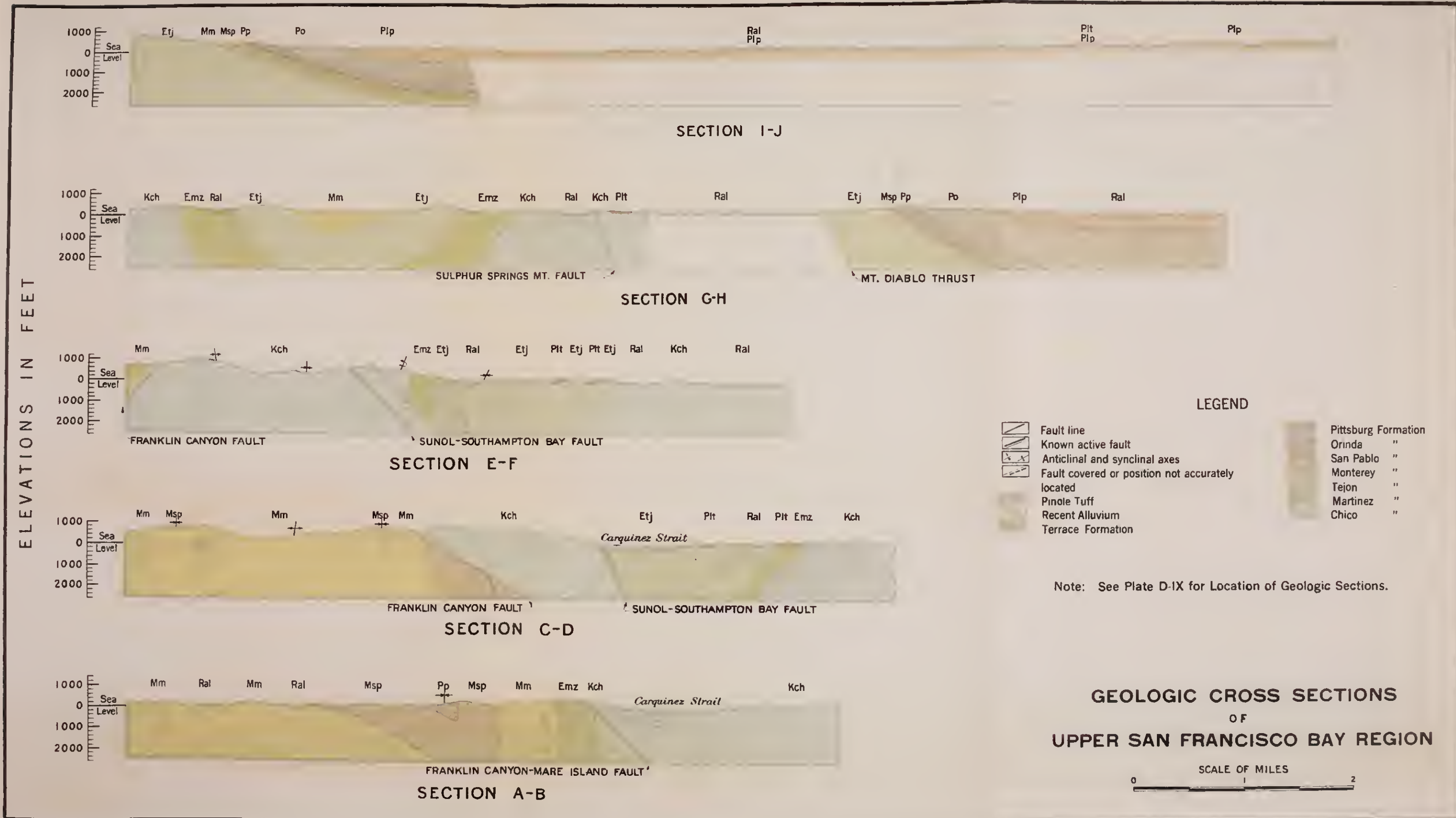
DESCRIPTION AND CORRELATION OF FORMATIONS

Age	Formation name	Thickness	Lithology		Correlation
Recent	Alluvium	0-200	Clays, organic muds, nonindurated clayey silts; sands, and gravels.	Clays and muds in delta region and river channel, partly cemented sands and gravels at bottom of deep cut channel of the Sacramento River. Clays, sands and gravels deposited by tributary streams.	Corresponds to recent alluvium of Lawson and Weaver.
Pleistocene	Terrace gravels	0-50	Coarse, cross-bedded sands and gravels. Some fine alluvium.	Cross bedding and dune stratification occasionally developed. Current cross bedding prominent.	More restricted use than that of Lawson and Weaver.
	Pittsburg	500 feet ?	Fine, clayey sandstone, tawny yellow to brown in color. Brownish yellow sandy silt.	Obscurely bedded. Layering between sandy silt and clayey sandstone observable.	Included in terrace deposits by Weaver and Clark.
Pliocene	Orinda	1,000	Fresh water clay shale, sandstone, conglomerate and lenticular layers of brecciated shells.	----------	Equivalent to Orinda formation of Lawson and Weaver.
	Pinole	200-1,000	Tuff made up largely of light colored rhyolitic pumice, fragments varying in size from fine dust to pumice pebbles several inches in diameter.	----------	Usage of Weaver and Lawson followed.
Miocene	San Pablo	1,800	Massive coarse to medium grained "blue sandstone."	Massive, thick bedded homogeneous sandstone. Prominent fossil reefs.	Corresponds to the San Pablo as mapped by Weaver and Lawson.
	Monterey	1,000-5,000	In the Rodeo Syncline, the Monterey, as mapped, is a thick series of alternating dark organic shale and fine-grained yellow ("pepper and salt") sandstone. In the Martinez Syncline there is only one poorly developed shale member. In the Antioch and adjacent Mt. Diablo Quadrangle the white "Kirker tuff" of Clark and Weaver was mapped as Monterey, although no rocks of Monterey age occur. The 'Kirker tuff ' lies below the San Pablo and therefore structurally takes the place of the Monterey, and for the purpose of this report it seemed advisable not to introduce the new division "Kirker tuff." Clark believes the "Kirker tuff" to be of Oligocene age.	Sandstone massive, fine-grained, alternating with thick shale members. "Blue sandstone" member at base in Martinez Syncline with a thin "Oligocene Shale" horizon (not separately mapped) separating the Monterey formation from the Tejon formation.	In the Rodeo Syncline it includes the following members recognized by Lawson: Briones sandstone, Hercules shale, Rodeo shale, Hambre sandstone, Tice shale, Oursan shale, Claremont shale, Sobrante sandstone. On the north slope of the Mt. Diablo range the term "Monterey" is substituted for the "Kirker tuff" of Clark and Weaver.

Eocene (and Oligocene?)	Tejon	3,000	Chiefly massive yellow sandstone. Some dark clay shale in the Martinez region. In the Suisun Bay region yellow to brown Micaceous sandstone containing 10 per cent interbedded brown clay shale is called the "Markeley" formation by Clark and Weaver, and considered to be Oligocene in age. This is mapped as Tejon in this work.	Sandstone massive with partings and thin layers of shale.	Includes the "Markeley" formation of Clark and Weaver.
	Martinez	2,000	Massive greenish-gray glauconitic sandstone and gray and brown shales.	Massive thick ledges of sandstone and thin layers of shale.	Only the lithologically characteristic Martinez formation was mapped as such. A shale horizon below the typical Martinez sandstone contains Martinez fossils, but lithologically resembles the Chico. This shale was mapped with the Chico formation. Otherwise corresponds to Weaver's usage.
Cretaceous	Chico	4,000	Massive yellow concretionary sandstone; calcareous bluish gray sandstone; brown sandy shales; gray clay shales, occasional lense of conglomerate.	Massive concretionary sandstone at top. Alternating sandstone and sandy shale with one horison of gray shale.	Fossils prove Upper Cretaceous age. Corresponds to classification of Weaver, Clark and Lawson.
	Knoxville	?	Gray clay shale; dense brown sandy shale; thin layers of gray brown limestone.	Formation largely shale	Corresponds to Weaver's classification.
Jurassic	Franciscan	?	At San Pedro and San Pablo indurated sandstone, cemented quartzite, dark clay shale, sandy shale. North of Suisun Bay includes various associated igneous rocks.	Massive sandstone members with alternating sandstone and shale members.	Only a small portion of extensive series in area mapped at San Pablo and San Pedro. Here corresponds to "undifferentiated Franciscan" of Lawson.

PLATE D-IX


STETSON FAULT
SAN PEDRO-SAN PABLO FAULT
McNEAR FAULT
SAN RAFAEL FAULT
HAYWARDS FAULT
PINOLE FAULT
FRANKLIN CANYON-MARE ISLAND FAULT
SUNOL-SOUTHAMPTON BAY FAULT
LOW ANGLE THRUST
SULPHUR SPRINGS MT. FAULT
MT DIABLO THRUST
MT DIABLO THRUST
LEGEND
Fault line
Contact line
Dip and Strike
Known active fault
Anticlinal and synclinal axes
Fault covered or position not accurately located
Dip from core, strike from general structure
Barrier sites
Location of geologic cross sections (See Plate D-X)
Tb Tertiary Basalt
Ta Tertiary Andesite
Volcanics
Sandstone ledges in Franciscan Formation
Pp Pinole Tuff
Ral Recent Alluvium
Plt Terrace Formation
Plp Pittsburg "
Po Orinda "
Msp San Pablo "
Mm Monterey "
Etj Tejon "
Emz Martinez "
Kch Chico "
Kkx Knoxville "
Jfc Franciscan "
Contorted Strata
GEOLOGY OF
UPPER SAN FRANCISCO BAY REGION
IN RELATION TO
SALT WATER BARRIER SITES
SCALE OF MILES
0 1 2 3 4


ELEVATIONS IN FEET
1000
Sea Level
0
1000
2000
Etj Mm Msp Pp Po Plp Ral Plp Plt Plp Plp
SECTION I-J
Kch Emz Ral Etj Mm Etj Emz Kch Ral Kch Plt Ral Etj Msp Pp Po Plp Ral
SULPHUR SPRINGS MT. FAULT
MT. DIABLO THRUST
SECTION G-H
Mm Kch Emz Etj Ral Etj Plt Etj Plt Etj Ral Kch Ral
FRANKLIN CANYON FAULT
SUNOL-SOUTHAMPTON BAY FAULT
SECTION E-F
Mm Msp Mm Msp Mm Kch Etj Plt Ral Plt Emz Kch
Carquinez Strait
FRANKLIN CANYON FAULT
SUNOL-SOUTHAMPTON BAY FAULT
SECTION C-D
Mm Ral Mm Ral Msp Pp Msp Mm Emz Kch Kch
Carquinez Strait
FRANKLIN CANYON-MARE ISLAND FAULT
SECTION A-B
LEGEND
Fault line
Known active fault
Anticlinal and synclinal axes
Fault covered or position not accurately located
Pinole Tuff
Recent Alluvium
Terrace Formation
Pittsburg Formation
Orinda "
San Pablo "
Monterey "
Tejon "
Martinez "
Chico "
Note: See Plate D-IX for Location of Geologic Sections.
GEOLOGIC CROSS SECTIONS
OF
UPPER SAN FRANCISCO BAY REGION
SCALE OF MILES
0
1
2

APPENDIX E

SEWAGE AND INDUSTRIAL WASTE DISPOSAL AND WATER REDEMPTION

With Special Reference to a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

TABLE OF CONTENTS

LIST OF TABLES

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LETTER OF TRANSMITTAL

MR. EDWARD HYATT,
State Engineer,
Sacramento, California.

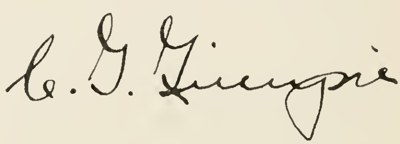
DEAR SIR: In accordance with your request, there is transmitted herewith a report on "Sewage and Industrial Waste Disposal and Water Redemption With Special Reference to a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers." The report is in reference particularly to barriers located at the Dillon Point and Point San Pablo sites.

Consideration has been given particularly to the aspects of pollution by sanitary sewage and organic industrial waste, and in collaboration with the Division of Highways, through its Testing and Research Laboratory, examination has been made of the pollution and possible disposal of mineralized wastes by the various industries now established along the shores of Suisun Bay.

Many data useful in this investigation have been contributed to the bureau by various city officials, industrial plant executives and land owners throughout the region. Much assistance has been rendered by the Testing and Research Laboratory of the Division of Highways, particularly in the chemical analysis and investigation of inorganic industrial wastes.

The Division of Epidemiology of the State Department of Public Health has investigated the incidence of typhoid fever in the area covered by the investigation and that report, with accompanying statistics, is presented as a portion of this report.

Respectfully submitted.



Chief, Bureau of Sanitary
Engineering, California State
Department of Public Health.

Berkeley, California.
December 22, 1930.

ORGANIZATION

DEPARTMENT OF PUBLIC HEALTH

W. M. DICKIE------------------------------*Director of Public Health*

The report covered by this appendix was prepared by

C. G. GILLESPIE
Chief, Bureau of Sanitary Engineering

Assisted by

J. M. SANCHIS
F. E. DEMARTINI

CHAPTER I

INTRODUCTION, SUMMARY AND CONCLUSIONS

The object of this inquiry is to consider whether construction of a salt water barrier below the confluence of the Sacramento and San Joaquin rivers would result in new or additional sewage and industrial waste disposal problems and, if so, to present reasonable projects for their solution. At the outset it is assumed that it would be essential to make possible the taking of a fresh-water supply from a barrier lake for cooling, factory and domestic uses in the area adjacent thereto, and that it might be desirable to conserve the water values of the wastes behind a barrier. These questions have been considered with particular reference to barriers located at both Dillon Point and Point San Pablo.

The assignment is not so simply disposed of as may appear from the somewhat common impression that sewage has less tendency to precipitate in fresh water than in salt and, therefore, that fresh water would assimilate the sewage more rapidly.

Present conditions in the area above the barrier sites are good to fair, due to tidal dilution and tidal currents so strong that they actually sweep away even the sewage sludge. Obviously, a barrier would remove these tidal benefits and create a problem of sewage disposal into a body of fresh water more or less quiescent except for wind-induced drift and the slight currents due to stream flow. Moreover, for 20 to 30 miles or more above the barrier sites considered in this report, the complexion of growth is industrial, especially such industries as oil and sugar refineries, chemical plants, creameries, canneries, fisheries, steel mills, tanneries and rubber and paper plants. Generally speaking, the industries in this area are large users of water and are anxious for a water disposal for their injurious wastes. The creation of a fresh-water barrier lake probably would attract more of the type of industry that has a troublesome industrial waste of large volume.

Past the barrier sites there escapes all the drainage of the great central valley, traversed by its two great rivers—the Sacramento and the San Joaquin. The great central valley lies between the crest of the Sierra Nevada on the east and the Coast ranges on the west, and between the Tehachapi range, below Bakersfield, on the south and the Siskiyous, or Cascades, above Mt. Shasta, on the north. Within this basin is an area of almost 60,000 square miles, something like 130 main settlements, only slightly less than half the state total, and a population of about 1,000,000 people.

Area Involved in Pollution of a Barrier Lake.

Practically all of the area in the upper Sacramento and San Joaquin valleys is so remote from the region of the barrier sites that it is out of the pollutional picture in which a barrier would appear. In fact, the inquiry can be confined safely to the lower region, or to that area lying within the present tidal reaches. It would comprise the Sacramento-San Joaquin Delta, extending to Sacramento on the Sacramento River, to Stockton on the San Joaquin, and the area adjacent to Suisun and San Pablo bays and small tributary sloughs, ending at such places as Suisun, Napa and Petaluma. This region may be said to encompass most of the industrial activity of the great central valley drainage basin, which activity is producing a waste far outranking the human waste in pollutional importance.

Pollution Loads in Upper San Francisco Bay and Delta Regions.

Within the lower basin industrial region and extending down upper San Francisco Bay to Point San Pablo, there are about 110 places where sewers or industrial waste outfalls now run to tidewater. The aggregate summer load of organic matter from these 110 outfalls is roughly equivalent, in its oxygen requirements for stabilization and hence in pollution effect, to the raw sewage of nearly 700,000 persons. Only slightly more than 30 per cent of this load is attributable to domestic sewage, the remainder being due to industrial wastes. In winter, due to seasonal decline in operations in certain factories, the pollutional equivalent is reduced to less than 500,000 persons.

Above the Dillon Point site the population equivalent of the wastes is somewhat smaller—approximately 550,000 persons for the summer load and 330,000 for the winter load. That portion of the pollution right at hand on Suisun Bay, between Dillon Point and Antioch and including Benicia, has a population equivalent of 150,000 persons in summer, of which 25,000 is from human sources. In winter the population equivalent figure may be reduced to about 110,000 persons.

Problem of River Pollution.

The two largest cities on the lower Sacramento and San Joaquin rivers, viz., Sacramento and Stockton on the respective streams, as well as some other down-river settlements, are dependent on dilution by the natural or tide-induced flow in the rivers. Generally, natural flow now suffices to keep the diluting waters well outside the septic limit and far from a state of nuisance. As natural stream flow subsides tidal movements that may extend several miles above the outfalls automatically begin, carrying the sewage to a fresh supply of oxygen at each turn of the tide. The construction of a barrier would remove the tidal action and, in dry years at least, natural river flow would require to be augmented or the sewage should be treated by high grade methods to compensate for the deficiency in dilution and removal of the tidal distributing medium.

The evidence in the case of Sacramento is that a river flow amounting to 1000 second-feet is now required to avoid septic water in the river and it is calculated that a sewering load of three times the present would require 2000 to 2500 second-feet of dilution water. In the absence of a barrier, and in ordinary years natural flow would seem adequate for a reasonable future growth.

Since the main body of the report was written the river has experienced this summer (1931) the unprecedented condition of practically no upland flow past Sacramento. The movement of water past Sacramento was almost entirely a tidal movement, with reversal of flow up and down stream at about six-hour intervals. There was a tidal flow upstream for several miles above Sacramento. Tidal gagings indicate that the up and downstream tidal flow averaged about 2200 second-feet and tests show that the tide acted as a distributing medium of the sewage with each ebb and flow to some 500 acres of river, covering a stretch of 10 to 12 miles. Oxygen was present at all points. At the most critical station the average was 50 to 60 per cent of saturation, and the lowest single value observed was 20 per cent of saturation. Oxygen depletion was found to affect approximately only five acres of river surface per 1000 persons served by the sewer, against some 15 acres during periods of considerable upland flow which could scatter the sewage downstream. B. Coli contamination dropped sharply from 700 to 1000 per cc. at points of high concentration to less than 50 just beyond the stretch of river to which the tides carried the sewage. No septic areas were found. The purification was evidently not unlike that taking place in oxidizing lagoons and fish ponds, and therefore offers a means of predicting that under drought conditions, without a barrier, the sewage load can not be more than doubled without danger of septic areas in the stream. However, such septic areas would with certainty remain local and cover a relatively short stretch of river.

So far as Sacramento sewage is concerned numerous tests under all conditions show the river to contain its normal pollution and contamination somewhere between Freeport and Walnut Grove, the exact point depending on the stream flow for the reason that recovery from pollution is a function of time and therefore the less the current the more restricted become the areas within which pollution and the recovery processes are operative.

Should a barrier be built, a more or less extensive septic area would surely result below the outfall in years of deficient stream flow. The remedy for the condition may be the construction of high grade sewage treatment in lieu of the release of upland water for sewage disposal purposes and the works would cost, as a rough figure, $10 to $12 per capita, allowing for the present population and industrial waste. Yearly operating costs, if continued throughout the year, would range from $1 to $2 per capita.

Recovery from pollution now taking place below Sacramento is repeated on a smaller scale, and in less distance, below each town sewering to the Sacramento River. The lowest town down stream is Rio Vista, twelve miles from Suisun Bay. At Rio Vista the river is very wide and it is safe to say the pollutional effect of its sewage on a barrier lake can be disregarded.

In the case of Stockton on the San Joaquin River, the situation is much the same as at Sacramento, except that the sewering loads are smaller and the city is more commonly dependent on tidal dilution. At Stockton, the human population and industrial load sewered to the San Joaquin River is about 60 per cent of that at Sacramento. The present dilution needs at Stockton to prevent nuisance probably do not exceed a flow of 400 to 500 second-feet in the San Joaquin River during the low water season. Under present conditions, the river flow and tides are adequate for Stockton sewage disposal. Should a barrier be built below the mouth of the San Joaquin River, the tidal action obviously would cease and, unless a river flow were developed past Stockton, whether up or down stream is immaterial, to compensate for the loss, offensive areas undoubtedly would occur in the river below each outfall.

The increase in organic pollution at Stockton is apt to be considerable in the course of the next few years. A ship canal, under construction between Stockton and the bay, undoubtedly will bring in more industries. Furthermore, there is an existing need for a change in the disposal of the paper mill waste running to Mormon Slough and producing a vile nuisance. This latter waste probably is equivalent in pollution possibilities to the sanitary sewage of the city itself. An outfall to the river would be highly attractive. With no more sewage treatment than now is employed at Stockton, and based on experience at Sacramento, the dilution need for three times the sewage load might amount to a river flow of 1000 second-feet during the low water season. In the absence of a barrier, dilution requirements would remain adequate to prevent nuisance for many years. With a barrier constructed, the dilution required must be supplied from upland flow, as would be developed if the plan for the San Joaquin River pumping system as proposed in the State Water Plan.* were consummated, but if adequate dilution could not be obtained, high grade sewage treatment would be possible and reasonable to compensate for the deficiency in dilution.

On tidal sloughs, as at Fairfield, Suisun, Napa and Petaluma, sanitary conditions already are more or less intolerable all the year, except at Napa, where floods normally clean out the slough each winter. Should a barrier be built at Dillon Point, diversion of the sewage of Suisun and Fairfield undoubtedly would be necessary to keep Suisun Slough clean enough for a source of water supply. Should a barrier be built at Point San Pablo, Napa, the Napa State Hospital and Petaluma also would require a high grade sewage treatment, such as is common in many California towns, to prevent the pollution of the water in Napa River and Petaluma Creek.

Effect of Sewage and Drainage Water from Delta Islands.

The effect of sewage and drainage water from the delta islands on the usefulness of the waters of a barrier lake for boiler purposes has been questioned also. Construction difficulties encountered, because of the poor bearing qualities of the peat lands in the delta and the nearness of the water table to the ground surface, limit the use of modern methods of sewage treatment and disposal in that area. As a result about 80 per cent of the delta's population of some 17,000 people sewers directly into the main drainage system of each island, or has privies built over drain ditches. The remainder use vault privies, generally built on the inner side of the levees. The drain ditches empty into the main drainage canal of the island which in turn leads to pumping plants where the accumulated sewage and drainage water is boosted over the levee into the river channels. When the huge pumps are operating, the accumulated mass of sewage must set up intense local contamination.

With regard to the general effect of the delta island drainage on a barrier lake, the best analysis that can be given of this question is derived from the experience of the city of Sacramento, which receives

*Bulletin 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

the drainage from as much as 150,000 acres of rice fields which are high in alkali and soluble salts. In summer, the flow past Sacramento sometimes has been made up almost entirely of this rice field drainage but, at most, the inconvenience to boiler operation has been slight. As nearly as can be learned, drainage from the delta islands is not more than 25 per cent of that reaching Sacramento from the rice fields and, therefore, should be unimportant.

Problem of Sewage and Waste Disposal in a Barrier Lake.

Along the shores of Suisun and San Pablo bays, and sewering to them, are many centers of population, including Vallejo, Mare Island, Benicia, Antioch, Pittsburg, Martinez, Crockett and others of lesser importance, with approximately 54,000 inhabitants and an industrial organic waste load appraised at 206,000 persons. These cities lie along shores close to fairly deep water and, having strong tidal currents at their doors, sludge banks, or other signs of filth, do not exist under prevailing conditions. Were it not for the strong tidal currents and winter flood flows from the Sacramento and San Joaquin rivers into Suisun Bay, such quantities of sewage could not possibly be run to the bays without unbearable nuisance, except possibly in winter. With a barrier below these centers of population, the situation would be one in which large amounts of organic and chemical wastes would be introduced along the shores of an inland fresh-water lake having a relatively small outflow for several months during the annual period of low run-off, as compared to present tidal flows.

The same laws of self-purification, as were referred to in discussing the river system, would tend to operate within a barrier lake. Oxygen would be restored to the polluted waters from the air and by aquatic plant life. Fortunately, winds are strong in this region and they would be of great assistance in whipping oxygen into the water and in the dispersal of the sewage and chemical wastes. Moreover, the direction of the prevailing winds and the resulting current movement are obliquely away from the southerly shore, rather than toward it. But, in spite of these factors, the outlook is unfavorable for sanitary sewage disposal in a barrier lake, except on a small scale.

Near Gary, Indiana, with a population of 115,000, sanitary conditions in Lake Michigan are said to be very bad. There the bacterial contamination travels nearly fifteen miles. At Cleveland, Ohio, the shores of Lake Erie are too polluted for bathing. It also is worth noting that it has been necessary in recent years to divert sewage below the Charles River Basin Dam at Boston. This latter project is the basis of one of the prominent arguments cited in earlier reports on a salt water barrier to indicate a barrier would not prevent sewage disposal behind it.

This investigation, however, shows quite definitely that contamination by sewage bacteria, sufficient to interfere with domestic water supplies, would cover not less than half a square mile of lake surface at the outset, according to the lowest estimate that can be given. According to other data, it might cover as much as four square miles. Considering that the contamination would streak along the shores, if there were no changes made in the sewers, it must be anticipated that in time no part of a barrier-lake shore would be safe for a domestic supply intake. Oxygen depletion probably would cover a much larger area than the bacterial contaminated area, considering the high percentage of organic waste compared to human sewage. Some areas actually would be septic. The only escape from such conditions is a general sewer system. This will be discussed subsequently.

The main constructive recommendations of this report, therefore, narrow down to disposal of sewage and industrial and chemical wastes, which would be produced along the shores of a barrier lake, in such a way as to allow the taking of water for domestic. boiler. process and cooling purposes anywhere offshore.

Waste Problems of Industries.

At the outset. the disposal of the watery wastes of the industries presents an unusual problem. From Antioch downstream to Richmond the industries now discharge to the bay about 75 million gallons per day. The bulk of the flow is harmless water. but several industries add highly concentrated wastes, for which a different disposal would be required should a barrier be constructed. At present the difficult chemical wastes fall into three classes: (1) iron sulphate wastes, (2) wastes containing the sodium radical. and (3) wash and rinse waters from the oil refineries. The latter are high in sulphurous compounds and contain so much gasoline that it is unsafe to carry them in sewers because of the danger of explosions.

In addition to this type of industrial waste, there are the many solids poured into the rivers, delta channels and bays by the canneries and other types of industries operating in the area above and adjoining the barrier sites. The principal solid waste is asparagus butts, emptied into the streams during the early spring canning season. The butts are dumped into the streams without any form of treatment in most instances. They do not decay rapidly and, as a result, would offer an unusual disposal problem in a barrier lake if they were continuously dumped therein and allowed to accumulate.

These solid wastes, together with the chemical wastes poured into the water ways by the industries, would present conditions in a barrier lake much more detrimental to a satisfactory water supply in upper San Francisco Bay than would human sewage, unless special steps were taken for their control. All organic factory wastes should be regarded in the same category as sanitary sewage because of their putrescibility. The magnitude of the industrial organic load represented has been stated previously.

It is found that most of the troublesome industrial chemical wastes could be singled out from the huge volume of general waste water and handled without great hardship by the producing industry. The segregated oil refinery wash water, amounting to around 500,000 gallons per day, appears to be the most undesirable waste. Were it not for its gasoline content, its disposal by way of a regional sewer system would not be burdensome. However, with so many records of explosions in sewers, the only disposal that can be offered is a separate carriage of this water in a closed pipe line. By this procedure the waste could be by-passed around treatment works and the reduced cost thereof would partly offset the cost of the separate pipe line for refinery wastes.

Bacterial Contamination.

While it appears that where water in the Sacramento and San Joaquin rivers is redeemable from a bacterial contamination standpoint it also is redeemable from an organic and oxygen-containing standpoint, it is not known whether such would be the case in a barrier lake more highly polluted by industrial wastes. The experience of eastern cities, notably Cleveland, which sewers to Lake Erie, and those sewering to Lake Michigan through the Indiana Harbor Ship Canal, together with surveys made by this Bureau around deep salt-water sewer outlets along the coast, lead to the belief that the untreated sewage of 1000 people entering a barrier lake could pollute 50 acres thereof beyond the point of redemption for a domestic supply. With the several larger communities sewering into the bays, sloughs and streams adjacent thereto, and with industries emptying large volumes of dangerous industrial wastes into the same streams, to be gathered behind a barrier if one were built, it also appears that ultimately, unless proper steps were taken to remove the sewage and wastes, the whole lake shore would be a nuisance and would be useless for a water supply from end to end, or even for the industrial expansion which is the goal of those urging construction of a barrier.

Health Conditions.

Past and present typhoid fever outbreaks in upper San Francisco Bay and the delta district also must be taken into consideration in surveying health conditions that would follow creation of a barrier lake. While it is true much progress has been made in checking outbreaks of this disease among transient workers in the seasonal industrial plants and agricultural districts of the upper bay and delta, there still exists a special typhoid problem in that area.

Investigations made by the State Department of Public Health reveal that, largely through immunization work, the number of typhoid fever cases in the river areas of Contra Costa, Sacramento, San Joaquin, Solano and Yolo counties has been reduced from 110 in 1925 to 61 in 1930. Of the 1930 total, 19 cases were in Sacramento County, 37 in San Joaquin, two in Contra Costa, two in Solano and one in Yolo. These 61 cases compare with a total of 685 for the state as a whole in 1930. This progress in reducing delta typhoid cases, the State Department of Public Health holds, is about all that can be expected, as the type of country in the delta region and the army of laborers working in and out of it make the complete control of typhoid almost impossible.

The hygienic reputation of the lower Sacramento River is not good, and the typhoid outbreaks in the regions bordering it probably can be associated with sewage contamination and use of the river for navigation and swimming. The San Joaquin River's reputation hygienically also is bad, the appearance of its waters being such that discriminating persons probably would prefer not even to swim in it.

A portion of the typhoid throughout the area is undoubtedly waterborne and the possible interruption of the tidal currents which now help scatter contamination would, in a small measure, improve health conditions in the delta and upper bay.

Conclusions.

The important conclusion that must be drawn after a survey of existing health, sewage and industrial waste disposal conditions, to determine what might be anticipated with a barrier cutting off tidal action in the upper San Francisco Bay and delta region, is that particularly acute sanitary and waste disposal problems that do not now exist would result along the water front behind a barrier, and would be chargeable to a barrier. Similarly, in the event there were subnormal upland river flow past Sacramento and Stockton, sanitary problems would be created at each sewage outfall in the not far distant future.

It is believed that septic areas, though probably not very extensive, would be created. The oxygen depletion, bacterial contamination and trade waste pollution to be anticipated would prevent the utilization of a wide strip of the water impounded behind a barrier unless steps were taken to prevent such pollution.

Notwithstanding, it is concluded the sanitary problems would be feasible of solution at a reasonable cost as sewage disposal costs go. The result of a proper program of sewage disposal and waste segregation would be a suitable quality of water along the shore for domestic and industrial purposes.

By a slight rearrangement of sewerage within the industries, about 80 per cent of the industrial waste water tributary to the bays could be kept unpolluted and returned to a barrier lake for re-use. The troublesome chemical wastes would have to be disposed of below a barrier. Whether the organic waste and sanitary sewage also could be conserved behind a barrier with uniform satisfaction is a question almost impossible to decide in advance of actual experience, bearing in mind the sluggish shoal waters in which the disposal would be attempted and the uncertainties as to the future organic loads. The outlook, however, is unfavorable for successful sewage disposal in a barrier lake. Although the costs of works for disposal without complete sewage treatment into a barrier lake would be somewhat cheaper than for disposal below a barrier, sewage disposal anywhere behind a barrier should be accepted as speculative and its success not reliable unless complete treatment were given the sewage. If complete sewage treatment were added, the costs, both capital and annual, would exceed those of diversion of sewage below a barrier by a considerable amount.

The more conservative project would be to dispose of the liquid organic wastes and sanitary sewage, after appropriate treatment, and the chemical wastes at a point well below a barrier in such a way that tidal action could be taken advantage of in causing its dilution. The estimated outlays for projects of this nature, which would gather and carry all the sewage and organic wastes from the settlements and industries in the area above a barrier to treatment works and thence to tidal outfalls below a barrier range from $3,800,000 to $6,800,000, depending on whether a barrier were built at Dillon Point or Point San Pablo, respectively. The respective annual costs for these sewer systems and treatment and disposal works are estimated at $400,000, or $68.50 per million gallons, and $780,000 or $74 per million gallons, with an operating capacity averaging 15 and 29 million gallons per day, respectively.

CHAPTER II

STREAM POLLUTION AND SELF-PURIFICATION

Oxygen has an important part in ridding a waterway of pollution. It may be contained in the water in its unpolluted state, absorbed through the action of wind and tidal currents or produced by aquatic plant growths. This phase of the purification of water for industrial and other uses is worthy of detailed consideration.

Oxygen Demand Phenomena.

It is well known that organic substances are unstable chemically and, therefore, in a state of change. The native oxygen of the water with which these substances are in contact is consumed until their oxygen demand is satisfied. The process is not instantaneous, but goes on at a gradually decreasing rate for a long time, because of the varying stability of the compounds composing the substance. Average values as used in this report of the rate of oxygen demand, by organic matter in sanitary sewage, expressed in pounds of oxygen per person, are shown in Table E-1.

TABLE E-1

OXYGEN DEMAND PER CAPITA AT 20 DEGREES CENTIGRADE

Period in days	Demand in pounds per capita	Period in days	Demand in pounds per capita
1	0.05	6	0.183
2	0.09	7	0.198
3	0.12	10	0.218
4	0.145	15	0.236
5	0.165	20	0.240

Temperature changes the rate of demand for oxygen. Higher temperatures speed up biologic activity and increase the rate of oxygen demand, at the same time shortening its period of action. The values just given are for 20 degrees Centigrade, which probably is a fair value of the average summer temperature that would prevail in the water behind a barrier.

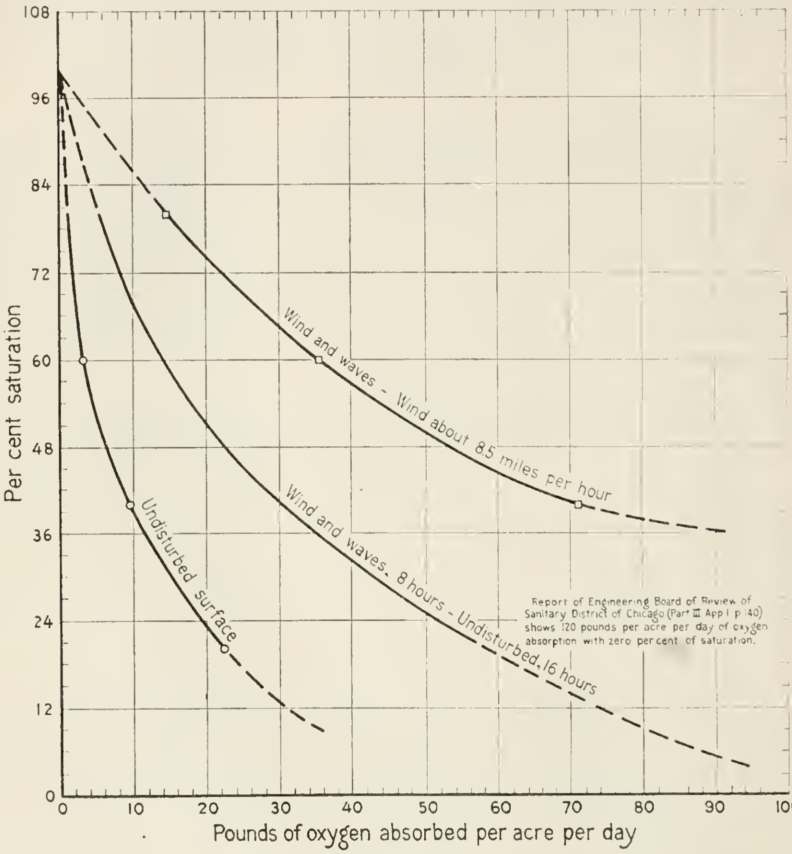
In the case of sludge deposits, which lie stationary, the action is most intense in a restricted area. It may last over several months in the same area, or until the oxygen avidity is fully satisfied. For this reason the removal of sludge from sewage improves the condition of the receiving water to a marked degree.

As oxygen in the diluting water is consumed, the first damage is to water supplies. Then fish life disappears. When the disappearance of the oxygen is complete, the water becomes black and septic and is apt to give off vile odors.

PLATE E-1

Per cent of saturation	OXYGEN ABSORPTION			
	Undisturbed surface		Wind and waves	
	Cubic centimeters per sq ft per day	Pounds per acre per day	Cubic centimeters per sq ft per day	Pounds per acre per day
80	—	—	115	14.6
60	25	3.18	280	35.5
40	75	9.50	560	71.0
20	175	22.20	—	—

NOTE
Compiled from data in Transactions, A.S.C.E., Vol. LXXXV, p. 730.



OXYGEN REABSORPTION FROM THE AIR

Oxygen Reabsorption from the Air.

Offsetting this loss of oxygen, restoration sets in at once. The oxygen can come from several sources. It may be supplied to the affected areas from an adjacent area richer in oxygen, through the instruments of tidal and wind-blown currents and upland flow. Universally, however, unless the surface water is sealed against it, as by oil or scum, oxygen is absorbed from the air, following the simple law of oxygen pressure equilibrium in water and the adjacent air. Therefore, the nearer a water approaches septicity, the more rapidly it will absorb oxygen from the air.

The oxygen obtainable by readsorption from the air has been investigated in New York Harbor, and some work has been done on the effect of winds. The transfer is greatly aided by wind and wave action or by any influence that disturbs the water surface. For example, in still water 80 per cent saturated with oxygen, the rate of absorption has been found to be about one pound per acre per day. If an 8.5 mile per hour wind is blowing the corresponding rate of oxygen absorption is nearly fifteen pounds. Still water 40 per cent saturated absorbs oxygen at the rate of about ten pounds per acre per day. The 8.5 mile per hour wind will increase this absorption rate to over 70 pounds. It is doubtful, however, if a higher oxygen reabsorption rate than 120 pounds per acre per day is attainable under usual wind conditions even when conditions are actually septic and the thirst for oxygen at its peak. The results of these investigations are shown on Plate E-I, "Oxygen Reabsorption From The Air." It also shows the reabsorption expected under the wind conditions apt to occur in the area above the barrier sites being studied. The wind was assumed to average 8.5 miles per hour and to prevail one-third of the time.

Assuming the removal of settleable sludge, the oxygen demand of the effluent would be about 0.12 pound per person for a three-day interval during which the effluent might lie in a zone critically low in oxygen. It can be computed from this that the settled sewage of 1000 persons would reduce one acre of water surface to septicity. Since the Antioch area now produces wastes having an oxygen demand of over 80,000 persons, at least 80 acres of water surface would be septic at the outset. In the course of years this septic area would greatly increase. Since the towns and industries from Antioch to Martinez are, or will be, almost continuous along the shore, it follows that shore outlets would be likely to ruin the entire waterfront.

Oxygen Production by Plankton.

Another source of oxygen normally available is that produced by the plant life known as plankton and commonly called "moss," if the water is not too low in oxygen to support the green plants. This is not only the stringy moss familiar to most people, but includes microscopic moss noticeable to the eye by the green or brown color it imparts to the water. Plankton thrive in the presence of sunlight and the fertilizer furnished by organic waste, quite the same as do land plants. In fact, it has been said that, acre for acre, water and soil in the same region can produce about an equal tonnage of plant life.

There is little accurate measure of oxygen production by plankton. Measurements on the mud flats of Potomac River indicated an oxygen production of 17.7 pounds per acre daily and "less in a mixture of fresh and salt water." An intense plankton growth occurs in the Sacramento and San Joaquin rivers. Oxygen supersaturation of the San Joaquin River reaches as high as 150 per cent of normal. In the predictions of future conditions, which is a part of this study, the oxygen production by plankton has been taken at fifteen pounds per acre daily. However, no allowance for oxygen from this source has been made when the oxygen falls below 30 per cent of saturation.

In the bays below the mouth of the two rivers, tidal currents and wind keep so much silt in suspension that sunlight can not penetrate the water deeply and plankton growth is not in evidence. Behind a barrier, it is likely that there would be plankton growth in the deeper water, as in the case of the rivers, but along the shallow shores it is probable wave action would keep sufficient silt in suspension to prevent plankton growth.

In the last few years these various phenomena of oxygen depletion and restoration have received more or less evaluation. This meager data, supplemented by tests on any particular water under investigation and by recourse to judgment and comparable precedents elsewhere, afford the best procedure available for predicting future conditions in a stream. In the case of a more or less still body of water or a lake, where the only currents are wind-induced and whimsical, the method is less satisfactory and one must put chief reliance on judgment and precedents.

Estimating the Oxygen Balance.

The procedure in the application of the foregoing data to an estimate of the oxygen status of a given stream is to construct the accumulative oxygen demand exerted downstream, taking into account the mean time of travel and increments to the pollution load as it passes points of new pollution. This gives the oxygen debit side. On the credit side is the oxygen supply at the beginning, plus oxygen restoration along the way from air and from plankton. Knowing the width of the stream and the distance covered in any given time, the oxygen derived from these sources can be evaluated. To ascertain the amount derived from air, a net degree of saturation is first tentatively assumed for the point in question, and if the final result does not agree closely a new value is assumed. After a few trials the answer is obtained. At the conclusion of such a series of calculations the net expected dissolved oxygen along the course of the stream can be set down. Comparing the calculated oxygen values for the Sacramento River with those actually determined by test for similar river flows, quite close agreement is to be observed.* This supports the reasonable correctness of the derivation of oxygen depletion and restoration.

In such a lake-like area as would be created by a barrier, sludge deposits would form readily, unless the sludge were previously settled out, and the water over the sludge would become particularly obnoxious. Sludge removal, therefore, often accomplishes a striking cleanup and is one of the first steps in sewage treatment. If there are sludge

*See Plates E-III, "Organic and Bacterial Pollution in the Sacramento and San Joaquin Rivers," and E-IV, "Hypothetical Organic Pollution in the Sacramento and San Joaquin Rivers for Average Organic Pollution Loads During the Critical Season and Given Flow Conditions."

deposits and the dissolved oxygen approaches 20 per cent of saturation, the danger of septic conditions is great. If there are no sludge deposits, a lower percentage may suffice to avoid septic conditions.

Bacterial Contamination.

If there were nothing other than dilution to reduce the health hazard from sewage contamination, the city of Sacramento, as an example, would require a river flow of about 100,000 second-feet just to keep the river redeemable for a water supply with careful treatment. To meet drinking water standards without treatment, would require a flow of fully 200,000,000 second-feet.

Sewage organisms do not thrive in water. Typhoid bacteria and the sewage index organisms, B. Coli, die quite rapidly and at nearly equal rates in ordinary waters. So far as known they do not multiply in natural waters. In a few days, or in a few miles of river flow, a majority will die. More than 90 per cent ordinarily will have disappeared within a week or two. As the number of bacteria declines the rate of disappearance slows up. Final disappearance is too slow a process to occur practically in any of these rivers. On the other hand, a water redeemable for domestic use by treatment is reached fairly soon in the course of river flow.

In the case of the Sacramento River, such reduction ordinarily takes place some distance above Courtland, which is about 22 miles below the city of Sacramento's sewer outlet. Sacramento River water is easily redeemable for a domestic supply considerably above Walnut Grove and, except for local areas of repollution, this condition is true clear to the mouth of the river. In the San Joaquin River also the same phenomenon of limitation of travel of bacterial contamination is found. Hence, the excessive bacterial contamination around outfalls to the river is not all-pervading, but affects only a local area around or below the sewer outlets and feathers out to a rather persistent residual, found to lie between about ten and twenty-five B. Coli per cubic centimeter not many miles away.

Comparing the point at which a redeemable water supply is reached below Sacramento and the dissolved oxygen findings, it appears that, where the water is redeemable from a bacterial contamination standpoint, it also is redeemable from an organic and oxygen containing standpoint. Whether this also would be true in a barrier lake, more highly polluted by industrial wastes, is a question. Within a lake formed by a barrier the same tendencies for disappearance of the sewage organism would prevail. However, there is only meager precedent to say how far the resultant contamination would travel.

In the case of Cleveland, with a population of about 800,000 sewering along the shore of Lake Erie, it is reported that the waters are not redeemable for water supply for a distance of two miles offshore and for a distance of sixteen miles along shore. The sewage is chlorinated to protect shore bathing. This indicates an area of contamination of about 30 acres per 1000 people. The Indiana Harbor Ship Canal empties the sewage of 115,000 people close to the shore in Lake Michigan. Surveys show contamination beyond that of a redeemable water to reach nearly 7000 feet offshore on an average, varying from 3000 to 10,000 feet, depending on wind. The length of shore affected to the same degree is from one and a half to fifteen miles, averaging ten miles. This would indicate an average zone of contamination of not less than three acres per 1000 people, and not more than 130 acres per 1000 people. The average figure was 100 acres per 1000 people. The range of the values illustrates the effect of wind piling the contamination on the shore, or driving it away. From surveys of the Sacramento River, its contamination factor is found to be about 15 acres per 1000 people.

It is said that B. Coli have about the same longevity in salt water as in fresh. This bureau has made several surveys around deep salt water sewer outlets along the coast and the contamination factor has been found to lie between about one acre per 1000 people for large cities and five acres per 1000 people for small communities.

From all this evidence it appears that, to be reasonably conservative, it should be assumed untreated human sewage of 1000 people could contaminate and pollute 50 acres of lake water beyond the point of redeemability for a domestic water supply. In still water the contaminated zone would approximate a circle. Due to wind-induced currents and outlets in shallow water near the shore, however, the shape of the area would elongate or indent under the pressure of winds and currents. Outside of the limits of the area so polluted, it appears that the water not only would be redeemable on hygienic grounds, but it would be far from stagnant or unusable due to organic pollution.

In determining the location of a water works intake for domestic and most industrial process water, the estimated area of pollution should be plotted for the given locality and the intake kept well outside of it. Of the present communities, where such a test should be applied, Pittsburg, Antioch and the California Water Service Company intake near Mallard Slough would seem most concerned. In the Pittsburg area, for example, it appears that the sewers already present might make domestic and industrial water diversion dangerous within an area of 500 acres. This might easily elongate a couple of miles up and down the shore and overlap neighboring zones of pollution, such as that due to the Antioch sewers. Ultimately the whole shore would be a nuisance if each community were to run its sewer offshore with no comprehensive plan, and the shores would be rendered useless from end to end for water supply and even for industrial occupation.

Population Equivalents of Industrial Pollution.

It is convenient in comparing the pollutional possibilities of industrial wastes, often varying widely in their characteristics, to determine the oxygen demand of the particular waste and to express its strength in terms of its oxygen demand compared to the more constant oxygen demand of human sewage. This strength of the waste is designated as its "population equivalent." Since this nomenclature and procedure is one of the developments of recent years in sewage disposal, all available information from various sources giving population equivalents of numerous industrial wastes is assembled here, including also special work performed in this particular investigation. These population equivalent values are summarized in Table E-2.

When sewage treatment is practiced, the oxygen demand, and hence the population equivalent, is reduced in proportion to the amount of treatment the wastes receive. The percentage reduction factors of oxygen demand employed in this report are:

Type of treatment	Per cent reduction of oxygen demand	Type of treatment	Per cent reduction of oxygen demand
Fine screens	5	Septic tank and drainage system (delta island conditions)	60
Septic tank	20	Septic tank and ponds	80
Chlorination	30	Activated sludge	85
Imhoff tank	30		

TABLE E-2

APPROXIMATE POPULATION EQUIVALENTS OF INDUSTRIAL WASTES

Industry	Specific nature of waste	Unit of measurement	Pounds per unit		Population equivalent	Source of information	Value adopted
			Oxygen consumed	20-day biochemical oxygen demand at 20 degrees centigrade			
Canning	Spinach canning (exclusive of trimmings)	Ton of raw material treated	7.0	11.5	50	[1]California Cooperative Producers, Sacramento	
		Ton of raw material received	5.0	8.0	30		30
	Asparagus canning (excluding asparagus butts)	Ton of raw material treated	4.5	7.0	30	[1]Bay Side Canning Company, Isleton	
		Ton of raw material treated	3.0	5.1	20	[1]California Cooperative Canneries, Isleton	
		Ton of raw material received	2.6	4.5	20	[1]Bay Side Canning Company and California Cooperative Canneries, Isleton	20
	Asparagus canning (including asparagus butts)	Ton of raw material treated		57.0	240	[1](Bottle experiments)	
		Ton of raw material received		55.0	230	(Bottle experiments)	230
	Peach canning	Ton of raw material received			290	[2]Lodi Sewage File, August 19-21, 1924	
		Ton of raw material received			480	[2]Lodi Sewage File, September 2-3, 1924	
		Ton of raw material received		35 0	150	[2]Tulare Sewage File, June 19 to August 15, 1928	200
		Ton of raw material received			120	[2]Gilroy Sewage File, September, 1929	
	Pear canning (exclusive of trimmings)	Ton of raw material received			30		30
	Pear canning (including trimmings)	Ton of raw material received			130		130
	Apricot canning (with lye peeling)	Ton of raw material received	86.8	76.25	320	[1]Hunt Bros. Packing Company, Hayward	300
	Apricot canning (without lye peeling)	Ton of raw material received			100	Estimated from results at Hunt Bros. plant	100
	Beet canning	Ton of raw material received			30		30
	Tomato canning	Ton of raw material received		28.8	120	[3]	
	Tomato canning (exclusive of trimmings)	Ton of raw material received			250	[4]	200

	Fig canning (exclusive of trimmings)	Ton of raw material received			30		30
	Sardine canning	Ton of raw material received			20		20
Dairy products	General Creamery	100 pounds of butter fat	2.18	5.74	*35	(3)	
	Two per cent skimmed milk	1,000 gallons of skimmed milk	7.30	11.80	50	(5)	50
	Whole milk	1,000 gallons of whole milk		822	3,420	Laboratory experiments file, March 23, 1928	3,420
	Skimmed milk	1,000 gallons of skimmed milk	340	672	2,800	(5)	2,800
	Buttermilk	1,000 gallons of buttermilk	312	624	2,600	(5)	2,600
	Whey	1,000 gallons of whey		420	1,750	(6)	1,750
	General creamery	100 pounds of butter fat received	2.02	3.99	20	(7)	
	General creamery	1,000 gallons of milk and cream received		11.60	50	(7)	
	General creamery	1,000 gallons of milk and cream received		8.24	35	Based on one per cent loss of material received	35
	Whole milk	1,000 gallons of milk received		822	3,420	From values previously adopted	
	Skimmed milk (90 per cent of whole milk)	1,000 gallons of milk received		612	2,550	From values previously adopted	
	Buttermilk (10 per cent of whole milk)	1,000 gallons of milk received		62.4	260	From values previously adopted	
	Whey (87 per cent of skimmed milk)	1,000 gallons of milk received		329	1,370	From values previously adopted	
Paper industries	Sulphite pulp	Ton of product	1,430		13,000	(8)	
	General paper mill	Ton of product	65.8		780		780
	Leatherboard	Ton of product	96.8		1,000	(3)	
	Strawboard	Ton of product	333	376	1,570	(3)	1,600
	Straw and paperboard	Ton of product	161	151	630	(3)	630
	Strawboard	Ton of product			2,500	(3)	
	Rag felt	Ton of product	39	47	200	[1]Johns Manville, Pittsburg	200
Cane sugar	General refinery	Ton of raw sugar	3.0	4.5	20	[1]California and Hawaiian Sugar Company, Crockett	20

TABLE E-2—Continued

APPROXIMATE POPULATION EQUIVALENTS OF INDUSTRIAL WASTES

Industry	Specific nature of waste	Unit of measurement	Pounds per unit		Population equivalent	Source of information	Value adopted
			Oxygen consumed	20-day biochemical oxygen demand at 20 degrees centigrade			
Brewing		[1]Barrel of beer	1.55	3.4	15	([3])	
Grain products	General flour mill	Ton of raw material		3.3	15	[1]Sperry Flour Mills, Vallejo	15
Dry fruit packing	Wash water	100 gallons of waste			20	Estimated from an assumed bacterial oxygen demand of 5,000 parts per million	20
Slaughtering and meat packing	General slaughterhouse	Per animal killed	1.03	9.76	40	([3])	
	Combined waste	Per animal killed	1.03	4.2	20	([3])	20
	General packinghouse	Per animal killed	.84	6.78	30	([3])	
	Pork packing	Per animal killed	.80	5.3	20	([3])	
	Hog killing	Per animal killed	.365	1.83	10	([3])	
	Cattle slaughtering	Per animal killed	1.21	4.78	20	([3])	
	Lard and sausage	Per animal killed		1.90	10	([3])	
	Poultry killing and cleaning	Per 100 head			25		25
	Fish cutting and cleaning	Per ton of shad Per ton of salmon Per ton of catfish			30 60 60		30 60 60
Rendering		Per employee	3.43	8.05	35	([3])	35
Glue		Per employee	9.74	4.53	20	([3])	
Grease and oil		Per employee	1.04	.32	1	([3])	
Soap		Per employee	45.9	3.34	15	([3])	
Textile industries	Wool scouring (grease wool)	100 pounds of raw material	3.41		30	([8])	

	Wool yarn and cloth scouring	100 pounds of raw material	2.79			([3])	
	Wool yarn and cloth dyeing	100 pounds of raw material	1.68			([3])	
	Wool yarn and cloth dyeing and scouring	100 pounds of raw material	15.65		124	([8])	
	Wool and mixed goods, washing and dyeing	100 pounds of raw material	5.22			([3])	
	Cotton yarn and cloth bleaching	100 pounds of raw material	14.00			([3])	
	Cotton yarn and cloth dyeing	100 pounds of raw material	2.90			([3])	
	Cotton yarn and cloth bleaching and dyeing	100 pounds of raw material	13.56		115	([8])	
	Cotton cloth, bleaching, dyeing and finishing	100 pounds of raw material	1.69			([3])	
	Silk washing and dyeing	1,000 gallons of waste water	300.0		10	([9])	10
Tanning	Hide tanning	One hide	2.79	4.0	15	([3])	17
	Hide tanning	One hide	2.79		22	([8])	
	Calf skin tanning	One skin	.778	1.14	5	([3])	
	Sheep skin tanning	One dozen skins	.290			([3])	
	Harness leather	One hide	3.55	5.18	20	([3])	
Corn products		One bushel One bushel	.53	1.58	7 5	([3]) ([8])	
Distilling		One barrel whisky (10 bushels mashed grain)	48.6			([3])	
Domestic sewage		One person	113	.24	1	([3])	1

* This value appears to be in error when compared with results obtained from other sources. The error, apparently, results from stating the results in kilograms instead of pounds, which is the customary way of presentation.

[1] Investigations made for this report, 1930.
[2] Files of State Department of Public Health.
[3] United States Public Health Service, Treasury Department, Public Health Bulletin No. 171, 1927.
[4] Estimated from data published in United States Public Health Service, Public Health Bulletin No. 118, 1923.
[5] Engineering Experiment Station, Iowa State College, Ames, Iowa, Bulletin No. 68.
[6] "The Biochemical Oxygen Demand of Substances of Known Composition," etc., a thesis by Villarruz and Sanchis.
[7] United States Public Health Service, Public Health Bulletin No. 109, 1921.
[8] Journal American Water Works Association, Volume 17, January, 1927.
[9] First and second biennial reports of the Industrial Waste Board, Connecticut Department of Health, 1918-1921.

CHAPTER III

SANITARY SURVEY OF THE DRAINAGE BASIN OF THE SACRAMENTO AND SAN JOAQUIN RIVERS

The Sacramento River, rising on the slopes of Mt. Shasta, is a beautiful mountain stream for miles at its headwaters. However, it receives sewage almost at its source, and sewage and waste are added to it every few miles to its mouth. Settlements, industrial plants and other improvements, contributing to the river's pollution, border the main stream and the several tributary rivers, including the McCloud, Pit, Feather, Yuba, Bear and American, and also several smaller tributaries.

Conditions in Sacramento River Above Sacramento.

Mt. Shasta City, formerly Sisson, is the farthest upstream settlement sewering into the Sacramento River. The city maintains a septic tank discharging its effluent to a small creek, which empties into the river about three miles away. Five miles downstream from the mouth of this creek is an old and well-known resort area. The owners of this outing spot endeavor to restrain all sewage of that locality in cesspools, but some of it may escape to the river. To this point the river still maintains the beauty of a mountain stream.

Lying just below this resort area is Dunsmuir, the next city of note making use of the river as a depository for its sewage. The sewage is gathered in a complete city sewage system, and quite effectively treated in an activated sludge plant below the city. The effluent then is run to the river. A railroad roundhouse maintained here occasionally loses some oily waste to the river. At this point the river begins to show signs of moss clinging to stones and banks, but otherwise it is clear and clean.

In the next six miles there are several resorts and the small settlement of Castella. Sewage pollution in the area may occur occasionally due to overflowing cesspools. Each mile of the river now shows a noticeable deterioration, principally in clearness. For the next 40 miles, or to the point of entry of the Pit River, there is scarcely any added contamination, but the waters fail to regain their original clearness and are more or less mossy and unpalatable.

The Pit River, which also carries the flow of the McCloud River into the Sacramento River, is more or less polluted for much of its length. Alturas, at its head, recently installed a new sewer system yielding a high grade effluent, which passes through ponds, where it is still further purified, before being emptied into the river. For 40 or 50 miles below Alturas the Pit is a badly discolored, slough-like stream flowing through a high Sierra plateau and is subject to much pollution by stock. Individual sewers at Adin and Bieber also contribute some pollution to the Pit as it wends its way toward the lower levels in the drainage basin. On reaching the Sacramento River the waters of the Pit have regained their blue appearance.

The McCloud River water, carried into the Sacramento by the Pit, is particularly free of contamination. However, some contamination may occur from occasional sewage overflow from the McCloud sewer farm several miles away from its channel. It is often muddy, due to mud flows from Mt. Shasta.

Fourteen miles below the junction of the Pit and Sacramento rivers is the city of Redding, which obtains its water supply from the Sacramento River and treats the water by aeration and chlorination. Redding has a complete sewer system discharging raw sewage to the river. It is now the uppermost source of any considerable contamination of the Sacramento River. However, the sewage mixes quickly with the large flow of the river and, except for a bad odor at the sewer outlet, there is no physical impairment to suggest the presence of sewage. The next main source of pollution downstream is at Red Bluff, about 44 miles from Redding by river. It has a sewer system but no sewage treatment. It depends on dilution in the Sacramento River and conditions are similar to those below Redding.

About 20 miles below Red Bluff is the town of Corning, which also sewers raw sewage to the Sacramento River without noticeable pollutional effect. From Corning to the mouth of the Feather River, about 85 miles by air line, no sewage drains to the Sacramento River. In the neighborhood of Colusa, Butte Creek discharges the drainage of the rice fields on the east side of the Sacramento Valley.

Along the upper Feather River is another of the great playgrounds of the State. The river undergoes substantially the same impairment as does the upper Sacramento. The first important source of sewage pollution, however, is at Oroville, at the foot of the Sierra. The city is completely sewered and its sewage is treated in a septic tank. From all appearances the river is clean. The water is popular for swimming and is largely diverted for irrigation. The Feather River is levied from Oroville to its mouth. Yuba City and Marysville lie on its banks, but neither of these places has contributed sewage, except during floods when their sewer farms overflow.

The Yuba River joins the Feather at Marysville. Nevada City sewers raw sewage to Deer Creek, a tributary of the Yuba River. Otherwise there is no pollution worth mentioning. The Bear River is tributary to the Feather about 20 miles upstream from its mouth. Wheatland has a filter bed in the dry sands adjoining the Bear River, which is generally dry, or nearly so, at this point in summer. Like the Yuba, the Bear River receives most of its pollution by way of small creeks. One of these is Wolf Creek, which carries the raw sewage of Grass Valley. On another creek is Weimar Sanitarium, having a complete sewage treatment. On still another is Colfax, having a septic tank and sewer farm.

Between the Bear River and the American River, the waters of several creeks drain across the valley and, after having gathered sewage from various towns, collect in small lakes and marshes behind the Sacramento River levee and then are discharged into the river. Towns sewering to the river by this indirect route include Auburn and Newcastle, each with Imhoff tanks; Lincoln with a septic tank; and Roseville with a separate sludge digestion tank.

On the west side of the Sacramento River are extensive rice fields. Their drainage finds an outlet to the river at Knights Landing or to Yolo By-Pass. The acreage of rice land has varied from 75,000 to 160,000 acres in the past ten years. The irrigation practice is to begin flooding the rice early in April. The duty of water is about six acre-feet per acre. A steady run-off of highly vegetable and more or less mineralized drainage water occurs throughout the growing months. In the harvest months of September and October the rice fields are de-watered in the course of a few weeks' time. Hence, a considerable portion of the dry weather and early fall flow past Sacramento is rice field drainage.

From a pollution standpoint, the principal result of rice field drainage is a considerable increase in the incrusting and corrosive properties of the water and an extremely high plankton growth in the river. These properties introduce a difficult water treatment problem at Sacramento. The plankton remain a prominent characteristic downstream nearly to the river's mouth, where silt turbidity destroys them. However, even without the rice fields to supply plankton to the river, it is probable the fertilizing elements of the sewage of the city of Sacramento alone would sustain plankton growth in scarcely less diminished amount.

The American River empties into the Sacramento River just above Sacramento. This stream receives the raw sewage of Placerville by way of Webber Creek and the supposedly chlorinated sewage from Folsom State Prison, about 25 miles east of Sacramento, as well as the sewage effluent from Folsom City, just below the penitentiary. Before entering the American River the sewage effluent from Folsom City first is passed through an Imhoff Tank and then over the coarse dredger fields near the city. It must percolate through these fields and several hundred feet of river sediment before entering the stream.

Generally speaking the Sacramento River above Redding and its major tributaries above the foothills have the characteristics of mountain streams, with successive rapids and pools of still water. From a short distance above the mouth of Stony Creek down through the valley to its mouth, the Sacramento River flows on a delta ridge. This is true also for the lower reaches of the main tributaries. To confine flood waters, the banks have been leveed and the river currents are more or less uniform and actually sluggish in the late summer and early fall. The levees also regulate the points of entry of tributary drainage water, a more or less polluted, highly colored run-off of rural areas. This water is collected behind the levees at a few points only and pumped into the rivers. In summer nearly all the natural run-off of these streams now is used for irrigation and the larger part of the flow reaching Sacramento is simply return water from irrigation operations. No diversion for domestic supply occurs between Redding and Sacramento.

Conditions in Sacramento River Below Sacramento*

The city of Sacramento has obtained its water supply at a point just below the confluence of the Sacramento and American rivers for some time. The river water is coagulated, settled, passed through rapid sand filters and chlorinated in one of the most complete water purification plants in the state.

Since its first sewers were constructed, Sacramento has discharged its sewage into the Sacramento River. In recent years North Sacramento has sewered to the river through the Sacramento system. In round numbers, the combined population of these cities was 45,000 in 1910, 67,000 in 1920 and 96,000 in 1930. All wastes, storm water and sanitary sewage flow through the same system of sewers into sumps located at two levee pumping stations, No. 1 being at the foot of U street and No. 2 farther south near the southern outskirts of Sacramento. From the sumps the sewage is pumped through the levee into the Sacramento River. The only treatment, if it may be so called, is passing the sewage through coarse screens to remove foreign matter that might damage the pumps.

For many years, prior to the erection of plant No. 2, all the city's sewage was brought to sump No. 1. Since the erection of plant No. 2 the practice has been to divert as much of the sewage as possible to this plant, because of its remoteness from the intake to the city's water works. This is especially true in summer, when tidal currents frequently reverse the river flow. The records of power and pumpage for 1929 indicate that during the rainy season plant No. 1 handled about 60 per cent of the total flow in the sewers and from May to November only 20 per cent. The remainder was pumped by station No. 2.

During the summer and fall periods one can not detect by eye signs of sewage-fouling in the vicinity of the outfall at pumping plant No. 1. This probably is due to the small quantity of sewage discharged and to the fact that the outlet remains submerged. At station No. 2, however, the pump outfall discharges into a shallow bay, formed by a protecting wall extending about 50 feet into the river channel. When the river is low, as it is in summer, the relative quiescence of the water in this bay results in offensive sludge banks in the shallow water and conditions in the immediate vicinity are septic and disgusting.

At Sacramento, as throughout the entire lower Sacramento River area, industrial waste outranks human sewage in pollutional effect. The most important waste producing industries are canneries and creameries. One cannery, located in the river bottom, however, settles its wastes through a septic tank and disposes of its effluent by broad irrigation instead of through an outfall to the river. The combined population equivalent of all industrial wastes at Sacramento varies from about 5000 in winter to 124,000 at the height of the canning season, making a maximum sewering load, including sanitary sewage, equivalent to that of approximately 220,000 persons.

Across the river from Sacramento is the unincorporated village of Broderick. It has no sewer system and its inhabitants depend on

*See Plates E-II, "Location of Principal Sources of Pollution and Sampling Stations of Pollution Surveys in Upper San Francisco Bay and Sacramento-San Joaquin Delta," and E-V, "Distribution of Typhoid Fever Cases in Upper San Francisco Bay and Sacramento-San Joaquin Delta Regions During Period 1925–1930," in explanation of following discussion.

cesspools and privies behind the levees for the disposal of sewage. Hence, little, if any, contamination reaches the river therefrom.

The Sacramento River, especially below Sacramento, is a busy navigable stream. Scores of vessels, large and small, moor along the banks at Sacramento. The large vessels plying the river are the principal means of freight and passenger transportation by water between river and bay points. The extent of pollution contributed by navigation is difficult to estimate, but it must equal that from any of the lower river communities.

The Sacramento River flows between high levees for over 50 miles through the rich delta region below Sacramento. This region having some of the richest land in the State is sometimes called the "Netherlands of America." The land for miles on both sides of the stream is extensively cultivated to asparagus, corn, grain, beans, alfalfa, beets, potatoes, fruit, seed, celery and other similar crops. Most of the people live just behind the levees. There are several small settlements and, here and there, wharfs, canneries and fruit-packing plants on the river's edge. In each of these plants, from 10 to 100 or more persons are employed at the height of their season.

Between Sacramento and Walnut Grove, a distance of 32 miles, there are several small settlements, including Freeport, Clarksburg, Hood, Courtland and Locke. These places all lie just back of the levees and, with the exception of Locke, create no sewage contamination or river pollution problem. Like other communities along the river, they get their water supply from wells nearby.

Near Clarksburg, about 16 miles below Sacramento, the river begins to divide into typical delta channels. Supplemented by dredger cuts, these channels form a large number of delta islands, each surrounded by levees. Homes and settlements cluster along these levees, especially in the Sacramento River delta area, where bridges and ferries interconnect many of the islands. Nearly all the homes use vault privies, cesspools or septic tanks for sewage disposal because of the expense of pumping small quantities of sewage to the river. Only two of the settlements, Walnut Grove and Rio Vista, sewer to the river. Considerable cannery and packing-house wastes, however, are dumped into the river in this area.

Locke, 30 miles below Sacramento, has a population of about 500 people, whose sewage is pumped into sloughs back from the river. A cannery in this vicinity discharges its wastes, mainly asparagus butts amounting to 15 tons daily, into the river. The population equivalent is about 8000 people. In August and September the plant handles pears and the waste then has a population equivalent of about 6500 persons.

Immediately below Locke is Walnut Grove with a population of 500 to 2000 or more. It is the largest settlement on the lower river. Three different sewerage systems serve this community. One system serves the hotel and carries the raw sewage of about 30 persons direct to the river. Another serves about 15 houses and business structures, including the bank and post office. It discharges its sewage, after settling in septic tanks, into a small ditch east of town. The effluent then passes into a drainage canal and generally seeps away into the sandy loam soil within a few hundred feet. The third system serves the Japanese and Chinese quarters and the remainder of the community, taking care of a population varying from 450 to 2000 persons during the cannery season. It discharges its sewage into a concrete sump at the easterly edge of the town. The effluent is pumped from this sump into the Sacramento River.

At Ryde, two and a half miles below Walnut Grove, there are about 400 people. Sewage is disposed of by vault privies, cesspools or septic tanks, with no sewerage to the Sacramento River. Two canneries in this vicinity handle asparagus. The wastes, comprising about 35 tons of asparagus butts daily from April to July, represent a population equivalent of about 17,000. The butts are dumped into the river without treatment.

Several canneries are located on Andrus Island in the six and a half miles between Ryde and Isleton. They discharge about 90 tons of asparagus butts to the Sacramento River, with a population equivalent of about 36,000 persons. One canning plant operates on spinach from March to April, asparagus from April to June, and pears from August to September. Two others handle asparagus as their only product and operate from April to June. Still another operates on spinach from March to April, asparagus from April to July, and tomatoes from September to November.

These plants dispose of their liquid wastes by discharging them away from the river into the drainage system of Andrus Island. These wastes are pumped, with the general drainage of the island, into Georgiana Slough, eventually reaching the San Joaquin River. A similar disposition is made of the wastes originating at a cannery near the mouth of Georgiana Slough which cans spinach and asparagus from March to June. The population equivalent of asparagus wastes dumped into Georgiana Slough is 7000 persons. All other solid wastes, such as spinach and tomato trimmings, pear cores, etc., are dumped on land. Each of these canneries, as well as the town of Isleton, settles domestic sewage in septic tanks prior to discharging it into the island drainage system.

Cache Slough joins the Sacramento River from the north at a point three miles below Isleton. Cache Slough is the outlet end of Yolo By-Pass, which begins opposite the mouth of Feather River and follows down the west side of the Sacramento River. The by-pass is practically dry, except during floods when it carries a wide stream of water polluted by enormous pastures and the raw sewage of Woodland, which is emptied into the by-pass continuously.

The next source of river pollution is at Rio Vista, about five miles below Isleton. The domestic sewage of about 1200 of its inhabitants is discharged into the river without treatment. A septic tank formerly used slid into the river recently, and has not been replaced. All the wastes produced at a local cannery, which include about 50 tons of asparagus butts daily, are dumped directly into the Sacramento River. This plant operates on asparagus between April and July, and its wastes have a population equivalent of nearly 20,000.

Collinsville, a small fishing colony, is located at the mouth of the Sacramento River about twelve and a half miles below Rio Vista. It is built almost entirely over the water, and the sewage from the few homes is dropped directly into the river.

A summary of the aggregate pollution reaching the Sacramento River, below the mouth of the American, is given in Table E-3.

TABLE E-3

SUMMARY OF ORGANIC POLLUTION LOAD IN THE LOWER SACRAMENTO RIVER IN TERMS OF HUMAN EQUIVALENT

Sources of pollution	Human	Human equivalent of industrial waste				
		June	July	August	September	Winter months
City of Sacramento (including North Sacramento)	96,000					
Four canneries		29,780	56,300	117,800	117,800	
Various dairy plants		5,090	5,090	5,090	5,090	5,090
Fish packing		840	840	840	840	50
Packing and rendering plants		250	250	250	250	250
Locke	[1](300)					
Cannery	[1](200)	8,030		6,500	6,500	
Walnut Grove	1,000					
Ryde	[1](100)					
Two canneries	[1](280)	17,170				
Isleton	[1](280)					
Four canneries	[1](500)	36,400	([2])	([2])	([2])	
Rio Vista	1,200					
Cannery		19,900				
Totals	98,200	117,460	62,480	130,480	130,480	5,390

[1] Figures in parentheses do not sewer to Sacramento River and do not appear in the total.
[2] Wastes during this time and blanching water during June diverted to Georgiana Slough and thence to San Joaquin River.

The organic load on the Sacramento River from Sacramento to its mouth is appraised as the sanitary sewage of about 98,000 people and an industrial load, occurring principally late in summer, equivalent in its oxygen demand to the sewage of at least 130,000 people.

Below Sacramento the waste having the greatest oxygen demand is asparagus butts. The fruit wastes run without treatment to drainage canals, but the asparagus butts are dumped directly into the river. The combined capacity of the plants, in terms of asparagus received, is about 400 tons daily, of which approximately 50 per cent is asparagus butts. These are dumped into the river and may be seen floating there in white masses until fall or winter. In the course of a season about 14,000 tons of butts, with a population equivalent of about 90,000, are disposed of. Probably the principal objections to their presence in the river are their unsightliness, the fact that they choke screens and fish nets, and the likelihood that they will give more or less trouble in future waterworks. It is believed the river should be freed of these butts to realize the fullest advantage of a barrier.

In some cases the butts are pulverized into a mulch, but this seems to be a step in the wrong direction as the fibrous mass causes a rapid extraction of oxygen from the diluting stream, which is not the case as long as the butts are protected by the outer skins. Another method of disposal used by some canneries is composting on land. This is a simple operation, but requires considerable isolation because of odors and flies. This method has merit, however, and should be perfected.

Pollution Surveys in the Sacramento River.—Twelve stream pollution surveys have been made of the Sacramento River by the Bureau of Sanitary Engineering during the past five years, 1925 to 1930.

Sampling points are shown on Plate E-II, "Location of Principal Sources of Pollution and Sampling Stations of Pollution Surveys in Upper San Francisco Bay and Sacramento-San Joaquin Delta." The results of the tests are presented in Tables E-4 to E-12, inclusive. The tests for dissolved oxygen and B. Coli are especially instructive and are shown on Plate E-III, "Organic and Bacterial Pollution in the Sacramento and San Joaquin Rivers."

On a dissolved oxygen basis, depletions have been found to occur from the lower sewage pumping plant of the city of Sacramento to the vicinity of Clarksburg. The tests covered periods in which the river flow ranged from 2450 second-feet to 56,200 second-feet. For the same flows and stations the percentage of oxygen saturation varied as much as 30 per cent. The point of lowest dissolved oxygen was in the vicinity of Freeport, running as low as 60 per cent of saturation. Oxygen restoration was quite rapid in the next 15 miles, and at a point a few miles above Walnut Grove the river had returned practically to normal. B. Coli tests showed the water to be redeemable for domestic purposes at about the same point.

The data on pollution surveys presented in this report comprise all survey data available up to and including 1930. No pollution surveys were made during periods of low stream flow such as occurred in the summers of 1920 and 1924, when the upland flow past Sacramento dropped to about 300 and 700 second-feet respectively. However, no septic conditions were reported during these periods of low flow either in 1920 or 1924.

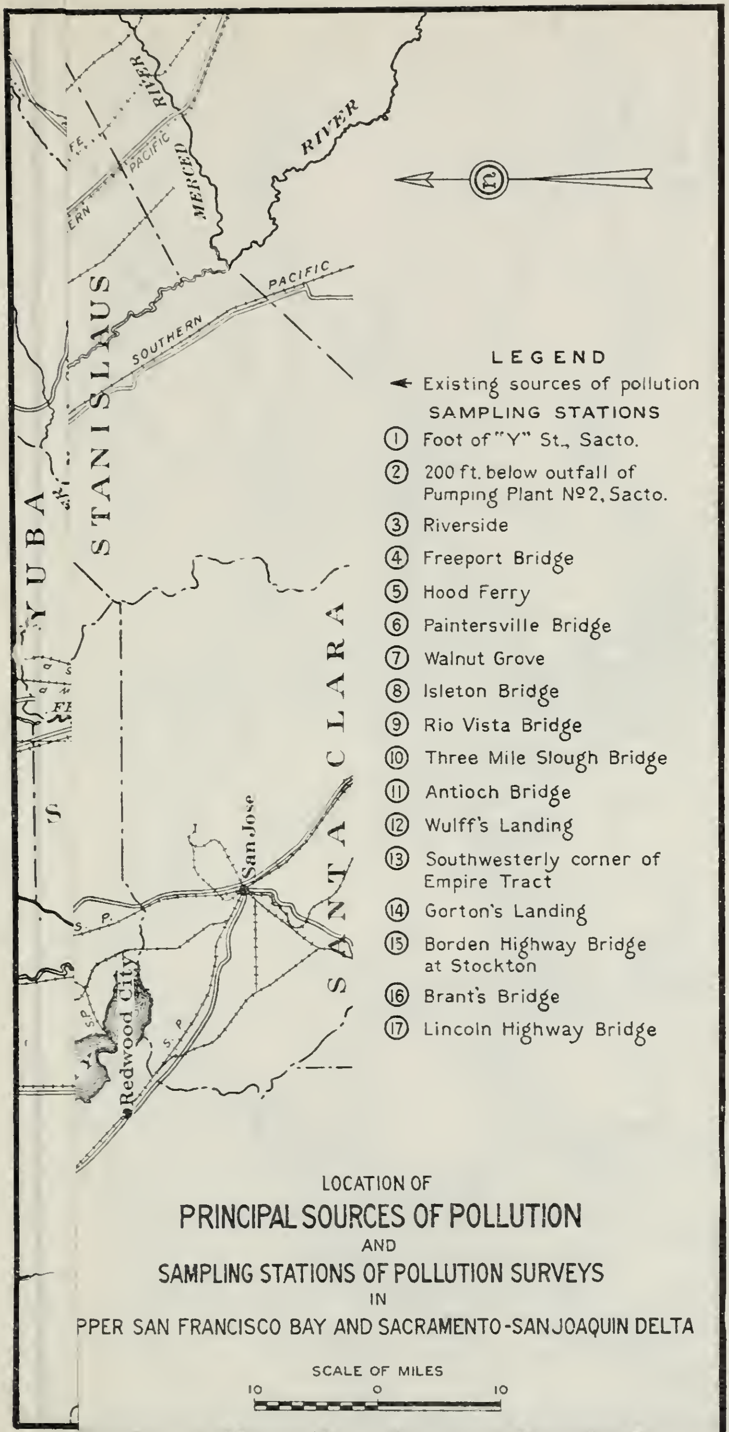
Subsequent to the preparation of this report, the dry season of 1930–31 occurred, resulting in an unprecedented low stream flow in the Sacramento River in July, 1931. During a period of several days, the flow of water past Sacramento was almost entirely a tidal movement with the flow reversing up and down stream at intervals of about six hours. Tidal cycle stream flow measurements made at Sacramento indicated an average tidal flow of about 2200 second-feet up and down stream during flood and ebb tides. Pollution surveys were made during this period of low flow, showing that the pollution load discharged into the river at Sacramento was distributed by the tidal currents and flow to some 500 acres of river channel, covering a stretch of 10 to 12 miles up and down stream. Oxygen was found present at all points in this polluted stretch of river and no septic areas were found. At the most critical stage, the average was 50 to 60 per cent of saturation and the lowest single value observed was 20 per cent of saturation. Oxygen depletion was found to effect approximately 5 acres of river surface per 1000 persons served by the sewer, as compared to about 15 acres which was found by the surveys made during times of greater upland flow passing Sacramento which had the effect of distributing the sewage over a greater stretch of river channel downstream from the sewage outfall. The conditions found by these pollution surveys in 1931 indicate that the purification was evidently not unlike that taking place in oxidizing lagoons and fish ponds. It appears probable that under similar conditions of low stream flow passing Sacramento as in 1931, the present sewage load at Sacramento could not be more than doubled without danger of septic areas being formed in the channel in the vicinity of the sewage outfall. However, such septic areas would certainly remain local and cover a relatively short stretch of river. During this period of low stream flow in 1931, the surveys showed that B. Coli contamination dropped sharply from 700 to 1000 per c.c. at points of high concentration to less than 50 per c.c. just beyond the stretch of river to which the tides carried the sewage.

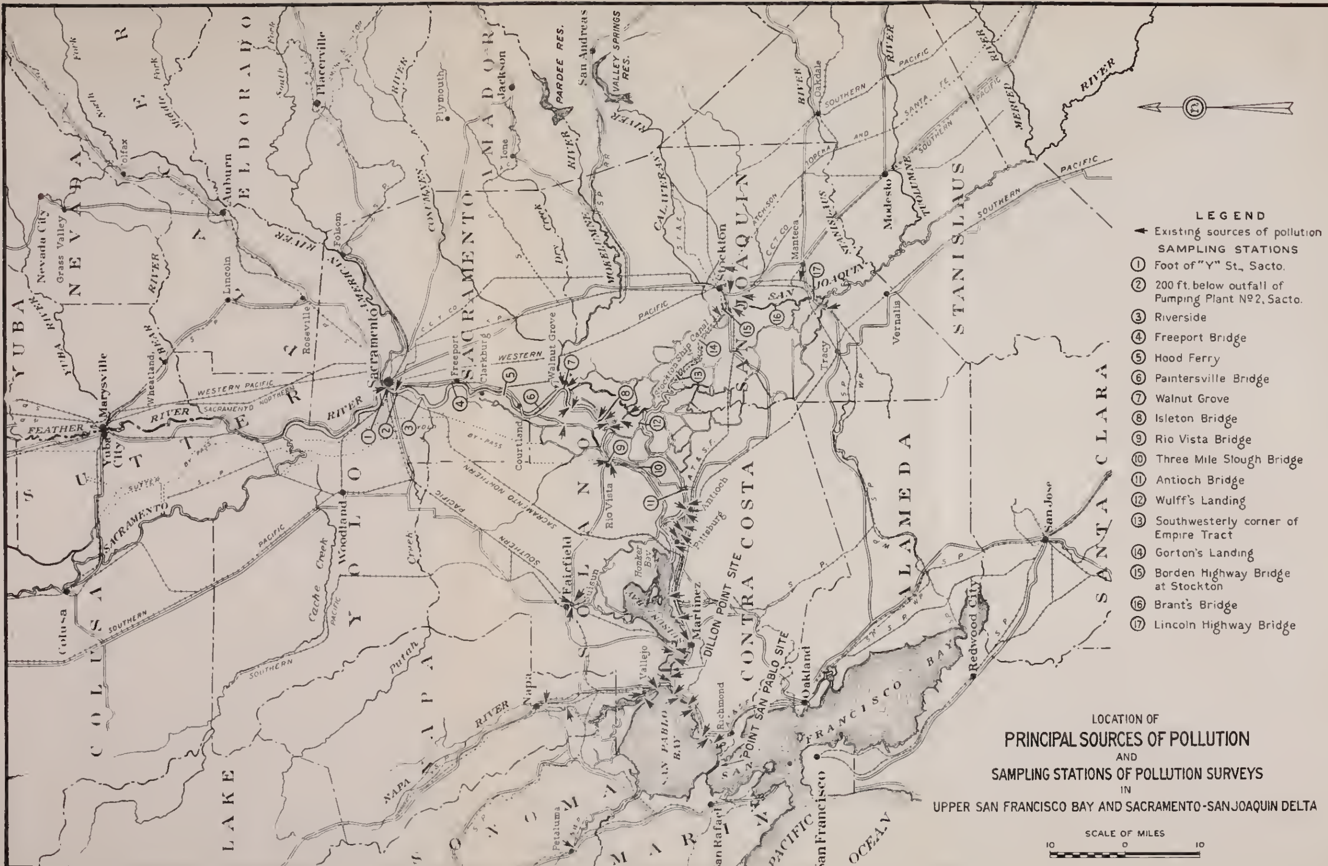
During these summer investigations plankton have always been prolific clear to the mouth of the Sacramento River and musty and fishy smells were noticeable close to the water and even on the levees during warm evenings. The general appearance of the river, however, is that of a normal, clean, low-land stream, the waters of which would be easily redeemable for domestic supply. The most noticeable signs of pollution are the green color due to moss growth, and the vegetable debris, dead tules, logs and the like close to the water's edge.

Studies have been made to estimate the effect of present and future organic pollution on the Sacramento River from Sacramento downstream, under the conditions which would obtain if a barrier were constructed below the confluence of the Sacramento and San Joaquin rivers, eliminating tidal action from the river channel above. The results of these calculations are shown on Plate E-IV, "Hypothetical Organic Pollution in the Sacramento and San Joaquin Rivers for Average Organic Pollution Loads During the Critical Season and Given Flow Conditions."

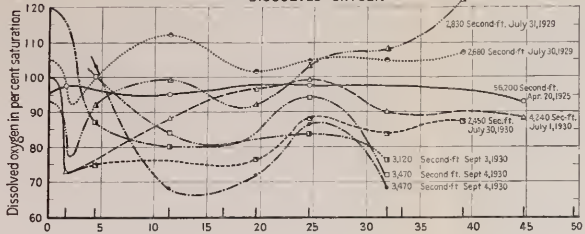
The conclusions to be drawn from these hypothetical pollution studies, are as follows:

1. Septic nuisances would be likely with the amount and distribution of pollution now reaching the lower Sacramento River, provided the river flow fell below 500 to 1000 second-feet.
2. Such zones of complete oxygen depletion may be expected to extend three to four miles downstream from the outfall of pumping plant No. 2 at Sacramento and cover about 230 acres, or somewhat over one acre per 1000 people.
3. Oxygen recovery would set in below the septic area and practically reach saturation at Walnut Grove.
4. There might be another slight depletion below Walnut Grove, but oxygen saturation again would be reached just below Rio Vista.
5. A river flow of 2000 to 2500 second-feet seems necessary to prevent septic nuisance with three times the present organic loads.

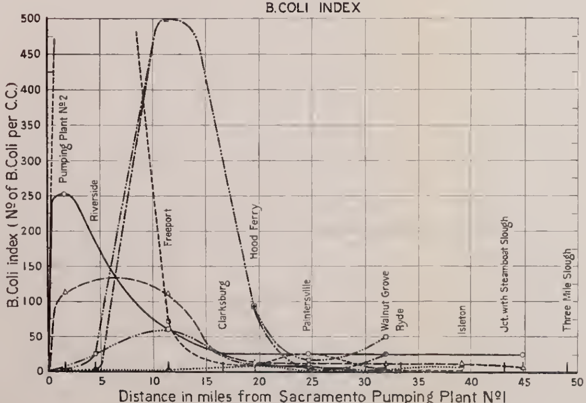

RIVER
MERCED
RIVER
PACIFIC
SOUTHERN PACIFIC
STANISLAUS
YUBA
SANTA CLARA
San Jose
Redwood City
S. P.
LEGEND
Existing sources of pollution
SAMPLING STATIONS
(1) Foot of "Y" St., Sacto.
(2) 200 ft. below outfall of Pumping Plant No 2, Sacto.
(3) Riverside
(4) Freeport Bridge
(5) Hood Ferry
(6) Paintersville Bridge
(7) Walnut Grove
(8) Isleton Bridge
(9) Rio Vista Bridge
(10) Three Mile Slough Bridge
(11) Antioch Bridge
(12) Wulff's Landing
(13) Southwesterly corner of Empire Tract
(14) Gorton's Landing
(15) Borden Highway Bridge at Stockton
(16) Brant's Bridge
(17) Lincoln Highway Bridge
LOCATION OF
PRINCIPAL SOURCES OF POLLUTION
AND
SAMPLING STATIONS OF POLLUTION SURVEYS
IN
PPER SAN FRANCISCO BAY AND SACRAMENTO-SANJOAQUIN DELTA
SCALE OF MILES
10 0 10


LEGEND
Existing sources of pollution
SAMPLING STATIONS
① Foot of "Y" St., Sacto.
② 200 ft. below outfall of Pumping Plant Nº 2, Sacto.
③ Riverside
④ Freeport Bridge
⑤ Hood Ferry
⑥ Paintersville Bridge
⑦ Walnut Grove
⑧ Isleton Bridge
⑨ Rio Vista Bridge
⑩ Three Mile Slough Bridge
⑪ Antioch Bridge
⑫ Wulff's Landing
⑬ Southwesterly corner of Empire Tract
⑭ Gorton's Landing
⑮ Borden Highway Bridge at Stockton
⑯ Brant's Bridge
⑰ Lincoln Highway Bridge
LOCATION OF
PRINCIPAL SOURCES OF POLLUTION
AND
SAMPLING STATIONS OF POLLUTION SURVEYS
IN
UPPER SAN FRANCISCO BAY AND SACRAMENTO-SANJOAQUIN DELTA
SCALE OF MILES
10 0 10

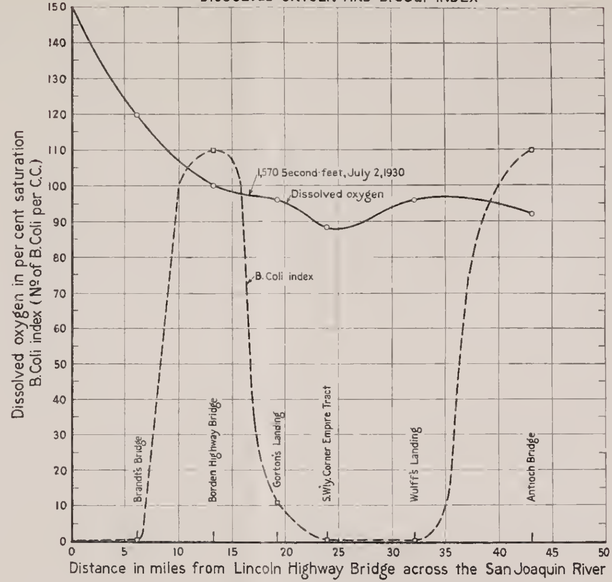
POLLUTION SURVEYS ON THE SACRAMENTO RIVER
DISSOLVED OXYGEN



B.COLI INDEX



POLLUTION SURVEYS ON THE SAN JOAQUIN RIVER
DISSOLVED OXYGEN AND B.COLI INDEX



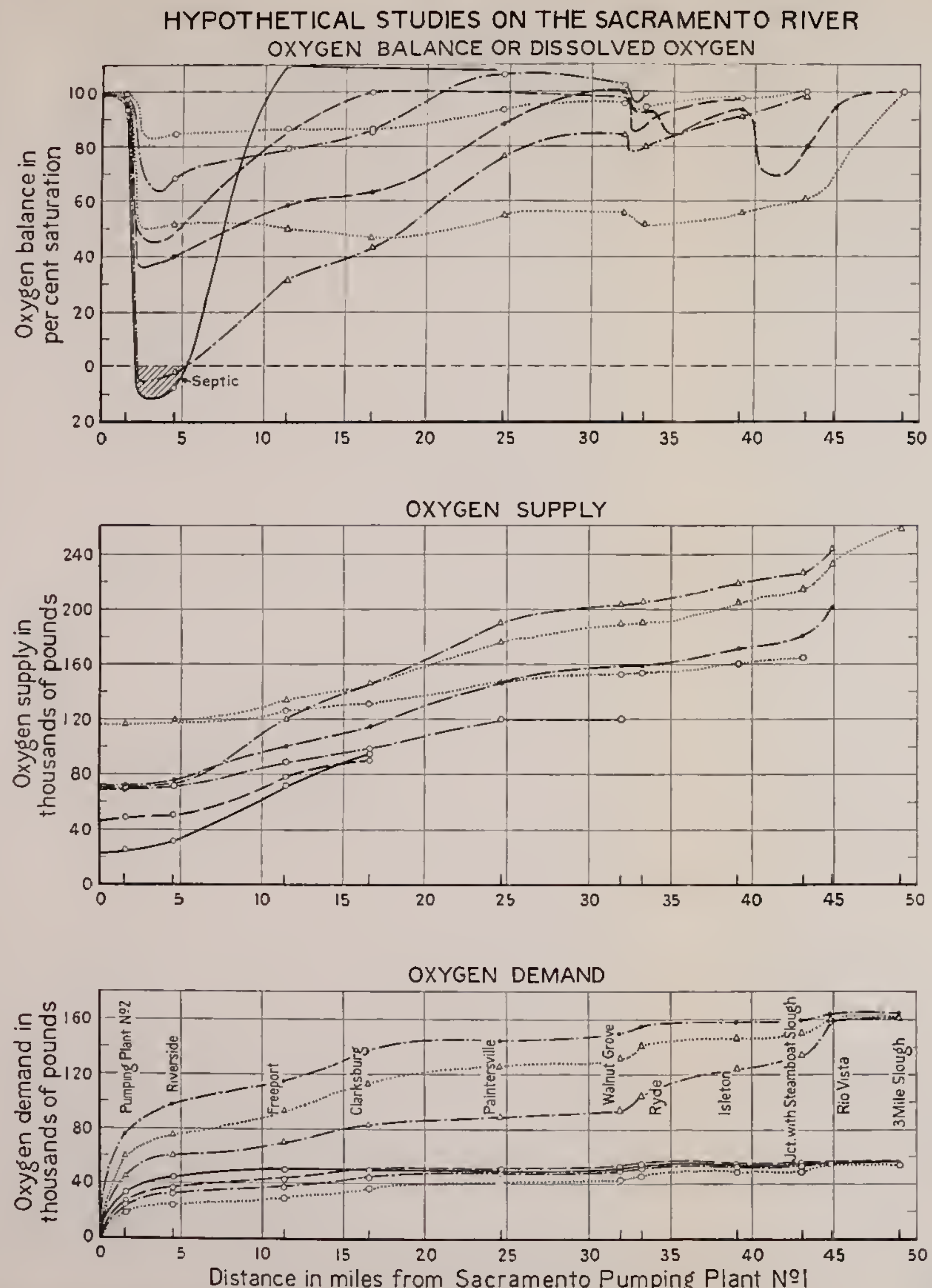
LEGEND

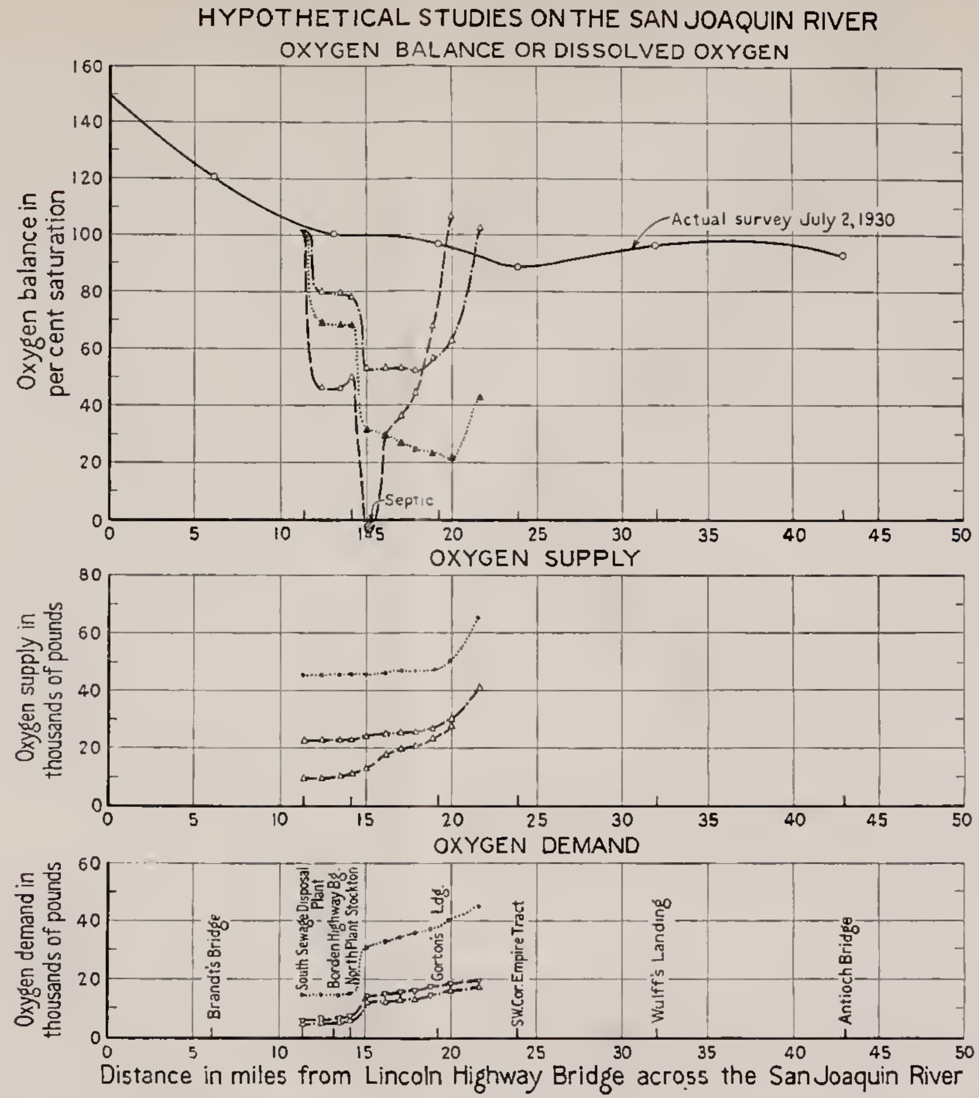
Pollution Surveys – Sacramento River
- 56,200 Second-feet Apr. 20,1925
- 4,240 " " July 1,1930
- 3,470 " " Sept. 4,1930
- 3,470 " " Sept. 4,1930
- 3,120 " " Sept. 3,1930
- 2,830 " " July 31,1929
- 2,680 " " July 30,1929
- 2,450 " " July 30,1930

Pollution Surveys – San Joaquin River
- Dissolved oxygen } Riv Survey July 2,1930
- B. Coli index } 1,570 Second-feet

Stream flow for Sacramento River as computed at Sacramento and for San Joaquin River as computed at Vernalis.

ORGANIC AND BACTERIAL POLLUTION
IN THE
SACRAMENTO AND SAN JOAQUIN RIVERS





LEGEND

Hypothetical Studies-Sacramento River

Present average organic loads, Aug. conditions.
- 500 Second-feet
- 1,000 " "
- 1,500 " "
- 2,500 " "

Three times present av. organic loads, Aug. conditions.
- 1,500 " " (Future)
- 2,500 " " "

" , June "
- 1,500 " " "

Pollution Studies-San Joaquin River
- Actual river survey, 1,570 second-feet at Vernalis July 2, 1930

Present average organic loads, Aug. conditions
- 200 Second-feet
- 500 " "

Three times present av. organic loads, Aug. conditions.
- 1,000 " " (Future)

NOTE:

The effect of tides has not been taken into consideration in these studies, since tidal movements would not exist should a salt water barrier be built.

HYPOTHETICAL ORGANIC POLLUTION IN THE SACRAMENTO AND SAN JOAQUIN RIVERS FOR AVERAGE ORGANIC POLLUTION LOADS DURING THE CRITICAL SEASON AND GIVEN FLOW CONDITIONS

TABLE E-4

SUMMARY OF POLLUTION SURVEYS ON THE SACRAMENTO RIVER

B. Coli and Dissolved Oxygen

Date	Intake at Sacramento filtration plant		Foot of Y Street, Sacramento		Outfall of pumping plant number 2, Sacramento		Riverside		Freeport Bridge		Hood Ferry		Paintersville Bridge		Walnut Grove Bridge		Isleton Bridge		Rio Vista Bridge	
	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index	Dissolved oxygen, per cent saturated	B. Coli index
April 20, 1925			95	2.5	97	250.0			95	60.0			97	25.0		25.0			92	25.0
September 10, 1925								2,500.0		25,000.0				11.0		11.0				
August 2, 1926																				70.0
September 29, 1926																70.0				
June 28, 1927										250.0										
July 30, 1929	100	[1]0.0	105	0.6			100	0.6	112	0.6	101	6.0	104	[1]0.0	104	0.6	107	0.6		
July 31, 1929	96	[1]0.0	93	0.6			92	25.0	99	60.0	92	6.0	103	6.0	108	[1]0.0	120	0.13		
July 1, 1930					73	110.0			88	110.0	96	11.0	99	11.0	90	11.0	90	11.0	88	7.0
July 30, 1930	100	2.5	100	60.0	73	1,100.0+	75	1,100.0+	59	70.0	76	6.0	88	25.0	84	1.3	87	2.5		
September 3, 1930			120				87		80				84		76					
September 4, 1930, a. m.	104						103	3.5	68	500.0	72	90.0	86	3.5	68	25.0				
September 4, 1930, p. m.	105	1.5					100	25.0	84	500.0	61	90.0	94	15.0	72	50.0				

[1] Two counts failed to disclose presence of B. Coli.

TABLE E-5

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 56,200 second-feet

Samples collected by C. G. Gillespie and E. A. Reinke, April 19-20, 1925.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant													
Foot of Y Street, Sacramento				95	1.2	2.5		42	6				
200 feet below outfall of pump-plant number 2, Sacramento				95	0.9	60.0		38	6				
Courtland				97	1.0	25.0		38	6				
Walnut Grove						25.0							
Rio Vista				92	0.7	25.0		40	9				
Collinsville				96	1.1	25.0		46	12				

TABLE E-6

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 2,680 second-feet

Samples collected by E. A. Reinke and M. S. Foreman, July 30, 1929.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	4:05 p. m.	27.5	8.2	100	1.5	[1]0.0	7.4	64	18	0.10	0.06	42 42	Navicula Synedra
Foot of Y Street, Sacramento	4:30 p. m.	25.0	8.8	105	1.6	0.6	----------	112	46	0.04	0.08	65 50	Melosira Pleurococcus
Riverside	2:20 p. m.	27.5	8.0	100	2.5	0.6	6.4	60	37	0.08	0.02	90 42	Suriella Melosira
Freeport Bridge	1:50 p. m.	27.5	9.0	112	2.1	0.6	7.0	108	41	0.04	0.10	128 112	Fragilaria Synedra
Hood Ferry	1:30 p. m.	25.5	8.4	101	2.2	6.0	6.4	76	39	0.04	0.06	184 64	Melosira Synedra
Paintersville Bridge	12:50 p. m.	24.5	8.8	104	1.6	[1]0.0	6.5	88	47	0.04	0.08	250 115	Melosira Fragilaria
Walnut Grove Bridge	11:30 a. m.	24.0	8.9	104	2.3	0.6	7.2	120	42	0.10	0.06	270 180	Melosira Pleurococcus
Isleton Bridge	10:00 a. m.	23.0	9.4	107	3.6	0.6	7.4	116	51	0.06	1.40	625 170	Melosira Fragilaria

[1] Two counts failed to disclose presence of B. Coli.

TABLE E-7

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 2,830 second-feet

Samples collected by E. A. Reinke and C. Herb. July 31. 1929.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	8:30 a. m.	22.0	8.5	96	3.8	[1]0.0	7.4	92	26	----------	----------	----------	----------
Foot of Y Street, Sacramento	9:30 a. m.	23.5	8.0	93	2.3	0.6	7.4	112	73	----------	----------	----------	----------
Riverside	9:45 a. m.	24.5	7.8	92	3.6	25.0	7.3	108	38	----------	----------	----------	----------
Freeport Bridge	10:15 a. m.	24.5	8.4	99	3.7	60.0	7.4	104	34	----------	----------	----------	----------
Hood Ferry	10:40 a. m.	24.5	7.8	92	2.8	6.0	7.4	116	34	----------	----------	----------	----------
Paintersville Bridge	11:15 a. m.	24.0	8.8	103	3.2	6.0	7.4	100	35	----------	----------	----------	----------
Walnut Grove Bridge	11:45 a. m.	24.5	9.4	108	3.3	[1]0.0	7.1	102	36	----------	----------	----------	----------
Isleton Bridge	1:20 p. m.	23.5	10.4	120	5.2	0.13	8.0	116	34	----------	----------	----------	----------

[1] Two counts failed to disclose presence of B. Coli.

TABLE E-8

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 4,210 second-feet

Samples collected by J. M. Sanchis and J. Harmon. July 1, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day bio-chemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------
200 feet below outfall of pumping plant number 2, Sacramento	7:20 p. m.	25.5	6.1	73	8.3	110.0	----------	68	65	0.08	0.24	380	Melosira, Navicula, Lyngbya
Freeport Bridge	6:10 p. m.	26.0	7.2	88	0.7	110.0	----------	56	42	0.04	0.08	802	Melosira, Synedra, Pleurococcus
Hood Ferry	5:20 p. m.	25.5	8.0	96	1.8	11.0	----------	56	39	0.04	0.04	385	Synedra, Melosira, Tabellaris
Paintersville Bridge	4:20 p. m.	25.5	8.2	99	1.4	11.0	----------	52	37	0.04	0.12	387	Melosira, Synedra, Pleurococcus
Walnut Grove Bridge	3:30 p. m.	25.0	7.5	90	1.7	11.0	----------	48	24	----------	----------	----------	----------
Isleton Bridge	2:30 p. m.	24.0	7.7	90	2.3	11.0	----------	48	32	0.06	0.08	936	Melosira, Asterionella, Tabellaria
Rio Vista Bridge	11:35 a. m.	22.0	7.8	88	3.8	7.0	----------	40	30	0.04	0.16	500	Melosira, Pleurococcus, Asterionella
Three-mile Slough Bridge	11:00 a. m.	20.8	7.7	85	1.6	2.5	----------	24	40	0.04	0.28	406	Pleurococcus, Chlamydemouas, Melosira

TABLE E-9

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 2,450 second-feet

Samples collected by F. E. DeMartini, July 30, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	8:05 a. m.	24.0	----------	87	------	6.0	6.9	114	50	------	------	350	Synedra
Intake at Sacramento filtration plant	5:05 p. m.	26.5	----------	116	----------	0.6	7.5	114	42	----------	------	412	Syndera
Foot of Y Street, Sacramento	7:45 a. m.	23.5	----------	87	----------	0.6	7.3	102	47	----------	----------	308	Synedra
Foot of Y Street, Sacramento	3:50 p. m.	26.5	----------	111	----------	110.0	7.3	114	600	----------	----------	108	Synedra
300 feet below outfall of pumping plant number 2, Sacramento	6:50 a. m.	23.5	----------	82	----------	1,100.0+	7.2	108	53	----------	----------	348	Synedra
300 feet below outfall of pumping plant number 2, Sacramento	3:40 p. m.	28.0	----------	63	----------	1,100.0+	6.9	126	126	----------	----------	292	Synedra
Riverside	10:30 a. m.	24.5	----------	75	----------	1,100.0+	6.9	110	52	----------	----------	252	Mongeotia
Freeport Bridge	10:45 a. m.	24.5	----------	59	----------	70.0	6.4	106	53	----------	----------	180	Mongeotia
Hood Ferry	11:40 a. m.	25.0	----------	76	----------	6.0	6.9	100	47	----------	----------	356	Mongeotia
Paintersville Bridge	12:10 p. m.	25.0	----------	88	----------	25.0	6.9	100	48	----------	----------	748	Mongeotia
Walnut Grove Bridge	1:20 p. m.	25.5	----------	84	----------	1.3	6.9	104	48	----------	----------	1,500	Mongeotia
Isleton Bridge	2:05 p. m.	25.5	----------	87	----------	2.5	7.0	100	49	----------	----------	1,280	Mongeotia

TABLE E-10

SACRAMENTO RIVER POLLUTION SURVEY

River flow past Sacramento, 3,120 second-feet

Samples collected by F. E. DeMartini and J. Harmon, September 3, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant													
Foot of Y Street, Sacramento	3:50 p. m.	24.5		120			7.1						
Riverside	3:20 p. m.	25.5		87			7.2						
Freeport Bridge	2:30 p. m.	24.0		80			7.0						
Paintersville Bridge	1:45 p. m.	24.0		84			7.1						
Walnut Grove Bridge	1:00 p. m.	23.5		76			7.1						

TABLE E-11
SACRAMENTO RIVER POLLUTION SURVEY
River flow past Sacramento, 3,470 second-feet

Samples collected by F. E. DeMartini and J. Harmon. September 4, 1930.

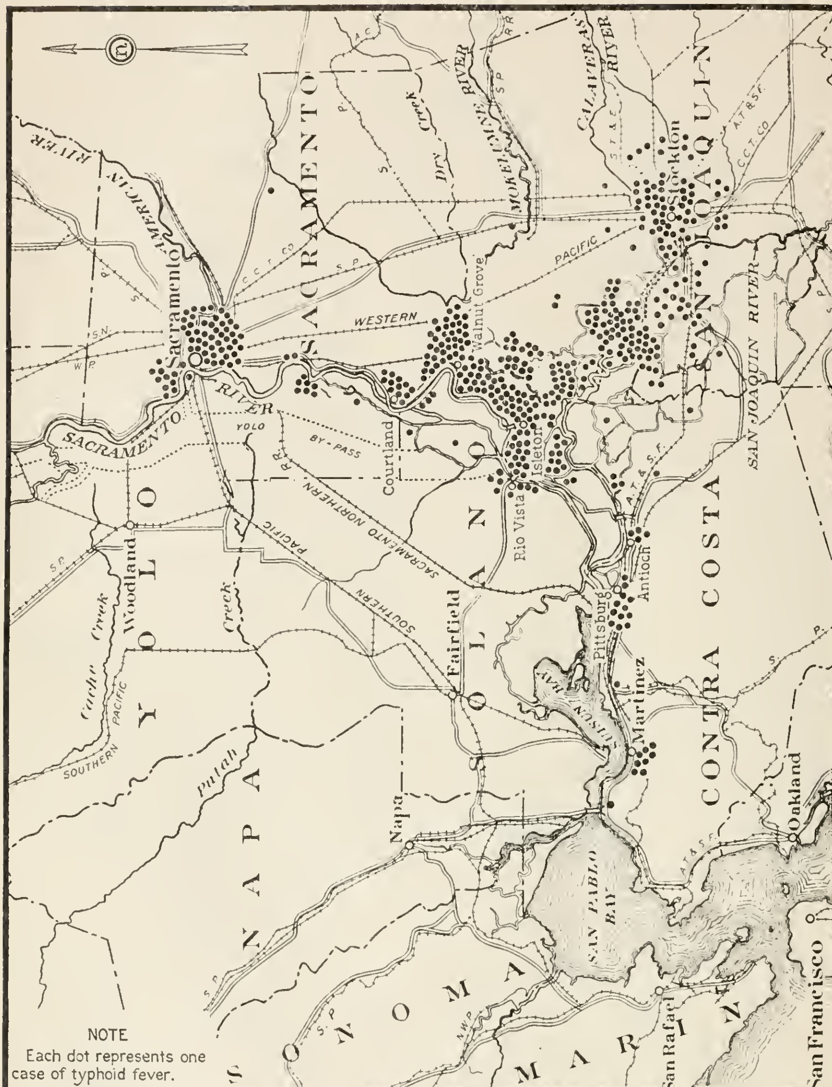
Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	10:22 a. m.	22.5	----	104	----	----	7.6	----	----	----	----	----	----
Riverside	11:15 a. m.	24.0	----	103	----	3.5	7.4	----	----	----	----	----	----
Freeport Bridge	9:35 a. m.	23.0	----	68	----	500.0	7.2	----	----	----	----	----	----
Hood Ferry	9:00 a. m.	23.0	----	72	----	90.0	7.0	----	----	----	----	----	----
Paintersville Bridge	8:15 a. m.	22.5	----	86	----	3.5	7.0	----	----	----	----	----	----
Walnut Grove Bridge	7:30 a. m.	22.0	----	68	----	25.0	7.0	----	----	----	----	----	----

TABLE E-12
SACRAMENTO RIVER POLLUTION SURVEY
River flow past Sacramento, 3,470 second-feet

Samples collected by F. E. DeMartini and J. Harmon, September 4, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkalinity, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Intake at Sacramento filtration plant	3:00 p. m.	24.0	----	105	----	1.5	7.4	----	----	----	----	----	----
Riverside	4:10 p. m.	24.5	----	100	----	25.0	7.4	----	----	----	----	----	----
Freeport Bridge	4:20 p. m.	23.5	----	84	----	500.0	6.9	----	----	----	----	----	----
Hood Ferry	3:55 p. m.	23.5	----	61	----	90.0	6.9	----	----	----	----	----	----
Paintersville Bridge	3:00 p. m.	24.0	----	94	----	15.0	6.8	----	----	----	----	----	----
Walnut Grove Bridge	2:20 p. m.	23.5	----	72	----	50.0	6.8	----	----	----	----	----	----

PLATE E-V



DISTRIBUTION OF TYPHOID FEVER CASES
IN UPPER SAN FRANCISCO BAY AND
SACRAMENTO-SAN JOAQUIN DELTA REGIONS
DURING PERIOD 1925-1930

SCALE OF MILES
8 0 8

Incidence of Typhoid Fever in Delta Region and Adjacent Territory.

The hygienic reputation of the Sacramento River is not good. It is well established that it was annually responsible for several hundred cases of typhoid fever in Sacramento prior to water treatment there. Even now there is a good deal of typhoid in the Sacramento-San Joaquin Delta islands and adjacent communities, probably associated with the sewage contamination and use of the river for navigation and swimming. The incidence of typhoid fever from 1925 to 1930 in that area has been studied by the Division of Epidemiology of the State Department of Public Health. Only those cases reported from districts directly adjacent to the delta channels and bay were noted, particularly those which most probably resulted from drinking raw river water within the incubation period of the infection. These data are summarized in Table E-13 and shown graphically on Plate E-V, "Distribution of Typhoid Fever Cases in Upper San Francisco Bay and Sacramento-San Joaquin Delta Regions During Period 1925–1930."

Typhoid fever is continuous in certain sections of the delta and upper bay region. The raw water of the area is a potential source of infection, and in the delta district the infection is largely water-borne. The type of country and the army of laborers working in and out of there make control of typhoid fever most difficult. The labor turnover is high, so that immunization, unless constantly practiced, does not materially affect the annual incidence. In San Joaquin County, where an immunization program was established for laborers in the delta region, there has been a marked reduction of typhoid fever in certain groups. However, changes in the percentage distribution of the different races, with more Mexicans coming in, have resulted in an increase in the number of cases in the Mexican quarters sufficient to offset the decrease among Orientals.

TABLE E-13

CASES OF TYPHOID FEVER IN THE RIVER AREA OF CONTRA COSTA, SACRAMENTO, SAN JOAQUIN, SOLANO AND YOLO COUNTIES

January, 1925, to December 1, 1930

Location	1925	1926	1927	1928	1929	1930	Total
Contra Costa County—							
Antioch		2	1		1		4
Bay Point				1			1
Crockett						1	1
Martinez	3	1	2	1	1		8
Pittsburg	3	5		3		1	12
Oakley				1			1
Jersey Island			2	1			3
Orwood Tract	1						1
Franks Tract	1						1
Total for Contra Costa County	8	8	5	7	2	2	32
Sacramento County—							
Courtland	4	4		1	1	2	12
Isleton	5	6	11	4	6	7	39
Sacramento City	8	15	6	5	9	3	46
Sacramento vicinity (outside city)	3	3	1	1	3		11
Walnut Grove	22	13	2	2	2	3	44
Andrus Island	1		1	1			3
Freeport			1	1			2
Grand Island	2	1					3
Locke	1	1					2
Near Rio Vista	2		4	1			7
Ryde	2	2	1	1		1	7
Sherman Island	1					1	2
Sloughhouse	1						1
Twitchell Island	1		2	2	2	3	10
Tyler Island	1			2	1		4
Vorden		2					2
Total for Sacramento County	54	47	29	21	24	20	195
San Joaquin County—							
Near Acampo						1	1
French Camp				4			4
Holt			3		3		6
Stockton	8	3	4	11	8	9	43
Stockton vicinity (outside city)	2		7	3	1	1	14
Thornton	1					1	2
Alemute Island						1	1
Bacon Island	1	1					2
Bishop Island		1		1			2
Boggs Tract	1						1
Bouldin Island	4	1	1	8	1	5	20
Brack Tract		1					1
Canal Ranch	2				1	2	5
Fern Island	1						1
Hog Island				1			1
Jones Tract		1				1	2
Kahn Tract						1	1
King Island	1	2		1		1	5
McDonald Island	1	5	6	2		7	21
Medford Island				1			1
Mildred Island	1	2					3
Rindge Tract	8	1	6	3	2	2	22
Rio Blanco Camp				2			2
Roberts Island		4	1	4	1	2	12
Rough and Ready Island				1			1
Shima Tract	2		1		1		4
Staten Island	6	1			2		9
Terminal Tract	1			2		1	4
Union Island				1			1
Venice Island	1			2	1		4
Victoria Island						1	1
Wright Tract	4	1					5
Zucker Tract				1			1
Total for San Joaquin County	45	24	29	48	21	36	203
Solano County—							
Rio Vista				4	2	2	8
Liberty Island		1					1
Ryer Island		1					1
Total for Solano County	0	2	0	4	2	2	10

TABLE E-13—Continued

CASES OF TYPHOID FEVER IN THE RIVER AREA OF CONTRA COSTA, SACRAMENTO, SAN JOAQUIN, SOLANO AND YOLO COUNTIES

January, 1925, to December 1, 1930

Location	1925	1926	1927	1928	1929	1930	Total
Yolo County							
Broderick				1			1
Clarksburg	1			4	1	1	7
Knights Landing	1						1
Holland Tract	1			1			2
Total for Yolo County	3	0	0	6	1	1	11
Total for area	110	81	63	86	50	61	451
Total reported for California	853	1,022	683	869	613	685	4,545

Conditions in San Joaquin River Above Lincoln Highway Bridge.

The upper San Joaquin River is cleaner, hygienically, than the Sacramento River above Sacramento. For one thing the Tulare Lake drainage has practically disappeared in recent years, and there is no sewerage to the upper San Joaquin River itself, except at a few power houses in the Sierra Nevada where the sewage is well treated. The San Joaquin River above Stockton, however, resembles the Sacramento River, except that its waters are dark or brown, due to land drainage, algae and vegetation growing in its sluggish waters. Through the valley proper most of the channel is leveed to prevent flood damage to adjacent lands and, as in the case of the Sacramento River, drainage waters are pumped or frequently gravitate to the river.

On its tributaries some pollution occurs. The Merced River now receives the seepage from land filtration of Yosemite Valley sewage, but this soon will be replaced by a complete sewage treatment plant discharging to the river. At Merced Falls, as the stream reaches the San Joaquin Valley, a small lumber community discharges chlorinated septic tank effluent to the stream. By way of small creeks, the Tuolumne River receives the septic tank effluent of Sonora and some raw sewage from Jamestown. At Modesto septic tank effluent and sludge from the city sewer farm occasionally escapes to the river, but the occurrence grows more infrequent as the city takes greater pains with its sewage disposal. The Stanislaus River receives the raw sewage of Angels Camp and Oakdale, and the septic tank overflow and the waste from a tomato cannery at Riverbank.

In the Sierra foothills are several settlements which dispose of raw sewage by dilution in adjoining creeks and rivers but, so far as summer conditions are concerned, the pollution never reaches the San Joaquin River. San Andreas, on the Calaveras River; Mokelumne Hill, on the Mokelumne River; and Ione, Sutter Creek, Jackson, Plymouth and Amador, on Dry Creek, are among this class of settlements.

Conditions in San Joaquin River Below Lincoln Highway Bridge.

Just above the Lincoln Highway Bridge the main channel of the San Joaquin River begins to subdivide into its delta channels, which reunite a few miles above Antioch. Between these points, the river system consists of numerous interconnected sloughs flowing in leveed and tule-grown channels surrounding many highly fertile, intensively cultivated islands. All of the channels are subject to tidal action most of the year. Most of the delta islands are irrigated from the river by gravity and their drainage is pumped to the river.

The domestic sewage of the 4000 residents of Tracy and the effluent from four small milk product plants, having a population equivalent of about 600, flow through the city sewers to the sewage treatment plant. The treatment of this sewage consists of settling through an Imhoff tank and a sprinkling filter, which is only half-filled with rock and very inefficient in operation. The treated effluent then flows to a barge canal, tributary to the sloughs of San Joaquin River about seven miles away. A beet sugar factory located nearby disposes of its four million gallons per day of waste water by broad irrigation on several acres of land adjoining the plant.

The city of Manteca has a population of 1600. The town is completely sewered. The principal industries discharging organic wastes into the city sewers are creameries and canneries. The combined wastes from this source represent a population equivalent varying from 400 in winter to 20,000 at the height of the peach-canning season. The city sewage is pumped into a Doton septic tank and the effluent is discharged into a series of ponds covering about two and one-half acres. Overflow is into a nearby drainage ditch, and thence to French Camp Slough about eight miles away. The effluent reaches the slough about four miles above its junction with the San Joaquin River.

A slaughterhouse and tallow works near French Camp discharge settled effluents into short sloughs tributary to San Joaquin River a mile away. The combined population equivalent of the wastes from these plants is about 1400. Conditions in the sloughs are filthy as a result.

The city of Stockton has a population of 48,000 and is well sewered. Stockton Channel, a ship canal, divides the city and its sewer system into two parts. The system south of the canal serves about 24,000 people and industries having a population equivalent estimated at 30,000. The south system discharges into an Imhoff tank and pumping station adjacent to The Santa Fe Railroad and about 800 feet from the San Joaquin River, to which sewage is pumped. The average load was 1.347 million gallons per day from 1922 to 1924 and 1.303 million gallons per day from 1926 to 1929.

The system north of the canal serves about 25,000 people and industries having a population equivalent of about 20,000. The sewage concentrates at a fine screening and pumping plant on Smith Canal, in the northwestern part of the city. The effluent is pumped 4500 feet to San Joaquin River. The average daily pumpage has been 2.520 million gallons for the last five years and averaged 1.790 million gallons for the four and one-half years preceding. The sewage pumped in the later period is 1.4 times that in the first four and one-half years' operation of the plant. The average age of the sewage reaching the treatment plants is two and one-half hours. The outfalls of the two systems are about three miles apart.

Aside from the industries now discharging their wastes into the city sewers, there are a few others that have their own systems for sewage disposal. One large industry on McDougal Canal makes paper pulp by a mechanical process, turning out about 250 tons daily. The process is illustrated on Plate E-VI, "Typical Industrial Process Charts," except that there is no strawboard waste. The waste amounts to about three million gallons per day, said to contain about 3000 pounds of waste pulp having a population equivalent of 50,000. The waste is emptied into McDougal Canal, which is fed by water originating at a gas well and by waste water from mineral baths. The canal is thickly overgrown with tules and bamboo, so that a good deal of the suspended fiber in the plant effluent is mechanically removed before it reaches Mormon Channel, a mile from its mouth. Nevertheless, fully 3000 feet of Mormon Channel is very septic. This corresponds to an area of nearly ten acres.

A slaughterhouse east of the city discharges its settled effluent into the Stockton Diverting Canal, at a point about two and one-half miles from the junction of this canal and the Calaveras River, and thence by way of the Calaveras River to the San Joaquin River. The population equivalent of the wastes from this plant has been evaluated at about 2500.

Waste producing industries connected to the Stockton sewer system include four large fruit and vegetable canneries, various milk and butter depots, which handle about 12,000 gallons per day, roundhouses and a brewery. With completion of the Stockton Ship Canal, a further addition to industries is expected, which will cause an increase in the dilution requirements for sewage.

Unlike the lower Sacramento River, the lower San Joaquin receives very little repollution. This repollution is limited to that by river boats plying between Stockton and the bay and the drainage of the delta islands.

Construction difficulties presented by the poor bearing qualities of peat lands and the nearness of the water table to the ground surface limit the use of modern methods of sewage treatment and disposal in the islands. As a result, about 80 per cent of the delta islands' population of some 17,000 people sewers directly into the main drainage system of each island or has privies built over drain ditches. The remainder use vault privies, generally built on the inner side of the levees. The land drainage ditches empty into the main drainage canal of each island. These lead to pumping plants, which operate at intervals of a few hours to a few days and boost the drainage over the levee.

When the huge drainage pumps are operating, the accumulated mass of sewage must set up an intense local pollution. Wells on the islands yield a poor quality water for domestic purposes because of excessive mineral content and many people use the river water, which may have been grossly contaminated not far above. Bowel diseases and typhoid are probably of more common occurrence here than in any equal area in the state.

A summary of pollution entering the San Joaquin River and the channels of the delta, with allowance for such sewage treatment as is employed, will be found in Table E-14.

TABLE E-14

SUMMARY OF ORGANIC POLLUTION LOAD IN THE LOWER SAN JOAQUIN RIVER IN TERMS OF HUMAN EQUIVALENT

Sources of pollution	Human	Human equivalent of industrial waste				
		June	July	August	September	Winter months
Tracy[1]	3,060					
Dairy plants		440	440	440	440	440
Manteca[2]	320					
Canneries		180	3,950	3,950	3,950	
Dairy plants		80	80	80	80	80
Plants near Stockton[3]						
Slaughter and tallow works	20	3,130	3,130	3,130	3,130	3,130
Stockton—						
a. South sewer plant[4]	16,800					
Canneries and dairy products plants		7,000	21,000	21,000	21,000	7,000
b. North sewer plant[5]	22,800					
Canning and preserving plants		6,950	19,000	19,800	19,800	
Dairy plants		550	550	550	550	550
Poultry plants		90	90	90	90	90
c. Not connected to sewer[6] Paper products plant		50,000	50,000	50,000	50,000	50,000
Delta Islands[7]	7,000					
Canneries	1,000	8,500		900	3,540	
Totals	51,000	76,920	98,240	99,940	102,580	61,290

[1] Tracy sewage treated in Imhoff tank and run through incomplete sprinkling filter.
[2] Manteca sewage treated in septic tank and ponds.
[3] Sewage from plants near Stockton treated in settling tanks.
[4] Sewage from plants in south Stockton run into Imhoff tank.
[5] Wastes from north Stockton system run through fine screening.
[6] Wastes from Stockton plants are not treated in any way.
[7] Sewage run directly to delta drainage ditches.

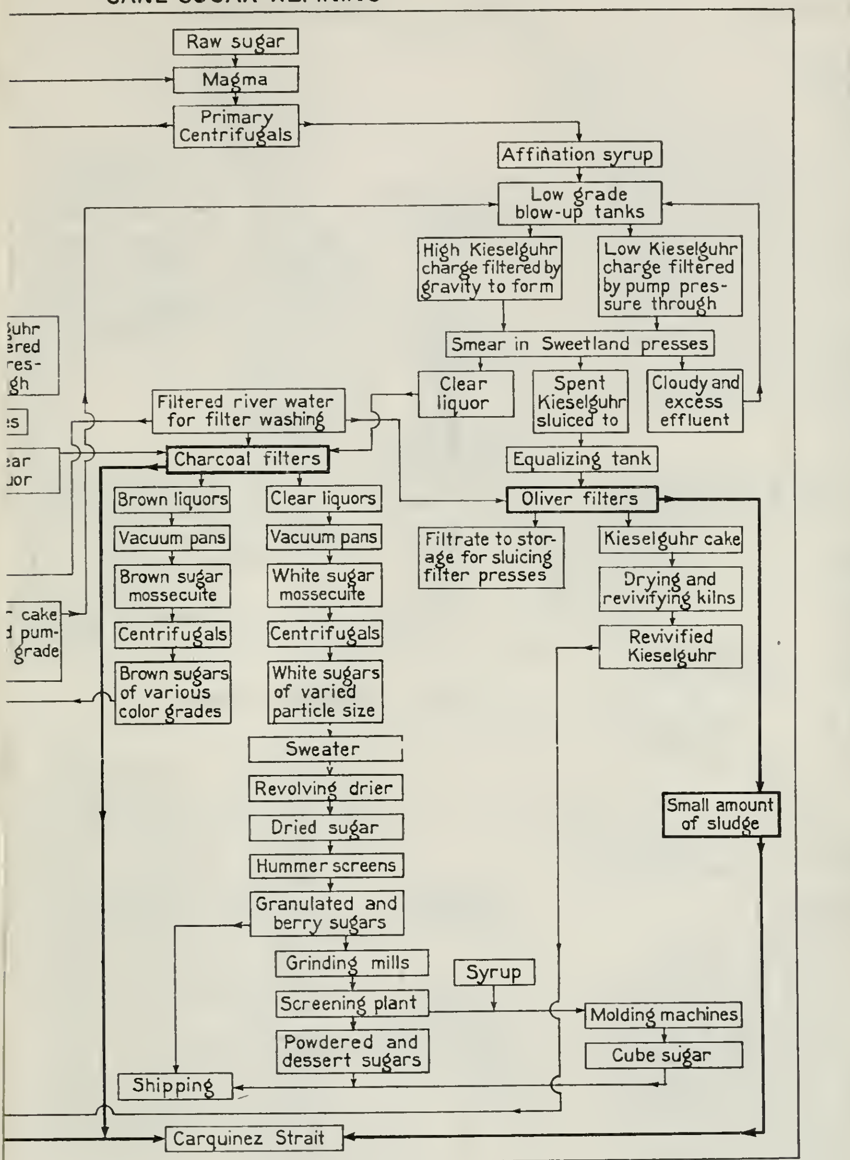
*Pollution Surveys in the San Joaquin River.**—There is little test work data available on the San Joaquin River. Hygienically, the reputation of the river is bad. Above and below Stockton the river water has a rather low grade appearance, in which discriminating persons probably would prefer not even to swim. French Camp Slough, receiving slaughterhouse waste, is in a filthy condition, as is Mormon Channel, in Stockton, which received a waste load equivalent to that of some 50,000 persons. At the highway bridge across Mormon Channel and down stream almost to the ship canal, the channel is highly septic. Gas ebullition and masses of sludge breaking on the surface may be seen more or less constantly. The visible septic area would amount to about twelve acres, or a quarter of an acre per 1000 persons. Oxygen depletion, however, may extend further than this.

Bacterially, except in the vicinity of the drainage pumps and the Stockton sewer outfalls, the river would pass as redeemable at most points. Plankton growth is prolific throughout the whole valley portion and results in an oxygen-supersaturated water where sewage pollution is low.

The only field tests on the San Joaquin River are for July 1 and 2, 1930. The results are summarized in Table E-15, and graphically shown on Plate E-III. These tests were made when the river flow at Vernalis, just above the Lincoln Highway Bridge, was about 1600 sec-

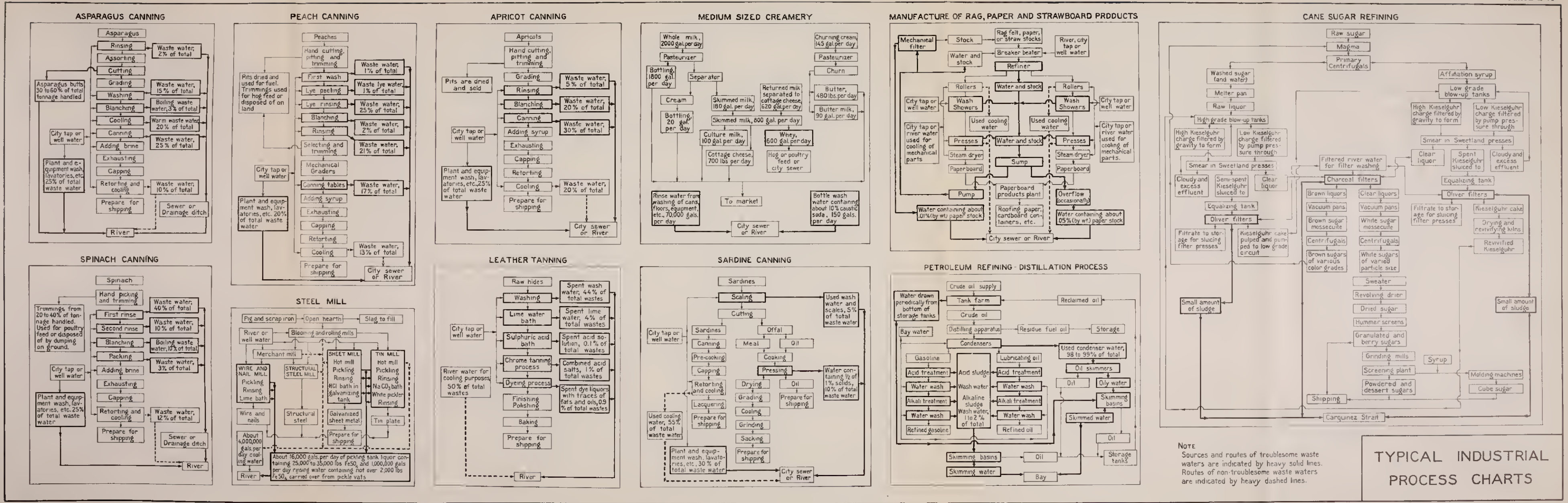
* See Plates E-II, "Location of Principal Sources of Pollution and Sampling Stations of Pollution Surveys in Upper San Francisco Bay and Sacramento-San Joaquin Delta," and E-III, "Organic and Bacterial Pollution in the Sacramento and San Joaquin Rivers."

CANE SUGAR REFINING



oublesome waste
heavy solid lines.
e waste waters
dashed lines.

TYPICAL INDUSTRIAL PROCESS CHARTS



Note
Sources and routes of troublesome waste waters are indicated by heavy solid lines. Routes of non-troublesome waste waters are indicated by heavy dashed lines.

TYPICAL INDUSTRIAL PROCESS CHARTS

TABLE E-15

SAN JOAQUIN RIVER POLLUTION SURVEY

River flow at Vernalis, 1,600 second-feet

Samples collected by J. M. Sanchis and J. Harmon. July 1-2, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkali, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Antioch Bridge	July 1, 9:30 a. m.	21.5	8.2	92	2.3	110.0	----------	40	218	0.02	0.06	295	Melosira Pleurococcus Melosira dics.
Wulff's Landing	1:30 p. m.	23.0	8.3	96	4.0	2.5	----------	32	43	0.02	0.22	352	Melosira dics. Pleurococcus Navicula
Empire Tract (southwest corner)	July 2, 11:05 a. m.	26.0	7.2	88	1.8	2.5	----------	24	67	0.04	0.16	456	Melosira dics. Melosira Pleurococcus
Gorton's Landing	2:25 p. m.	26.0	7.9	96	9.0	11.0	----------	40	105	0.08	0.08	450	Melosira Melosira dics. Pleurococcus
Borden Highway Bridge	3:10 p. m.	25.5	8.3	100	2.8	110.0	----------	48	64	0.04	0.12	528	Melosira Synedra Melosira dics.
Brandt's Bridge	4:00 p. m.	25.0	10.2	120	4.3	2.5	----------	28	51	0.16	0.04	791	Synedra Melosira Pleurococcus
Lincoln Highway Bridge	4:45 p. m.	25.0	12.3	150	5.3	0.25	----------	36	50	0.20	0.12	973	Pleurococcus Melosira Synedra

TABLE E-15

SAN JOAQUIN RIVER POLLUTION SURVEY

River flow at Vernalis, 1,600 second-feet

Samples collected by J. M. Sanchis and J. Harmon. July 1-2, 1930.

Sampling point	Time	Temperature, in degrees centigrade	Dissolved oxygen		Five-day biochemical oxygen demand, in parts per million	B. Coli index	pH	Alkali, in parts per million	Chloride in parts per million	Cubic centimeters per liter		Plankton in standard units	Predominant types
			In parts per million	In per cent saturated						Plankton	Amorphous matter		
Antioch Bridge	July 1, 9:30 a. m.	21.5	8.2	92	2.3	110.0	----------	40	218	0.02	0.06	295	Melosira; Pleurococcus; Melosira dies.
Wulff's Landing	1:30 p. m.	23.0	8.3	96	4.0	2.5	----------	32	43	0.02	0.22	352	Melosira dies.; Pleurococcus; Navicula
Empire Tract (southwest corner)	July 2, 11:05 a. m.	26.0	7.2	88	1.8	2.5	----------	24	67	0.04	0.16	456	Melosira dies.; Melosira; Pleurococcus
Gorton's Landing	2:25 p. m.	26.0	7.9	96	9.0	11.0	----------	40	105	0.08	0.08	450	Melosira; Melosira dies.; Pleurococcus
Borden Highway Bridge	3:10 p. m.	25.5	8.3	100	2.8	110.0	----------	48	64	0.04	0.12	528	Melosira; Synedra; Melosira dies.
Brandt's Bridge	4:00 p. m.	25.0	10.2	120	4.3	2.5	----------	28	51	0.16	0.04	791	Synedra; Melosira; Pleurococcus
Lincoln Highway Bridge	4:45 p. m.	25.0	12.3	150	5.3	0.25	----------	36	50	0.20	0.12	973	Pleurococcus; Melosira; Synedra

ond-feet. One hundred and fifty per cent of oxygen saturation, probably due to plankton, was found at the Lincoln Highway Bridge; 120 per cent of saturation at Brandt's bridge; 100 per cent at Borden Highway Bridge; 96 per cent at Gorton's Landing, north of Roberts Island; 88 per cent at the Empire Tract; and 96 per cent at Wulff's Landing. At some point between the Borden Highway Bridge and the upper end of the Empire Tract the river had recovered from its B. Coli contamination and represented water redeemable with safety. Due to tidal action available in greatest degree during low stream flow, it is unlikely that septic conditions would arise in the San Joaquin River for many years.

Should a barrier be built, upland flow only would be available for sewage disposal and to determine its amount it was necessary to resort to calculation as indicated in Plate E-IV. For an assumed flow of 500 second-feet and present pollution loads, oxygen depletion down to about 50 per cent is to be expected, but recovery would be almost complete at the upper end of the Empire Tract. With an assumed flow of 1000 second-feet and three times the present pollution load, the calculations indicate oxygen depletion down to about 20 per cent over the same stretch, and recovery well established near the lower end of the Empire Tract. These calculations, however, are not based on a diluting water supersaturated with oxygen above Stockton. If water supersaturated with oxygen continues to be available to dilute the sewage, as is to be expected, conditions would be much improved over the estimates. Septic odors would be likely if the flow passing Stockton fell below the above amounts.

There is considerable drainage from the delta islands which carries human sewage to the river. It appears also that the island drainage water is quite high in organic seepage, as the river shows some oxygen depletion throughout the islands. The sanitary sewage from the islands is particularly dangerous because of a high typhoid incidence among the island dwellers. The situation among the residents is said to have improved in recent years, due to a campaign of typhoid immunization carried on by the San Joaquin County Local Health District. However, among the itinerant population the typhoid rate still is high.

CHAPTER IV

SANITARY SURVEY OF SUISUN AND SAN PABLO BAY BASINS

The region adjacent to Suisun and San Pablo bays, particularly along the south shore, is one of considerable present and much greater potential industrial development. It naturally follows that the wastes from the factories are of great importance in a study and solution of the problem of a redeemable water supply in a barrier lake. These wastes, therefore, must be carefully considered along with the sanitary sewage of the several rapidly growing industrial centers in the area.

The wastes from these industries are both organic and inorganic. The former are considered in terms of their oxygen demand, as previously discussed. The latter, consisting mainly of iron sulphates, compounds containing the sodium radical and oil-containing wash waters, present a separate problem.

Conditions in the Suisun Bay Area.*

Along the shores of Suisun Bay there now are four incorporated cities. Of these Antioch, Pittsburg and Martinez are on the south shore and Benicia is on the north shore. Smaller settlements are located at Bay Point, Nichols, Avon, Concord and Clyde. At present the most polluting organic wastes are from fruit and fish canneries in the vicinity of Antioch and Pittsburg and from a paper manufacturing plant at Antioch. Two large oil refineries and several other industries within the area are large producers of chemical wastes. The survey indicated that sanitary sewage from about 25,000 people and industrial wastes, with a peak population equivalent of fully 125,000 persons in the summer and about 85,000 in winter, sewer directly to the bay practically at the shore line.

At low tide some odors are noticeable at the outlets in Pittsburg and Antioch. In general, the sewage disposal would pass as unoffensive and, at present, does not constitute a problem. Tidal currents are good and, in addition, prevailing winds are strong and parallel to or offshore. In view of the tidal velocities, it is doubtful if sludge banks form.

The city of Antioch discharges the raw sewage of its 3500 inhabitants directly to the San Joaquin River. A cannery and a paper products plant, both of which discharge their untreated effluents into the river, are the only local industries of pollutional importance.

The cannery operates on asparagus from April to June, apricots and peaches from July to August and pears from August to September. The maximum tonnage handled is 55 tons daily. The population equivalent of the wastes resulting from the various canning processes varies from 8000 in May to 20,000 from July to October. Water con-

*See Plates E-II, "Location of Principal Sources of Pollution and Sampling Stations of Pollution Surveys in Upper San Francisco Bay and Sacramento-San Joaquin Delta," and E-VI, "Typical Industrial Process Charts."

sumption is given as 85,000 gallons in a ten-hour day. This concern expects to increase its operations 25 per cent in 1931. An attempt has been made at this plant to dispose of the fifteen tons of asparagus butts produced daily during the asparagus season by dumping them on land. The method now used is rather crude and not altogether satisfactory but, if improved upon, may result in a possible solution of the waste disposal problem existing throughout the delta region.

The paper products plant manufactures paper board and strawboard products from old paper and straw by the process shown on Plate E-VI. Two machines operate on mechanically prepared pulp and one operates on straw pulp prepared by digesting straw with lime and soda ash. The whole plant discharges from one and a half to two million gallons of waste water per day into the river. The waste is said to contain from four to five pounds of pulp per 1000 gallons. The approximate population equivalent of the wastes, as the plant now is operated, has been estimated at 250,000 persons. It is said that a system of save-alls, recently installed on the strawboard waste, will reduce the loss of pulp about 75 per cent. It is planned to treat all wastes in this manner. When consummated, the population equivalent should drop to about 66,000 persons, nearly two-thirds of which would be from the manufacture of strawboard. If a barrier were constructed, it is concluded that the strawboard waste, at least, would require diversion to a regional sewer system, while the waste paper pulp machines might safely discharge their waste to the river as they now do, provided an excellent system of save-alls were used.

Antioch has taken its water supply from San Joaquin River for 50 years or more. For the past fifteen years the water has been filtered and chlorinated and there have been no known outbreaks of typhoid fever. During the past five or six years, because of encroachment of salinity around its intake in the summertime, the city has made it a practice to use water from an impounding reservoir, which it fills by pumping from the river in the winter and spring months. This has yielded a very safe supply.

About a mile below Antioch the river divides. The main channel, which is nearly three-quarters of a mile wide, turns north to join the Sacramento River. The other channel, running westerly for about three miles, is known as New York Slough and, although only about 1000 feet wide, carries a considerable portion of the river flow. The absence of shoal areas, particularly near shore, probably is responsible for the fact that the most compact industrial activity in the region lies along New York Slough.

Pittsburg is located at the westerly end of New York Slough, six miles below Antioch, and discharges raw sewage of 9600 inhabitants into the slough through four separate outfalls distributed along its shore line. It is essentially a manufacturing community. Among its more important industries are chemical, lumber, asbestos products and fish packing plants, steel and rubber mills, canneries and creameries.

Bacterial contamination is intensive opposite Antioch and Pittsburg. Prior to 1920, Pittsburg obtained its water supply directly offshore from the heart of the city. The treatment was far from perfect and, in a period when chlorination was not practiced, a serious typhoid outbreak occurred. The epidemic was reasonably attributed to the river water. Since then the city has obtained its water from wells. Pollution by mineralized wastes is more likely here than at any other part of the drainage system.

A large chemical industry in this vicinity has three main activities. The largest of these is the manufacture of sodium hydroxide, or caustic soda, with chlorine gas and bleaching powder produced as by-products and amounting to something like 8600 tons yearly. The second major activity of this plant is the manufacture of anhydrous sulphur dioxide, and the third is the manufacture of xanthate. Caustic soda, in addition, is made by a separate process. The waste water for this plant is practically all condensing and cooling water, amounting to from three to four million gallons per day. A grab sample on December 3, 1930, and a continuous 24-hour composite on December 4, 1930, were taken from the main outlet flume. These were analyzed by the Testing and Research Laboratories of the State Division of Highways and showed the following:

Constituents	In parts per million	
	Grab sample, on December 3, 1930	Composite sample, on December 4, 1930
Turbidity, silica standard	105	100
Oil and residual organic compounds	25	5
Free acid, as H_2SO_4	0	0
Iron and alumina, as oxides	20	-------
Combined sulphates, as SO_4	130	170
Chlorides, as Cl	900	1,200
Lime, as CaO	43	-------
Magnesia, as MgO	69	-------

Most of the chlorides found in the analyses come from New York Slough water, which is the plant's main source of water supply. Some chlorides, however, enter as impurities with the sodium sulphate waste from the "white liquor" plant. On December 11, 1930, the chlorides in the slough water itself amounted to 933 parts per million. Sulphates amounted to 120 parts per million on November 18, 108 parts per million on November 24 and 150 parts per million on December 11. The conclusion is that, if waste from the "white liquor" plant, amounting to some 10,000 gallons per day and containing 3000 to 5000 pounds of sodium sulphate, were excluded, the waste water could be returned to a barrier lake without harmful results.

The other major activities of this plant produce only small quantities of waste. Anhydrous sulphur dioxide, manufactured by burning sulphur, yields a waste of about 1400 gallons per day of hot water containing traces of sulphur dioxide. The production of xanthate is from alcohol, carbon bisulphide and caustic soda. A small amount of waste, said to amount to 500 gallons per day, containing traces of xanthate and caustic soda, is run to the slough.

Another chemical plant in this vicinity manufactures arsenic compounds to be used as insecticides and germicides. The various processes of manufacture involve reactions, decantation and distillation or evaporation. From 8000 to 10,000 gallons of water per day are used for making solutions, cooling and other uses around the plant. The only wastes finding their way into the river result from cleaning equipment, and amount to from 6000 to 10,000 gallons of water three or four times a year.

A steel mill in this locality, the operation processes for which are shown on Plate E-VI, operates rolling, sheet, wire nail and tin mills. Scrap iron, with a portion of pig iron, is heated to a molten mass in open hearth furnaces and poured into ingots. The resulting slag is disposed of as a fill. The ingots go to the rolling mill where they are heated and rolled to the desired shapes between rollers requiring a cooling water supply of about 2.8 million gallons per day. This is the main source of waste water from the plant. The water contains merely some discoloration and iron scale. Part of the output of the rolling mill is structural steel. The balance goes to the sheet mill, the wire nail mill and the tin mill.

In the sheet mill the plates are first reheated and rerolled and then immersed in one of two pickling tanks, holding about 1700 gallons of strong sulphuric acid, to obtain a clean iron surface. After a short contact, in which some iron sulphate solution forms in the pickle tanks, the lot is lifted to rinsing tanks. There, the lot is washed with a continuous stream of water, amounting to about 250,000 gallons per day. When the iron sulphate concentration in the pickle tanks reaches about 18 to 22 per cent, it is emptied into the drainage system, generally twice a day. From the rinse tanks the sheets are put through a hydrochloric acid bath, consuming nearly 100 pounds of acid daily. The sheets then go to galvanizing tanks and to stock.

In the wire nail mill, wire rods go through a similar pickling operation to clean the surface. The vats hold about 3000 gallons. The rods then are rinsed in continuous flow tanks, discharging about 500,000 gallons per day to the drainage system. Next, the rods go through a small lime tank, where they take on a lime lubrication. The lime tank is emptied at long intervals and is of no consequence as a waste producer. From this point on, the process is a mechanical one of shaping the nails.

In the tin mill the sheets are reheated, rerolled and immersed in pickling tanks holding almost 3000 gallons. These are similar in their use to the other pickling tanks. The plates then are lifted to continuous flow rinse tanks, then to a weak soda ash bath, after which they are annealed, repickled, rinsed and tinned. The rinse water streams from all the processes involving pickling aggregate about 600,000 gallons per day.

The normal monthly use of sulphuric acid in the sheet mill is 60 tons, in the wire nail mill 47 tons and in the tin mill 20 tons. It is expected to increase the tin mill operations so as to consume about 25 tons monthly. The whole plant operation may increase these figures 25 per cent in five years, hence the daily consumption of sulphuric acid would average close to six tons in a few years.

The fresh batch of pickle contains from 4 to 6 per cent acid. When dumped, it contains about 1 per cent acid and 18 to 22 per cent iron sulphate. In the transfer of the plates or rods from the pickle vats to the rinsing tanks, a small percentage of the vat contents is carried over from the pickle tanks to the main drainage system. This loss would be difficult to avoid. It might amount to about 1000 to 1200 pounds per day of iron sulphate and 300 to 400 pounds per day of acid. The remainder is drained from the pickle tanks and aggregates about 50,000 pounds per day of iron sulphate and 2500 pounds per day of acid, being contained in some 30,000 gallons of water.

It is understood that, at many of the steel mills on eastern streams, it is necessary to divert this iron sulphate solution to crystallizing beds for disposal. Such disposal would be unavoidable here if a barrier were built, otherwise New York Slough water would be unusable for most purposes, at least throughout the summer. The great bulk of waste water, amounting to about four million gallons per day, is quite harmless and, after settling, could continue to run to the adjacent water front.

A rubber products industry in this vicinity produces mechanical rubber goods. It requires about 1000 pounds of crude rubber and 25 tons of old tires daily. The latter are reclaimed by the alkali process, using about 500 pounds per day of caustic soda. The total amount of water used is given as 150,000 gallons per day, part of which is returned directly to New York Slough and part first passed through settling basins and thence to the slough. Some caustic soda undoubtedly reaches the slough. The plant was not running during the investigation and little is known of the waste. A grab sample of the waste in the pump sump December 3, 1930, shows:

Constituents	In parts per million
Turbidity, silica standard	5
Oil and residual organic compounds	Trace
Free acid, as H_2SO_4	nil
Iron and alumina, as oxides	2
Combined sulphates, as SO_4	130
Chlorides, as Cl	1300—
Lime, as CaO	69
Magnesia, as MgO	17

Indications are that there would be 300 pounds or so of caustic soda reaching the slough daily; otherwise, the waste appears to be low in minerals. Since the plant was not running, the organic character of the waste could not be investigated. The literature indicates that wastes from this type of industry resemble sewage in their pollutional effect on streams and, in this case, if a barrier were constructed, it probably would be inadmissible into New York Slough.

Another large industry in the Pittsburg area manufactures about eight tons of rag felt and ten tons of asbestos felt daily. The process is largely mechanical and losses are essentially fibrous. The volume of waste in a twelve-hour day is given as 600,000 gallons from rag felt operations and 900,000 gallons from the asbestos plant. The daily losses are given as 2400 pounds of rag felt and 2600 pounds of asbestos, which is inert. It is understood the fibrous losses injure fish life. The population equivalent is considered to be 2500 persons. Save-alls would reduce the losses materially. The asbestos waste probably could go to New York Slough, but it would be safer to divert the rag felt waste to a regional sewer, if a barrier were constructed.

A large cannery in Pittsburg discharges asparagus butts and all liquid wastes into the slough. Its water consumption is about 150,000 gallons per day. From August to February the plant handles up to 240 tons a day of sardines, using the process illustrated on Plate E-VI. The average is 165 tons daily and the seasonal total 21,000 tons. Coarse refuse goes to a fertilizer plant. The cooling water, amounting to 125,000 gallons per day, is clear, but there are about 30,000 gallons per day of polluted waste water, said to contain nearly a ton of solids. The population equivalent is roughly estimated at 10,000 persons.

The company also cans tomatoes from September to November, handling about 65 tons daily. The seasonal total is approximately 2600 tons. Loss to the river is given as about half a ton of trimmings per day, and 150,000 gallons of wash water. In the peach season, July to September, the company cans about 2000 tons, averaging about 50 tons daily. Waste to the slough is said to be 800 gallons of spent lye water, 2000 gallons of blanching water, 25,000 gallons of cooking water and 80,000 gallons of cooling water per day.

In the asparagus season, April to June, the company handles about 40 tons daily, or about 3700 tons for the season. It is estimated by the company that refuse reaching the slough amounts to about 1000 tons of asparagus butts for the season, 5000 gallons per day of asparagus blanching water and 72,000 gallons per day of cooling water. The latter could safely be returned to the slough indefinitely, but the other wastes should be turned into a regional sewer if a barrier were built.

Plans are being perfected to erect another sardine packing plant at Pittsburg to handle about 150 tons per day. The population equivalent of its wastes would be about 8000 persons. Waste disposal problems would resemble those previously described for the other sardine canning plant.

One large creamery, making butter and cheese, receives about 2000 gallons per day of whole milk and 145 gallons per day of churning cream. All waste water, amounting to about 70,000 gallons per day, goes to the river.

There also are several fresh fish packing plants in Pittsburg, handling shad, bass, catfish and salmon for both market and smoking. Shad refuse is sent to a fertilizer plant nearby. The waste to the slough is refuse from the other fish. Heavy shad fishing is in March and April, when perhaps fifteen tons daily are handled. The salmon season is best from July to September, with the catch amounting to two or three tons daily. About one-third of the total catch is returned to the river as refuse.

In the vicinity of Mallard Slough about two and a half miles below Pittsburg, a public utility recently has established a water supply intake. Fresh water is pumped in the flood season and stored in a reservoir near Clyde, after the same principles employed at Antioch. The present capacity of the works, including filters, is understood to be three million gallons per day. This water is furnished to consumers along the south bay shore from Pittsburg to Rodeo. In this area there are a few developments from wells.

Another large chemical plant in the Antioch-Martinez area produces sulphuric and nitric acids, aluminum sulphates and insecticides, chiefly lead arsenate. Salt water is used for condensing purposes at an average rate of 5000 gallons per minute, although it varies from 1000 to over 6000 gallons per minute, depending upon the plant activity.

In sulphuric acid manufacture, sulphur is burned to sulphur dioxide, which then is converted to sulphuric acid by a catalytic process using platinum. The residue is an iron oxide slag, containing a slight amount of copper which is shipped to another plant nearby. In manufacturing nitric acid, sodium nitrate is treated with sulphuric acid, with the evolution of nitric acid. The solid residue is sodium bisulphate, which is stored and shipped. Liquid wastes from these processes are slight losses of acid through leakage and spilling.

In making aluminum sulphate, bauxite—an aluminum oxide—is treated with sulphuric acid and crystalline aluminum sulphate results from the reaction. The residue, consisting of undigested bauxite, silica and inert solids, is stored on waste land. There are no liquid wastes.

To make lead arsenate, litharge and arsenic acid react to form lead arsenate. The mixture then is evaporated, leaving behind the dry insecticide. There are no wastes from this process. Other insecticides are similarly produced, positively retaining the liquid as the insecticide and rejecting the solid to waste land.

All liquid wastes from the plant go through a settling pond, about 200 feet by 250 feet in plan and from one to two feet deep, which overflows to the bay. No particular waste disposal problem exists at this plant and there is no reason why future waste disposal problems could not be taken care of at the plant.

Bay Point, with a population of 1600, discharges domestic sewage at the head of a tidal canal about twenty feet wide and three-fourths of a mile long. Conditions do not appear offensive. Clyde, with a population of 200, is located just below Bay Point and has an Imhoff tank discharging to a slough about ten feet wide that leads to Suisun Bay, four miles away. Concord is inland four miles. It has a population of approximately 1200 and sewers to a septic tank and sewer farm, but the sludge and overflow runs to Walnut Creek and thence to Suisun Bay via Avon. The septic tank is becoming quite unsatisfactory and the city logically would sewer to a regional sewer, if permitted. Avon, a couple of miles west of Clyde, has a population of about 600. Part of the sewage goes to a septic tank and thence to a slough, the terminus of Walnut Creek which also may receive the Concord sewage, and part of the sewage runs to an oil refinery's ponds.

There are two large oil refineries near Martinez producing a full line of fuels, lubricating oils, greases and similar products from asphaltic base crude oil. One plant now uses the fractional distillation process in producing petroleum products varying from gasoline and kerosene to motor oils and greases, but is making a change to the cracking process. The distillation process is illustrated on Plate E-VI. The residue is used for fuel oil.

In the distillation part of the process the liquid waste is cooling or condensing water, which may contain some oil due to leakage or oil spillage at various parts of the plant. The amount of this condensing and cooling water is given as fourteen million gallons per day. The kerosene distilled off is purified by the sulphur dioxide process and no further liquid waste results in this step. A considerable portion of the lighter distillates are so pure that, after a slight water wash using about 40,000 gallons daily, no other treatment is necessary. Other gasoline and lubricating oil distillates are purified by successive contact with from five-tenths to three per cent of sulphuric acid and alkali. Following contact with the acid and again with alkali, the distillates are washed with water. There are variations in this part of the treatment, and in strength of acidification, depending upon the type of products being made and the raw material itself.

The first waste is an acid sludge, drawn off in batches from the bottom of the separators. This waste now goes to the oil separating ponds with the other wastes. However, it can be burned. The acid it carries imparts an acid reaction to the contents of the oil skimming ponds. After the acid sludge is drawn off in the separators, the gasoline is washed with water. Oils receive two or more such washings, depending upon the product. The amount of wash water so used at one of these plants aggregates close to 350,000 gallons per day. A similar amount is believed to be used at the other, which is of about the same size. This wash water contains slight traces of acid or alkali and smells strongly of gasoline. It now is disposed of to the oil skimming ponds and thence to the bay. When mixed with the cooling water, the gasoline odors become only faintly noticeable.

Having no information other than these observations, it would appear unwise to pollute the waters behind a barrier with this waste. Furthermore, the amount of gasoline in the water would make it dangerous to carry it in sewers, because of the great danger of explosions. In all sewer projects investigated it has been planned to carry the rinse waters in a separate sewer.

In the cracking process of refining now being installed to replace the distillation process, crude oils are heated to high temperatures and then are given an acid treatment two or three times stronger than required in the distillation process. This results in the production of a greater amount of acid sludge and the inclusion of pyridine, phenol and sulphuric compounds in the wash water following the acid or alkali treatment. These wash wastes, likewise, carry a strong smell of gasoline and the remarks above, relative to a separate line for the gasoline-containing wastes, apply to those from the cracking process.

Analyses of the skimming ponds' effluents in November, 1930, are as follows:

Constituents	In parts per million			
	On November 10, 1930		On November 24, 1930	
	East ponds	West ponds	East ponds	West ponds
Turbidity, silica standard	40	60	150	47
Oil and residual organic compounds	43	23	49	nil
Free acid, as H_2SO_4	580	120	740	5
Iron and ammonia, as oxides		37	30	21
Combined sulphates, as SO_4	1,000	870	940	680
Chlorides, as Cl	7,500	6,000	7,300	5,400
Lime, as CaO		210	250	200
Magnesia, as MgO		650	590	120

This waste might cause injury to barrier lake waters, chiefly because of the sulphates and free acid. The origin of the troublesome waste is thought to be the acid sludge and the acid wash water, both of which could be disposed of without fouling the harmless cooling water. Samples taken December 15, 1930, to ascertain the origin of the acidity and sulphates gave the following results:

Source of sample	In parts per million	
	Sulphates, as SO_4	Acidity, as H_2SO_4
Fresh water supply	900	16
Mixed salt and fresh supply as used	860	4
Condenser and cooling water	940	8
Mixed wastes from pond	980	100

These tests tend to confirm the supposition that the main source of acidity and sulphates is not the condensing water and is either in the acid sludge or in the wash water, or both. It appears from this that the sulphates would aggregate about five tons per day. In a barrier lake such quantities of sulphate would cause considerable boiler incrustation and in septic sewage would cause considerable odor.

The other oil refinery already employing the cracking process now uses from three to five million gallons per day of salt water and one million gallons per day of fresh water. The wash water aggregates 350,000 gallons per day, as previously stated. The acid sludge at this plant now is burned, and the acid wash waters disposed of to the bay. Grab samples November 10 and 24, 1930, showed the following results:

Constituents	In parts per million			
	On November 10, 1930		On November 24, 1930	
	East pond	West pond	East pond	West pond
Turbidity, silica standard	75	38	35	40
Oil and residual organic compounds	16	37	21	28
Free acid, as H_2SO_4	1,700	1,710	nil	nil
Iron and alumina, as oxides		39	37	36
Combined sulphates, as SO_4	1,480	1,440	1,530	1,460
Chlorides, as Cl	10,200	9,700	8,700	8,500
Lime, as CaO		340	310	300
Magnesia, as MgO		860	500	470

Samples of particular batches taken on December 15, 1930, to ascertain the origin of the sulphates and the acidity, show:

Source of sample	In parts per million	
	Sulphates, as SO_4	Acidity, as H_2SO_4
Salt water supply	1,030	10
Rinse water distillation process—126,000 gallons per day	1,180	38
Rinse water cracking process—170,000 gallons per day	1,640	800
Waste to bay—say, three million gallons per day	1,350	120

From this series of tests it appears that the sulphate imparted to the wastes aggregates about 3.5 tons per day, but only half a ton daily can be accounted for as due to the wash waters. It may be that sludge remaining in the ponds was still imparting a sulphate pollution. The results do not agree with those found at the other plant. Further work would be desirable to make certain the condensing water could safely be run to a barrier lake.

Still another chemical plant in the Antioch-Martinez area has as its chief product a mineral phosphate fertilizer. It also manufactures sulphuric acid and reclaims copper by a leaching process. To make phosphate fertilizer, rock is ground to a flour and treated in vats with sulphuric acid. The phosphate in the rock is converted to a water soluble superphosphate. No wastes result from this process. To make sulphuric acid, pyrites, an iron sulphide ore containing some copper, is roasted to liberate the sulphur used as the starting point. The sulphur then is burned to sulphur dioxide and converted to sulphuric acid by a catalytic process. From 400 to 500 pounds of sodium bisulphate are produced daily as a by-product which, at present, is washed out through the sewer. The flow of water is given as 75,000 gallons per day. The sodium bisulphate need not be allowed in the sewer, as it could be stored as a solid and disposed of to waste land or by other methods, if necessary. Other liquid wastes consist of some small amounts of acid from leakage or spilling.

In reclaiming copper, the cinders from the roasting of the pyrites, which contains some copper, are leached in contact with sulphuric acid for about 36 hours. The treatment results in the formation of a solution of copper sulphate, which is drawn off and evaporated, forming copper sulphate crystals. The acid-soaked cinders are washed with salt water several times after the drainable acid is drawn off. The washings contain a small amount of copper sulphate. They are conducted to a tank with iron scrap suspended in it and follow a circuitous path through the tank. The copper in the solution is precipitated as metallic copper, being replaced by iron. The waste water thus consists of an acid solution of iron sulphate. About 200 tons of iron scrap per year are dissolved in this treatment. The waste water from this process amounts to about 25,000 gallons per day. It is expected to double the capacity of this part of the plan within the next year. Grab samples, collected November 24, 1930, showed:

Constituents	In parts per million	
	Leaching plant overflow	Main sewer overflow
Total solids	73,000	----------
Free acid, as H_2SO_4	660	370
Free acid, as HCl	----------	130
Combined sulphates, as SO_4	30,700	530
Iron and alumina, as oxides	19,000	1,120
Magnesia, as MgO	250	190
Chlorides, as Cl	6,100	5,200
Zinc, as ZnO	6,250	140
Lime, as CaO	----------	31

Although the volume of waste is small, the constituents are high, particularly from the leaching plant. The waste can be concentrated through reuse and evaporation to a point where it can be crystallized. The remaining wastes could then go into a regional sewer.

The city of Martinez discharges its untreated sewage into the upper end of Carquinez Strait. The main sewer, having an eighteen-inch outfall, sewers about 90 per cent of the area of the city and serves about 5000 population. This outfall is located near the western edge of the city. The end of the outfall is about 75 feet beyond the high water mark on the shore and has two feet of submergence at high tide. At low tide, the water line is at least 300 feet beyond the outlet. The shore here slopes very gradually and, hence, the tidal action is an important factor in flushing away the sewage. There are two other outlets. An eight-inch sewer, serving 500 to 1000 population, is located several hundred feet upstream. A six-inch sewer, serving about 100 population, is located about a mile farther upstream. Two sections of the city, with a combined population of 1100 to 1200, sewer a septic tank effluent to the strait through a drainage ditch.

From Martinez to Eckley, opposite Dillon Point, the steep hillsides come down almost to the shore and there is little room for further expansion. Port Costa discharges the untreated sewage of about 500 population into the relatively deep water of Carquinez Strait.

As previously mentioned, the city of Benicia is the main source of pollution on the northerly shore. The sewage of about 2300 persons, which represents about 80 per cent of the total population, is discharged into Carquinez Strait through three separate outfalls. The rest of the population utilizes cesspools and vault privies. Just above Benicia is the United States Arsenal, with a present population of about 200. Raw sewage is discharged directly to tide water.

The main waste producing industry at Benicia is a cannery, which operates on asparagus, peaches and tomatoes at various times during the canning season and discharges all its wastes directly into the strait. The plant can handle 50 to 80 tons daily. Peach canning runs about 2200 tons per season and consumes about two tons of lye per day, or 70 tons per season. Water used totals about 100,000 gallons per day. The waste, or the greater part of it, could be handled with the sanitary sewage. The population equivalent of these wastes varies from 7000 to 10,000.

Fifteen miles northerly, on Suisun Slough, are the cities of Suisun, and Fairfield, with a combined population of about 2000. Suisun Slough is tributary to Suisun Bay and its waters are brackish. It is about 100 feet wide at Suisun but widens out shortly below and has a more or less uniform width of several hundred feet to its mouth. It has a diurnal tidal range of nearly seven feet. Suisun discharges raw sewage to the head of the slough through six outlets. Fairfield sewers to the slough a mile lower down through a single outlet. In Suisun there also is a cannery, canning asparagus from April to June, apricots in June and July and peaches from July to September. All wastes, including about 20 tons a day of asparagus butts, which are chopped to a mulch, are run to the slough. The population equivalent is estimated to vary from 8000 to 16,000 persons, depending on the crop.

During the time the cannery is not in operation the condition of Suisun Slough has been reported as fair, there being only small areas near the outlets showing a sewage field. During the canning season, however, considerable trouble is created by the accumulation of large amounts of cannery wastes in the upper end of the slough. This portion becomes septic soon after operations start and remains so practically throughout the canning period. Fortunately, the prevailing winds blow away from town toward open waste land to the east and no serious complaints have arisen regarding the method of disposal. The cannery waste and sewage undoubtedly would require disposal in some other manner if Suisun Slough ever were considered as a source of fresh water supply following completion of a barrier.

Pollution Surveys in Suisun Bay.—Sanitary conditions on Suisun Bay are generally good. In New York Slough there is little to suggest the presence of sewage, except smells at sewer outlets when the tide is low and a bacterial contamination at all times. At Martinez and Benicia, the waters are more shallow at the sewer outfalls and are susceptible to the formation of sludge deposits but, according to reports, the conditions are not serious.

A summary of organic pollution loads on Suisun Bay is given in Table E-16.

TABLE E-16

SUMMARY OF ORGANIC POLLUTION LOAD IN SUISUN BAY IN TERMS OF HUMAN EQUIVALENT

Sources of pollution	Human	Human equivalent of industrial wastes				
		June	July	August	September	Winter months
Antioch	3,540					
Canneries		8,000	20,000	19,800	19,800	
Paper products plants		66,000	66,000	66,000	66,000	66,000
Pittsburg	9,600					
Canneries		8,900	9,400	17,400	15,800	8,000
Creameries		1,130	1,130	1,130	1,130	1,130
Fisheries		180	180	8,180	8,180	8,000
Manufacturing plants		2,500	2,500	2,500	2,500	2,500
Bay Point	1,570					
Clyde[1]	160					
Avon[1]	480					
Martinez	6,300					
Port Costa	590					
Benicia	2,300					
Cannery	200	6,900	10,000	10,000	10,000	
Creamery		70	70	70	70	70
U. S. Arsenal	200					
Suisun	650					
Cannery	200	15,000	16,000	16,000	16,000	
Fairfield	1,200					
Total	26,990	108,680	125,280	141,080	139,480	85,700
Total, exclusive of Fairfield and Suisun	24,940	93,680	109,280	125,080	123,480	85,700

[1] Treatment—septic tank.

Conditions in San Pablo Bay Area.

Adjacent to San Pablo Bay are Crockett, Selby, Oleum, Rodeo, Pinole, Hercules, Giant, San Pablo and Richmond, at intervals along the south shore, and Vallejo and Mare Island, on the north shore. Wastes from all these cities find their way into the bay, and, in addition, the wastes reaching the north side of the bay from Vallejo are augmented by those from Napa and Petaluma, which flow to the bay through Napa River and Petaluma Slough, respectively.

Crockett discharges the untreated sewage of its 4200 inhabitants into Carquinez Strait near the entrance to San Pablo Bay. Four sewer outlets are located at various points along a three-quarter mile water front. All these outfalls, with the exception of the most westerly one, are in good depths of water and in strong tidal currents.

At Crockett there is a cane sugar refining plant, the process being illustrated on Plate E-VI. This plant discharges to the strait about 1.5 million gallons per day of discolored water from the charcoal filters and wash water from the Oliver filters. This waste water contains some sludge. The combined population equivalent of the wastes is about 47,000 persons. Turbid wash waters from the water filters also are poured into the strait.

At Selby, just below Crockett, is a smelter which uses about 600,000 gallons per day of salt water for cooling purposes in the smelting of lead. Hot slag is dumped along the shore, forming a fill. The raw sewage of about 80 employees is run directly to the bay.

An oil refinery at Oleum discharges waste water amounting to about five million gallons per day, which is similar in character and variation to the wastes from the oil refineries previously described. The wastes are run through several acres of skimming ponds and thence to the bay.

The town of Rodeo and vicinity discharges the domestic sewage of about 1500 people into tidal mud flats without treatment. The sewer outfall is located at the northern end of the town. It extends about 200 feet beyond the high water mark, but is wholly uncovered at low tide.

Proceeding westerly down the bay is Hercules. Part of the untreated sewage of about 400 residents is discharged through a pipe line extending into a tidal marsh. The rest of the wastes are allowed to overflow into a nearby creek at a point a few hundred feet from the bay.

At Pinole, adjoining Hercules on the west, the raw sewage of about 1000 people reaches the bay. Powder plants at Hercules and Giant dispose of over a million gallons per day of cooling water used in manufacturing explosives. There also is some waste water which contains traces of acid from nitroglycerine manufacture. It is said that at times as much as 300 to 400 pounds of acid escapes to the bay. The cooling water could undoubtedly return to the bay. In addition, the raw sewage of about 370 employees at these plants is disposed of in the bay. Waste water from oil storage tanks near Giant is drained from the tanks and run to plowed fields and cultivated in, but in winter it might reach the bay. It contains some crude oil.

At San Pablo, just north of Richmond, the sewage of a population of 1500 is discharged without treatment into the shallow waters of the bay. At Richmond, most of the sewage is discharged into San Francisco Bay about four miles south of Point San Pablo. One 30-inch sewer, however, discharges into a cove north of the city. It serves about 1500 people and several factories. One of these plants has a considerable quantity of waste water, which seems to contain a certain amount of emulsified oil. A large oil refinery easily could dispose of all, or part, of its wastes on either side of a barrier at Point San Pablo, as might seem desirable. About 100,000 gallons per day of wash water from locomotives of a railroad company are run to the bay in the vicinity of the 30-inch sewer. The waste is passed through oil skimming ponds where about 150 gallons of oil are recovered daily. The effluent appears to contain some oil films.

One industry above Richmond is devoted principally to the manufacture of rag felt, used as base material in the manufacture of roofing products. The raw materials used at the plant consist principally of rags with some paper. The process is similar to that used at the paper products plant previously described. The wash water, containing large amounts of fiber and dirt, is passed through a save-all rotary screen, where most of the fiber is supposed to be recovered. The effluent from the save-all passes through a settling basin. The settled water is pumped into the system and again used in the process. Some 144,000 gallons per day of fresh water are taken into the system to displace an equal amount of unreclaimable water run to the city sewer. About 1800 cubic feet of material is collected in the settling basin and flushed into the sewer once a week, frequently causing a stoppage in the sewer. The remainder of the plant houses a paint manufacturing department, where rolling, grinding, mixing and packing of paints and varnishes is carried on. There are no wastes resulting from these various processes, other than the dried paint removed while cleaning the equipment. These paint scraps are disposed of by incineration.

On Mare Island Strait, an arm of San Pablo Bay, are Vallejo and Mare Island. The city of Vallejo discharges the raw sewage of about 14,000 people into Mare Island Strait through some fifteen short outfalls. Tidal currents are good and the water front looks clean. There are several milk-handling plants in Vallejo, one of which is planning to make cottage cheese. The largest plant receives about 1600 gallons of milk and 300 gallons of cream daily. The milk is separated, the cream churned and the skim milk and buttermilk are sold for chicken feed. Floor and can wash goes to the sewer. A large milling industry at Vallejo discharges about 175,000 gallons per day of waste water to the tidal flats. The waste, resulting from washing wheat and other cereals, is milky and foams in the sewers, possibly due to fermentation. The population equivalent of all these industrial wastes is about 19,000.

On the opposite side of the strait, and facing the Vallejo water front, is Mare Island Navy Yard. The sewage from an estimated present population of about 2000 and a transient population equivalent to about 2500 inhabitants is discharged through 36 outlets into Mare Island Strait. The population is quite variable and may increase several fold in war time.

Napa River, tidal as far upstream as Napa nearly all the time, empties into Mare Island Strait at Vallejo. Dilution is inadequate during low water periods but, while the slough is not strictly clean, a nuisance may not actually exist. Wastes sewered to it are mainly from Napa and the Napa State Hospital, with the city of Napa representing the principal source of pollution. This community discharges the untreated sewage of some 6600 people through eight separate outfalls located along the river's banks. A tannery is the main source of factory waste. The population equivalent of the waste produced at this plant has been estimated at about 5000. The process is illustrated on Plate E-VI. Other wastes of lesser importance are from fruit packing plants and creameries, the combined population equivalent of these wastes being evaluated at 1000 persons. Two and one-half miles below Napa, at

Spreckels Bend, the Napa State Hospital discharges the raw sewage of 3400 inmates and employees to the river. During certain seasons of the year, the sewage is used intermittently for the irrigation of crops on a 200 acre farm adjoining the river. Sewage treatment of a high degree would seem to be required at both Napa and the Napa State Hospital, if a barrier were built at Point San Pablo.

Petaluma Slough is tributary to San Pablo Bay. The only important source of pollution is the city of Petaluma, situated at the head of the slough. Petaluma discharges the raw sewage of its 8200 inhabitants through nineteen outlets into nearby bodies of water. Seventeen of these outlets discharge directly into Petaluma Slough. One discharges into Thomas Creek, about 100 yards above the entrance of the creek into Petaluma Slough, and the other overflows into a canal leading to Petaluma Slough. There are creameries, canneries, poultry products and feed plants and other industries producing oxygen consuming wastes at Petaluma. The combined population equivalent of the wastes from these plants is estimated at 4100 persons. However, the organic wastes vary widely, depending principally on the amount of whey produced in the milk factories, and it is conceivable the population equivalent may be fully three times that estimated. In the vicinity of Petaluma, the slough had a decided appearance of septicity at the time of inspection. During periods of low run-off, odors are said to extend several hundred feet from the slough. During the rainy season, however, this condition is substantially improved. It is doubtful if construction of a barrier at Point San Pablo would make conditions noticeably worse than at present.

TABLE E-17

SUMMARY OF ORGANIC POLLUTION LOAD IN SAN PABLO BAY IN TERMS OF HUMAN EQUIVALENT

Sources of pollution	Human	Human equivalent of industrial wastes				
		June	July	August	September	Winter months
Crockett and Valona	4,300					
Sugar refinery		47,000	47,000	47,000	47,000	47,000
Oleum	150					
Rodeo	1,500					
Hercules	250					
Powder plant	200					
Pinole	1,000					
Giant	170					
San Pablo	1,500					
Richmond[1]	1,500					
Paper products plant		15,000	15,000	15,000	15,000	15,000
Napa	6,600					
Canning, tanning and dairy plants		5,270	5,270	6,090	6,090	5,270
Napa State Hospital	3,400					
Vallejo	14,360					
Flour mill and dairies		19,100	19,100	19,100	19,100	19,100
Mare Island	2,000					
Daily transient population	2,500					
Petaluma	8,200					
Creameries		3,500	3,500	3,500	3,500	3,500
Poultry industries		500	500	500	500	500
Silk plant		100	100	100	100	100
Total	47,630	90,470	90,470	91,290	91,290	90,470
Total, exclusive of Napa, Napa State Hospital and Petaluma	29,435	81,100	81,100	81,100	81,100	81,100

[1] Portion sewering to San Pablo Bay only.

Pollution Surveys in San Pablo Bay.—Inspection of the shores of San Pablo Bay during the summer of 1930 did not disclose objectionable conditions along the southern water front. On the northern shore conditions are less satisfactory. In the vicinity of the flour mill at Vallejo there is a considerable accumulation of sludge on the tidal mud flats. These sludge banks are formed by the continuous washing to shore of material orginating at the flour mill. This situation is not considered objectionable at present. Conditions in Napa River and Petaluma Slough have been mentioned previously.

In Table E-17 are compiled the organic pollution loads for San Pablo Bay.

Summary of Organic Pollution Load.

For the whole area, heading at Sacramento and Stockton and terminating at Point San Pablo, the population equivalents of the organic pollution loads are appraised in Table E-18.

TABLE E-18

SUMMARY OF ORGANIC POLLUTION LOAD IN LOWER SACRAMENTO AND SAN JOAQUIN RIVERS AND SUISUN AND SAN PABLO BAYS IN TERMS OF HUMAN EQUIVALENT

Sources of pollution	Human	Human equivalent of industrial wastes				
		June	July	August	September	Winter months
Lower Sacramento River, Sacramento to Rio Vista	98,200	117,460	62,480	130,480	130,480	5,390
Lower San Joaquin River, Lincoln Highway Bridge to Antioch	51,000	76,920	98,240	99,940	102,580	61,290
Suisun Bay above Dillon Point, Antioch to Benicia	26,990	108,680	125,280	141,080	139,480	85,700
San Pablo Bay above Point San Pablo and below Dillon Point	47,630	90,470	90,470	91,290	91,290	90,470
Grand total above Point San Pablo	223,820	393,530	376,470	462,790	463,830	242,850
Total, exclusive of Fairfield, Suisun, Napa, Napa State Hospital and Petaluma	203,870	369,160	351,100	436,600	437,640	233,480
Total for lower Sacramento, lower San Joaquin and Suisun Bay above Dillon Point	176,190	303,060	286,000	371,500	372,540	152,380
Total, Suisun Bay above Dillon Point, exclusive of Fairfield and Suisun	24,940	93,680	109,280	125,080	123,480	85,700

CHAPTER V

REMEDIAL MEASURES

Construction of a barrier at Dillon Point, or Point San Pablo, would precipitate the most unmistakable sanitary problems along the shores of the lake so created. Elsewhere on the river system and tributary sloughs, sanitary problems will develop even without a barrier, but at certain points, as at Napa, Suisun and Fairfield, a barrier would hasten and intensify unsanitary conditions due to the removal of tidal currents.

Sewerage for the Lower Sacramento and San Joaquin Rivers.

Below the outfalls of the city of Stockton, sanitary conditions are not now a nuisance, but nuisance would likely result if tidal currents were eliminated. The uncertainty as to future conditions of the San Joaquin River below Stockton lies in the outcome of the State Water Plan* to reverse the flow of the lower San Joaquin River for irrigation purposes. It is concluded that a flow of 1000 second-feet, whether upstream or downstream being immaterial, would dispose of the Stockton sewage without nuisance for many years to come.

On the Sacramento River the flows normally have been adequate to prevent sewage nuisance, but there have been years when the flow was critically low. Since the organic load is constantly increasing, particularly at Sacramento, a recurrence of these low flows probably would result before long in a nuisance immediately below that place. However, investigations show the problem, which would be created there at such times, would be local in character. It would extend only about halfway to Suisun Bay, terminating at a point above Walnut Grove. Consummation of the State Water Plan* also would solve this local nuisance problem between Sacramento and Walnut Grove. Bacterially, the river water would be classed as unsafe without proper treatment.

Sewerage for the Area Above Dillon Point.

On the shores of Suisun Bay, present sewerage and sanitary conditions are not at all a nuisance. As far as one can anticipate the industrial development, whatever problems would arise in the natural course of events without a barrier would be a long way off and, moreover, would be simple of solution through the utilization of the tides. There is, however, considerable bacterial contamination along the shores. If a barrier were constructed, the conditions, at least along the shore of the lake so created, would become a nuisance at once, and the waters would be highly mineralized by the chemical industrial wastes. After reviewing the processes now employed in the industries, it appears that the troublesome wastes could be segregated out of the main stream of

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

waste water by rather simple rearrangements. They then could be disposed of, by methods other than dilution, without great hardship on the individual industries. Thereupon, fully 80 per cent of the waste water produced could be returned to a barrier lake just offshore.

There would remain for disposal the sanitary sewage, organic wastes of the industries, small amounts of chemical wastes and the wash waters of the oil refineries. A separate method of disposal must be sought for these wastes if a barrier were constructed. The methods of disposal selected should preserve the cleanliness of the shores, and especially intakes for domestic supply. Some idea of the magnitude of the problem may be had from the fact that the population to be taken care of above Dillon Point and below Antioch is now about 25,000 persons and that the organic matter from industries would impose a burden equal to that of about 125,000 persons.

The most commendable sewerage project, with a barrier at the Dillon Point site, would be diversion to San Pablo Bay with an outfall terminating at a point about one mile offshore from Oleum. This is a suitable site for sewage sedimentation works and one which would put the sewage well below a barrier. Such a project would prove the most satisfactory in the long run, due to the greater security in results.

The sewage from the Contra Costa County shore could be conveyed below the barrier by successive boosting, while that from the Benicia side could be pumped across Carquinez Strait by way of the barrier structure and into the main line. The oil refinery wastes, estimated at less than 7 per cent of the total flow, should be carried to the same outfall in a separate line, due to the danger of explosions.

Under such an arrangement, the present day sewage flow, which would be carried in the sanitary sewer, appears to average not over six million gallons per day, with about 400,000 gallons per day originating on the Benicia side. The refinery wash water now amounts to about 500,000 gallons per day. In view of this information, it is considered adequate to provide for an average sewage flow of 13.7 million gallons per day from the south shore, for 1.3 million gallons per day from the Benicia side and for one million gallons per day in the refinery wash line. A system of such capacity would be capable of handling approximately two and one-half times the present needs.

Rough estimates indicate that the outlay required for such a project of sewage diversion of the above capacity would be approximately $3,800,000. The annual cost of the system, based on capacity operation, is figured at $400,000, or $68.50 per million gallons. This is not at all unreasonable for sewage disposal alone, without considering the special advantages in water supply that complete sewage disposal would bring.

One of the outstanding precedents for sewage diversion is in Chicago. While still a small city, it went to the expense of diverting its sewage out of the Lake Michigan Basin at a cost of about $90,000,000. The city has never regretted this expenditure. It may be mentioned, too, that it has been necessary in recent years to divert more and more sewage below the Charles River Basin Dam at Boston in order to maintain proper sanitary conditions for the recreational activities for which the lake above the dam is dedicated. This was not necessary in the early operations of the structure.

Conservation of Sewage Water.—In the project of sewage diversion below a barrier, approximately thirty million gallons per day of the more harmless waste waters would be conserved above a barrier at the present time, but approximately six million gallons per day of the stronger wastes, disposed of below a barrier, would be lost to beneficial use. In the course of fifteen to twenty-five years, the quantities lost might reasonably double or even treble. It has been suggested that it would be desirable to consider full conservation of all wastes behind a barrier. This would require a different scheme of sewerage, which should hinge on developing a sewage disposal as far as possible from domestic and industrial water supply intakes and also as far as possible from usable shores. Assuming that a barrier be built at the Dillon Point site, such a project has been laid out.

This project would intercept the sanitary sewage, organic wastes and refractory chemical wastes from the south shore of Suisun Bay and pump them under the bay to Chipps Island. The sewage would be treated there in settling tanks and the effluent dispersed through several outlets into Honker Bay. Wash waters from the refineries would be carried in a separate pipe line and emptied just below the barrier. Rough estimates indicate that such a project, laid out on the same basis of flows as assumed for the plan of sewage diversion below a barrier, would cost in the neighborhood of $2,225,000 for the south shore, and $225,000 for the Benicia side, or a total of $2,450,000. The annual cost of the south shore system, based on an average annual flow of 13.7 million gallons per day in the sanitary sewer and one million gallons per day of refinery wash water, is figured at $247,000, or about $46 per million gallons. For the Benicia side, annual costs, based on an average of 1.3 million gallons per day, are figured at $59.20 per million gallons. For both shores the annual costs are figured at $275,-000, or $47.20 per million gallons.

It is difficult to predict how satisfactory such a sewage disposal scheme would prove. It should be anticipated that the pollution load on Honker and Suisun bays, even after the sewage treatment proposed, would eventually equal that of 375,000 persons. In Honker Bay the waters are shallow and opportunities for dispersal are not the best. Furthermore, the concentration of sulphates in the wastes of industries already located along the south shore is conducive to odor production out of the ordinary. Since septic areas in the dispersal field undoubtedly would occur, the nuisance would be widespread. The project, therefore, is not offered with confidence. Diversion of the sewage below a barrier would be the safer method. If this project of maximum conservation of the water values behind the barrier should be entered into, it should by all means contemplate the eventual necessity of sewage oxidation works in addition to mere sewage desludging. The additional expense required for complete treatment would approximate $500,000 and the added annual cost would be in the neighborhood of $200,000. With this refinement of treatment, the project should be tenable on sanitary grounds. It would be necessary to decide whether the added annual cost would justify the conservation of the 5500 million gallons of water per year, which the project would make possible.

Sewerage for the Area Above Point San Pablo.

The discussion of the preceding projects was based upon a barrier located in Carquinez Strait. In the event that a barrier were placed below San Pablo Bay, such as at Point San Pablo, the sewage disposal of Crockett, Vallejo, Mare Island, Napa, Petaluma, part of Richmond and several other communities would become affected. All these places sewer without treatment into San Pablo Bay or tributary channels. The survey indicates a human population of about 30,000 and an industrial waste equivalent, practically constant throughout the year, of about 81,000 people thus sewering to San Pablo Bay.

Napa and Petaluma both sewer into what amounts to the head end of small tidal slough systems. Sewerage conditions are already bad at both places but, for the present, appear to be tenable. It is probable sewage disposal improvements would be precipitated at Napa and the Napa State Hospital if tidal influence were eliminated. Elsewhere water front conditions on San Pablo Bay are fair to good at present. Inasmuch as sewer outlets are short and there is no sewage treatment, all these places would have to make changes if the tidal currents were excluded from San Pablo Bay.

Complete interception, treatment and disposal below a barrier at Point San Pablo, of all sewage and injurious industrial wastes would be a huge project. Obviously, it would set a higher standard of cleanliness for San Pablo Bay. To keep the bay waters below Point San Pablo clean an outfall into the bay one and a half to two miles long is considered necessary. A rough estimate of outlay, probably not conservative, for complete interception and treatment of all sewage and injurious industrial wastes on both sides of the bay, amounting to an average of 29 million gallons per day with delivery 8000 feet offshore below Point San Pablo, is $6,800,000. The annual cost is figured at $780,000, or about $74 per million gallons. Oil refinery wash water would be disposed of in San Pablo Bay under these estimates. It is contemplated that the Benicia-Vallejo area could be served by a line crossing on Carquinez Bridge.

In the preceding chapter it was shown that the population equivalent of the sewage and wastes now produced in the area adjacent to Suisun and San Pablo bays is 260,000 persons in round numbers. A pollutional load equal to that of fully 800,000 should be counted on within the life of the system.

Conservation of Sewage Water.—With a barrier at the Point San Pablo site, approximately twice as much water could be saved for reuse as with a barrier at Dillon Point. The value of the water so conserved would have to be balanced against the additional cost of treatment necessary to prevent contamination of the barrier lake.

The problem of sewage disposal from Martinez to the mouth of Carquinez Strait, including Vallejo and Mare Island on the north, would be decidedly baffling and expensive, because of the long sewers required, the dearth of sewage treatment sites and the desirability of keeping the fresh water of Carquinez Strait fairly clean. Interception of the sewage, together with multiple pumping plants, desludging works and long outfalls discharging into San Pablo Bay proper, is the most reasonable type of project that can be outlined for these conditions.

The Vallejo-Benicia area would have a similar disposal problem to work out. That part of the Richmond sewage now disposed of by emptying into the bay and which would be caught behind such a barrier could be diverted westerly with comparative ease to a point below the barrier. This plan of sewerage, like the others that have been outlined heretofore, would contemplate keeping the shores free of sewage so that water supply projects would not be difficult or unwieldly. The success of this scheme would lie in desludging treatment, plus long outfalls to San Pablo Bay, which is very wide. No estimates have been made for such a project. It probably would be somewhat less costly than complete diversion of all the sewage below Point San Pablo.

APPENDIX F

THE FISHING INDUSTRY

With Special Reference to a

SALT WATER BARRIER

Below Confluence of Sacramento and San Joaquin Rivers

TABLE OF CONTENTS

LETTER OF TRANSMITTAL

MR. EDWARD HYATT,
State Engineer,
Sacramento, California.

DEAR SIR: In compliance with your request, there is transmitted herewith a report on "The Fishing Industry with Special Reference to a Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers." The report was prepared by N. B. Scofield, who is in charge of the Bureau of Commercial Fisheries.

The report presents information on the fishing industry and the principal species of commercial fish in San Francisco Bay and the Sacramento and San Joaquin rivers, and deals with the effect that a salt water barrier, if constructed, might have on fish life and the fishing industry.

Respectfully submitted.

John L. Farley

Executive Officer,
Division of Fish and Game,
California State Department of
Natural Resources.

Sacramento, California,
January 2, 1931.

ORGANIZATION

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF FISH AND GAME

F. G. STEVENOT-------------------------*Director of Natural Resources*

JOHN L. FARLEY---------*Executive Officer, Division of Fish and Game*

The report covered by this appendix was prepared by

N. B. SCOFIELD
Chief, Bureau of Commercial Fisheries

FISHING INDUSTRY

The waters included in the San Francisco Bay region and tributary rivers are the largest inland commercial fisheries of the State of California. The fish within these waters are a natural resource of much importance. Serious consideration should be given to any development which might adversely affect the continuance of this resource. The erection of a salt water barrier in tide water would be such a development.

These waters are the entering area for a vast number of migrating fish. It is here also that the young fish, while on their way to the sea, must become gradually accustomed to salt water before their migration into the ocean. The disturbance of the existing condition of a gradually increasing saline content in the waters, from the fresh water of the spawning reaches of the rivers to the salt water of the ocean, where the greater portion of the adult life of the fish is spent, might well be detrimental not only to the fishing industry within the delta and upper bay area, but to ocean fishing as well.

There are three important bay and river fisheries, all of which would be affected by the building of a salt water barrier below the confluence of the Sacramento and San Joaquin rivers. These are the salmon, shad and striped bass. Fisheries of less economic importance, but which would be affected by such a barrier, are the sturgeon and the soft shell clam.

The four fish mentioned are anadromous, entering the bay and continuing up the rivers in the spring or fall for the purpose of spawning. The resulting young must find their way to the ocean. None of these fish can exist unless they are permitted to pass back and forth between salt and fresh water. Commercial fishing is carried on in the bays and in the rivers as far upstream as Sacramento and Stockton. Commercial fishing has been prohibited above these two points, and in most of the sloughs and tributaries, in the interest of conservation. There are many other restrictive laws, all of which are designed to permit a sufficient number of the fish to escape the nets of the fishermen and to reach their spawning grounds farther up the rivers, and thus perpetuate the supply of each species.

Importance of Commercial Fishing Industry.

The importance of the fishing industry in the upper San Francisco Bay and Sacramento-San Joaquin Delta region can be best measured by the commercial interests involved. Recreational fishing in the area is of importance, but no definite figures are available as to the amount of catch nor capital involved.

The licensed commercial fishermen in Solano, Yolo, Sacramento, San Joaquin, Contra Costa and Alameda counties, who fish in San Pablo Bay, Suisun Bay and the Sacramento and San Joaquin rivers, definitely gain their livelihood from the fishing industry. The numbers so licensed during the 1928–1929 year were as follows:

Solano-Yolo	117
Sacramento-San Joaquin	125
Alameda-Contra Costa	303
Total	545

Probably 50 of these fishermen were engaged in taking catfish, or working out of Oakland and Richmond, and would not be affected to any great extent if a salt water barrier were built and in any way influenced the salmon, striped bass and shad fisheries. Other people engaged in cannery and packing activities, however, would be affected.

Capital invested in the fishing industry would be affected by any detrimental influence upon the fisheries. Plant investment would have small salvage value, although equipment could be largely salvaged. The capital invested in this area in 1929 is estimated as follows:

Plant	*Estimated value*
Pittsburg, six plants	$160,000
Stockton, two plants	30,000
Sacramento, one plant	10,000
Martinez, Benicia, Rio Vista, Walnut Grove	5,000
Subtotal	$205,000
Equipment	
275 boats, fishing and pick-up	$412,500
550 gill nets and trammel nets	151,500
300 fyke nets	6,925
Subtotal	$570,925
Total, plants and equipment	$775,925

The annual catch in pounds of commercial fish for the year 1928 in the upper San Francisco Bay and Sacramento-San Joaquin Delta, divided into the principal species taken, was as follows:

District	*Shad in pounds*	*Salmon in pounds*	*Striped bass in pounds*	*Total commercial catch in pounds*
Solano-Yolo	334,973	116,485	43,712	514,553
Sacramento-San Joaquin	103,058	180,679	126,333	736,834
Contra Costa-Alameda	1,567,977	256,613	298,551	2,332,911
Totals	2,006,008	553,777	468,596	3,584,298

Of the total catch taken from this area in 1928, 3,028,371 pounds were of the three species separately listed, while the miscellaneous species taken amounted to 555,927 pounds. Of this latter figure, the catfish taken amounted to 384,475 pounds and carp accounted for 81,533 pounds.

Principal Species of Anadromous Fish.

The three important commercial fish and the sturgeon are the principal anadromous species entering the fresh waters of the rivers from the salt water of the ocean. Each of these has separate characteristics, knowledge of which is pertinent to determining the affect of a salt water barrier upon its continued existence.

Salmon.—The King or Chinook is the only species of salmon entering the Sacramento-San Joaquin River system. The salmon fishery is the oldest in the State and for a long time was the most important. The salmon runs in the Sacramento River have been greatly reduced by several causes, chief among which are the building of power and irrigation dams, which have shut the fish off from much of their spawning grounds, and too intensive fishing within the bays and rivers and in the open sea. It still is hoped that, with more restricted fishing and with better fishways and screens at dams, the salmon runs can again be built up so as to furnish ten to fifteen million pounds of food annually, as they did in former years.

The salmon enter the bays and pass Carquinez Strait in two fairly distinct runs. The spring run occurs in April and May, and the fall run in August and September. Of these two runs, the fall run is much the larger. After spawning in the headwaters, the salmon die. The young salmon hatch from the eggs and begin their seaward migration in November and continue until hot weather in midsummer.

Salmon hatcheries and spawn-taking stations are maintained by the United States Bureau of Fisheries on Mill Creek, near Tehama; Battle Creek, near Anderson, and on McCloud River at Baird. The State maintains salmon hatcheries at Mt. Shasta. The investment in these stations, including the land, is estimated roughly at $300,000.

*Shad.**—The shad is an introduced fish. In 1871 a shipment of 12,000 fry, taken from the Hudson River in New York, was planted in the Sacramento River near Tehama by the California Fish and Game Commission. Subsequent plantings continued to 1880. From this comparatively small beginning the shad have distributed themselves along the Pacific Coast from San Pedro, in southern California, to southeastern Alaska.

The shad fishery in California is carried on almost entirely in San Francisco Bay and adjacent river localities. The catches made outside of these regions amount to very little, not more than 2000 pounds, and usually not over 200 pounds per year. The catch is divided into three classes:

1. When no distinction of the catch is made, the fish are termed "unclassified";
2. The "roe shad" (female fish); and
3. "Buck shad" (male fish).

The higher price is paid for the females because shad roe is highly prized as a delicate food and more than half of the catch is classified as "roe shad."

San Francisco Bay and the adjacent river region seem to be advantageously suited to the shad, for they have increased to large numbers since their introduction into these waters. They enter the bays in February and March and, for a time, feed on small shrimps and similar food before continuing their spawning migration up the rivers. This run continues until near the end of June. The young, after hatching, drift dowstream, reaching the bays in August and September. The shad are seldom caught in the open sea.

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* Shad in California, Nidever, H. B.; California Fish and Game, Vol. 2, No. 2, p. 59; 1916.

Over four million pounds of shad have been taken in a single season. The supply at one time was seriously depleted by too much fishing, but after establishing a closed season, beginning the middle of May, the run has increased until it is believed that three or four million pounds could be taken each year without again endangering the supply.

*Striped Bass.**—The striped bass was introduced into California from the eastern coast in 1879. when a planting of 135 small and medium sized fish was liberated in Carquinez Strait near Martinez. A second and final planting was made in 1882, when about 300 fish were released in Suisun Bay near Army Point. From this meager beginning the present population of striped bass has developed. The range of the striped bass on the Pacific Coast is from San Diego to Coos Bay, Oregon. However, the largest number of this species are caught in the San Francisco Bay and Sacramento-San Joaquin Delta region, only a few being caught in Marin County and in Monterey Bay.

The spawning migration of striped bass enters the bay and rivers in the spring. They spawn in fresh water, as do the shad and salmon, although they do not run as far up the streams. They spawn in June and July. The eggs hatch in a few days and the young drift with the current to the bays, where they feed in the brackish water until winter, when most of them take to the ocean. Some remain in the brackish water of the bays until the second winter before they run to the ocean. There is another migration of fish from the ocean into fresh water during the fall for the purpose of feeding.

The striped bass supply is gradually increasing under the present fishing restrictions. The commercial fishing has been reduced greatly by legislation. The catch by anglers, however, has increased until it is believed it is much greater than that of the commercial fishermen but there are no accurate data except of the commercial catch. Ten years ago, when there was not as much bass angling as today, the commercial catch in the bays and rivers was nearly 1,400,000 pounds, and it is fairly certain this amount of fish will be available to anglers and commercial fishermen annually, if the conditions can be maintained as at present.

Sturgeon.—The sturgeon enter the bays from the ocean and feed in the brackish water on crustaceans and clams a good part of the year. They ascend the river well above Sacramento in the spring and spawn in deep pools in June. In the early history of the state's fisheries, the sturgeon was next in importance to the salmon, but they soon were almost exterminated by reckless fishing. They have been protected by a perpetual closed season for several years, and now have no commercial importance. It is doubtful if they ever will recover sufficiently to again permit their being taken commercially.

Effect of a Salt Water Barrier.

Salmon will pass up fishways over low barriers, such as the one proposed, if these fishways are properly installed. The salmon, however, must be able to easily find and enter the fishways. The lower side of a barrier should not have pockets between abutments where fresh water

* The Striped Bass in California; Scofield, N. B., and Bryant, H. C.; California Fish and Game, Vol. 12, No. 2, p. 65; 1916.

would flow or leak through. The salmon might enter such pockets and kill themselves trying to leap the barrier or be prevented from moving along the face of the barrier until they reach a fishway. Any barrier would be a detriment to salmon, no matter how carefully the fishways were built or maintained. A migrating adult salmon can not pass suddenly from salt to fresh water. If there were not a sufficient intergradation of brackish water, adult salmon would not be able to make the passage of the barrier.

It is extremely doubtful if striped bass and shad could be induced to pass over a barrier by any of the known fishways. The barrier gates might be open when these fish were on their spawning migration, but, if not, it is probable that the spawning migration would be almost or entirely prevented.

The young salmon migrating seaward would experience difficulty in getting to the ocean if a sufficient current did not exist during the winter months to lead them past a barrier. If the impounding of the water above a barrier should tend to raise the temperature of the water, young salmon might be destroyed.

The food supply for the young salmon and both the young and adult striped bass and shad might be seriously affected by the elimination of the tidal flow of brackish water over the shallow mud flats and in the sloughs of the upper bays. Adult salmon do not feed after entering the bay so a barrier would not affect them as far as food is concerned. This matter of food supply should be the subject of study, as it is possible the rich feeding grounds in San Pablo and Suisun bays and tributary sloughs might be eliminated if the present brackish water areas over the shallow mud flats and in the sloughs were changed to fresh water or salt water above and below a barrier, respectively. Such a change in conditions would have a profound effect on the minute marine life which furnishes the basic food supply for these migrating fish.

Catfish and carp, which are of minor commercial importance, probably would not be affected by construction of a salt water barrier. On the other hand, the soft-shelled clam, which is of some minor commercial value, would be eliminated from the areas above a barrier and possibly also from the areas below a barrier, depending upon whether proper brackish water and tidal flow conditions required for the same would be available with a barrier in operation.

Conclusion.

A salt water barrier would seriously interfere with the free migration and propagation of the anadromous species of fish—salmon, shad and striped bass—which enter the bays and river channels to spawn. It also would materially change the brackish areas of the shallow waters over the flats and in the sloughs of the upper bay and possibly eliminate the minute marine life which furnishes the basic food supply required by the young salmon and by both the young and adult shad and striped bass. Therefore, it is concluded that a salt water barrier would have a detrimental effect upon the fishing industry in upper San Francisco Bay and the lower channels of the Sacramento and San Joaquin rivers.

PUBLICATIONS

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PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

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*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.

*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.

*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.

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*Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.

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*Bulletin No. 2—Irrigation Districts in California, 1887–1915.

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*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.

*Bulletin No. 5—Report on the Utilization of Mojave River for Irrigation in Victor Valley, California, 1918.

*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).

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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922.
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Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
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Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
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Bulletin No. 24—A Proposed Major Development on American River, 1929.
Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
Bulletin No. 28—Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, 1931.
Bulletin No. 28-A—Industrial Survey of Upper San Francisco Bay Area, 1930.
Bulletin No. 31—Santa Ana River Basin, 1930.
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*Report on Lower Pit River Project, July, 1915.

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*Report on Iron Canyon Project, California, May, 1920.

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Conclusions and Recommendations of the Report of the California Irrigation and Reclamation Financing and Refinancing Commission, 1930.

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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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