STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

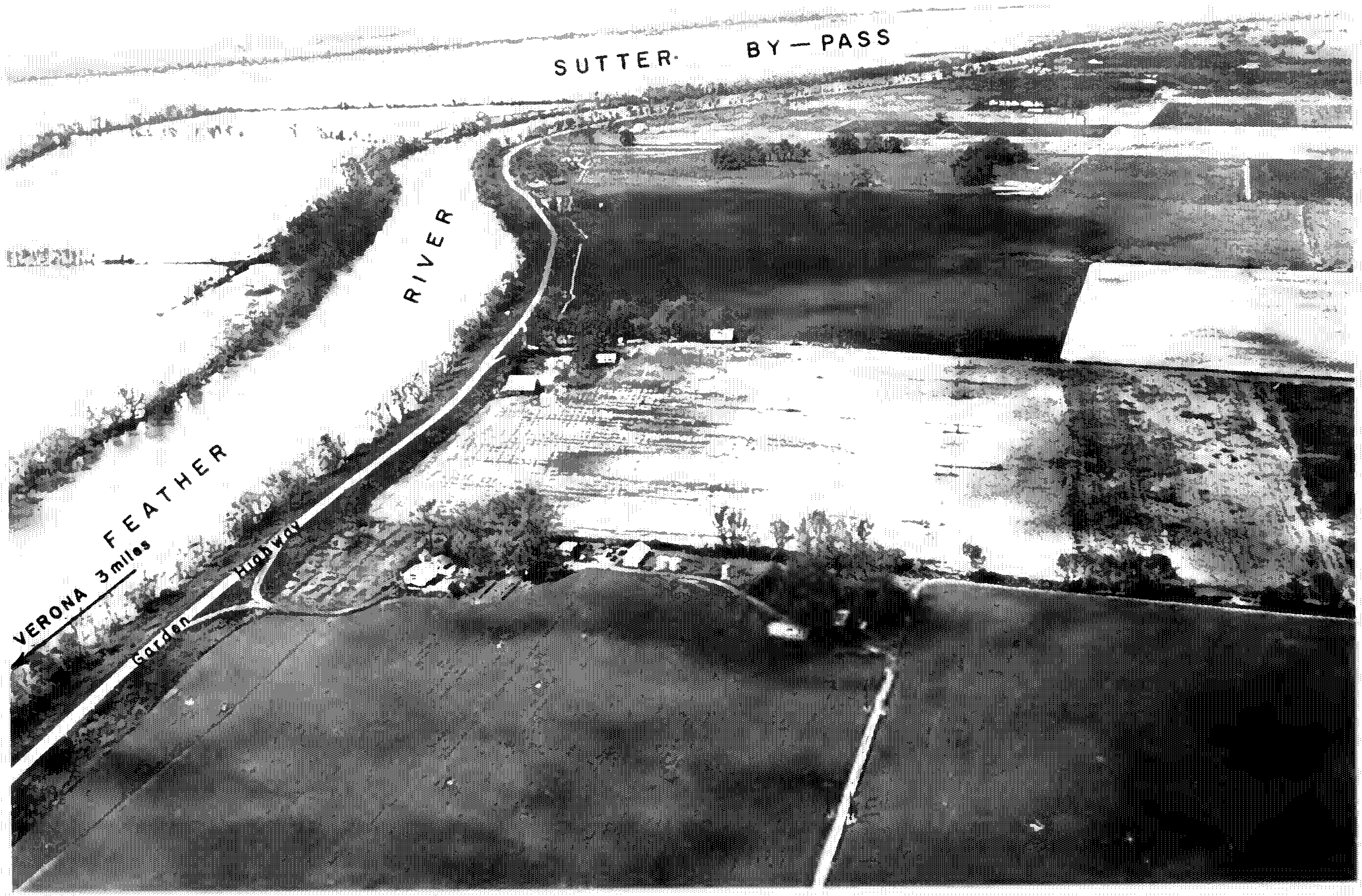
BULLETIN No. 125

SACRAMENTO VALLEY SEEPAGE INVESTIGATION

AUGUST 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources



DFCG-6

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FOREWORD

This report presents the results of an investigation of seepage conditions along the Sacramento and Feather Rivers in the Sacramento Valley and was prepared under authority of Sections 12627.3 and 12627.4 of the Water Code. The study area extended on the north from the vicinity of Ord Ferry on the Sacramento River and just north of Marysville on the Feather River to Walnut Grove on the south.

Available seepage data was reviewed and new data on seepage conditions was collected for the period 1959 through 1965. Moreover, data on the economic effects of seepage was compiled. This data was analyzed and guidelines were developed for estimating seepage conditions under various river regimen.

The information in this report will be of value in predicting future seepage conditions resulting from additional development of California's water resources. It also will be of value in planning remedial works to alleviate seepage conditions.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
State of California
June 14, 1967

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ACKNOWLEDGMENT

Valuable assistance and cooperation was received during the investigation from numerous agencies and individuals. Landowners along the rivers allowed the installation of observation wells in their fields and furnished information on seepage damage. Without the landowners' cooperation much information vital to this investigation could not have been obtained. Assistance from the various county farm advisors and reclamation districts also was important to successful completion of the investigation.

STATE OF CALIFORNIA
The Resources Agency
DEPARTMENT OF WATER RESOURCES

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WILLIAM R. GIANELLI, Director, Department of Water Resources
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ABSTRACT

Seepage occurs nearly every year along the Sacramento River system, and may persist for extensive periods, causing considerable damage. Future water development projects will modify the flow of the Sacramento River system and change the present level of seepage. Considerable concern has been expressed about the effects of both present and possible future seepage. This long-standing concern, stimulated by the extensive seepage damage which occurred in the spring of 1958, culminated in legislative authorization of this investigation. The investigation was conducted to: (1) document present seepage conditions for the purpose of providing a base for evaluating the effects of future water development projects on seepage, (2) develop relationships between river regimen and seepage conditions to aid in determining the most advantageous operating criteria for future upstream water development projects, (3) estimate the effects on seepage conditions of changed river regimen which could result from operation of future water projects, (4) determine whether need exists for detailed studies that would lead to authorization of seepage mitigation measures. /To attain the objectives of the investigation it was necessary to gather and analyze hydrologic, geologic, topographic and economic information pertaining to seepage, and from these data to develop relationships between riverflow and seepage conditions. Since the dynamic influence of the river on seepage conditions had not been studied before in detail, it was necessary to develop new methods of data collection and analysis. A technique was developed combining the use of infrared aerial photography to delineate seepage areas and the use of electrical resistivity measurements of the subsurface strata to define lateral seepage boundaries. This technique proved to be rapid, accurate, and low in cost. /The extent and damage resulting from six measured seepage occurrences were estimated. Guidelines were developed for estimating seepage conditions under various river regimen. The influence of Oroville reservoir and modified riverflows on seepage conditions were evaluated. /The major findings of the investigation were: (1) the present effects of seepage are greater on agriculture than on the urban economy; (2) operation of Oroville reservoir should reduce seepage along the Feather River, except for that attributable to high flows of long duration which will not be changed significantly; (3) operation of Oroville reservoir should reduce the probability of seepage and seepage damage along the Feather River from December through June; (4) seepage does not presently occur along the Feather River in the summer and should not occur in the future in the summer with Oroville reservoir in operation; (5) effects of the Oroville operation on seepage should be documented by a 5-year post-operative study; (6) a maximum flow of approximately 9,000 cubic feet per second can be conveyed down the Sacramento River for considerable periods without causing seepage; (7) under foreseeable conditions, there should not be any seepage along the Sacramento River attributable to importation of water prior to about 1990 and imported water should not influence seepage conditions during the winter; (8) a drainage system adjacent to the Sacramento River should be the best method for controlling possible future summer seepage; (9) alternate routes other than the Sacramento River should be considered for conveying imported water from developments which will become operational after about 1990; (10) there is no need for state action at this time to mitigate seepage, but there are areas where seepage alleviation facilities should be given further consideration by individuals or local agencies.

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CHAPTER I

SUMMARY AND CONCLUSIONS

The Sacramento Valley is a broad, gentle expanse, located between the Sierra-Nevada to the east and the Coast Range to the west. The Sacramento River, the principal watercourse in the valley, originates near Mount Shasta and flows southerly through the Sacramento-San Joaquin Delta to the Pacific Ocean.

The Sacramento River system has been extensively leveed in the valley to contain floodwaters which primarily result from snowmelt in the Sierra-Nevada and from intense rainfall in the foothills. During periods of high runoff, the waters confined within the levees are frequently higher than the surface of adjoining lands. When this occurs for more than a short period of time, water seeps under and through the levees, saturating the lands abutting the levees and often ponding on the land surface.

Seepage has a considerable adverse effect on the economy, particularly in agricultural areas. Seepage damages orchards and perennial crops and delays or prevents the normal planting of annual crops. Lands frequently subjected to seepage are often not utilized to their maximum extent. Seepage also necessitates construction of drainage facilities and the operating and maintenance of these facilities. It also has many lesser effects such as increasing the construction costs of buildings, roads, and airports, and sometime delays urban development.

The term seepage is frequently used in more than one sense. In its broadest meaning, and as most commonly applied, seepage is used to describe the high ground water table and any surface water which result in part from percolate from the river channels and in part from local rainfall and runoff. Seepage has also been used in a more restricted sense to describe the water which results from percolation through or under levees, appearing as surface water or ground water within the root zone on lands adjacent to the levees.

In this investigation "seepage" is defined in the more restrictive sense--that is, water on or near the ground surface on the landside of leveed watercourses which is attributable to percolation from the confined channels. A typical seepage situation is illustrated on Figure 1.

Historical Seepage Conditions

Prior to construction of levees along the river channels in the Sacramento Valley, floodwaters often nearly covered the valley in a continuous sheet, overflowing the natural levees which had been built up by the rivers. Early efforts at land reclamation consisted of construction of low levees on the natural levees. These levees confined floodwaters within narrower bounds with resultant increased elevations of the head of water against the levees. This caused an increase in seepage through and under the natural levees. When the stage increased sufficiently, seepage also occurred through the man-made levees.

At the time California was admitted to the Union, waterlogging occurred in many areas along the Sacramento River. There was not much concern about this seepage until years later when the affected lands were more extensively developed. Records of historic river stages indicate that seepage could have occurred to some degree in a number of years, but

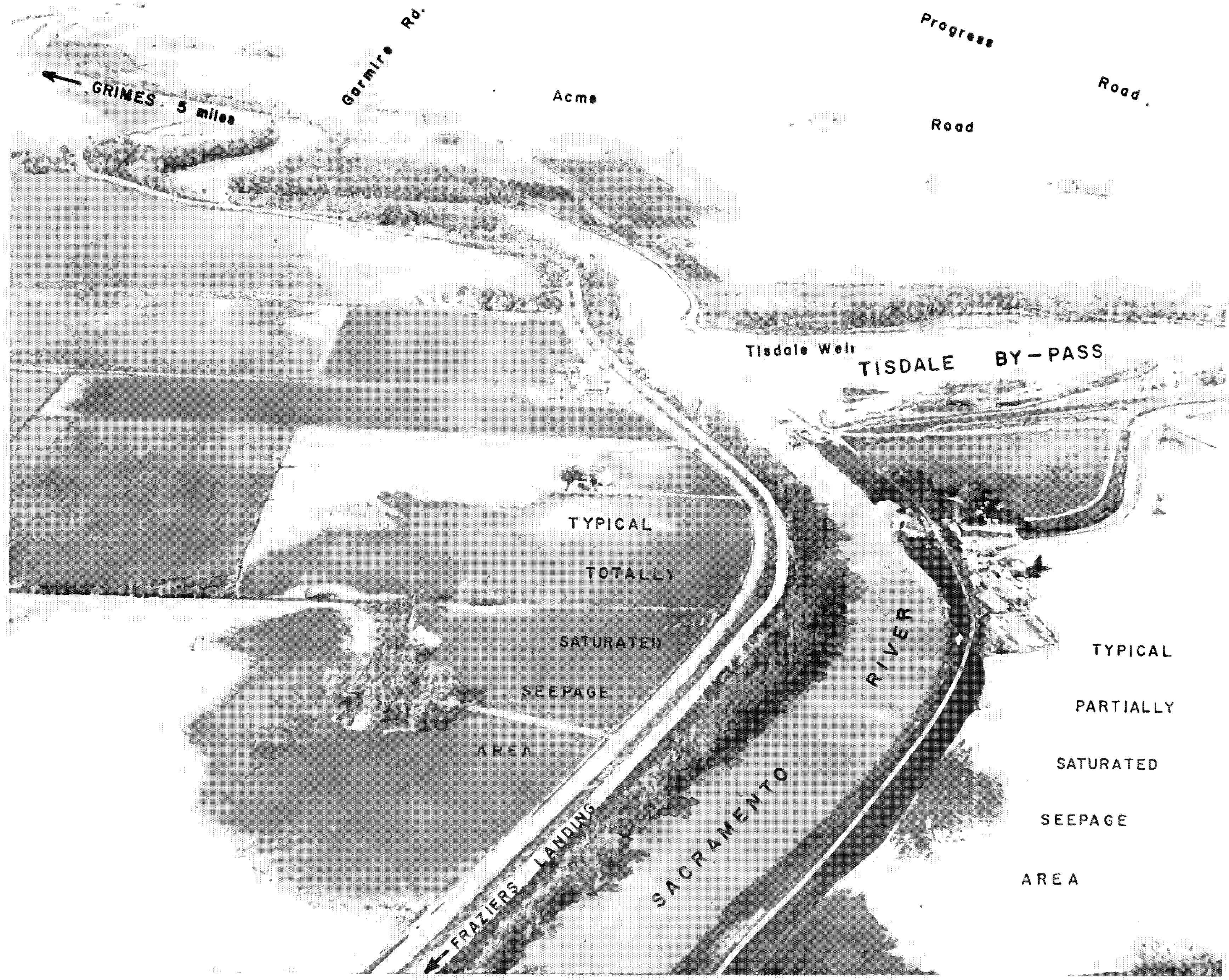


Figure 1. Seepage along the Sacramento River near Tisdale Weir.

no seepage was reported prior to 1937. After the high river stages in 1937-38, there was great concern over the resultant damages from seepage to thousands of acres of crops. A report by the former Division of Water Resources on conditions in April 1938 states:

> ". . . The condition in the district north and south of (Reclamation District) No. 70 is comparable. Most peaches are dying. The annual crop land close to the river is normally double crop land, beets being the first, then peas or some later crop, but with present conditions the beets cannot be planted. . . ."

Following that year, no significant seepage damage occurred until January 1940. Flows during 1940 and 1941 again were of sufficient magnitude and duration to cause extensive seepage and severe damage. Because of the increased interest in seepage and concern over the effects of the newly completed Shasta Reservoir, the United States Bureau of Reclamation in 1941 initiated a survey of seepage and ground water conditions along the Sacramento River from Stony Creek to Knights Landing. The Bureau collected data intensively for a 7-year period. After 1948, observations of seepage were continued on a limited basis. The Bureau has also investigated and reported upon ground water conditions in the lower Sacramento Valley and the Sacramento-San Joaquin Delta. Valuable surveys of seepage and seepage damage have also been made by other agencies, including the U. S. Army, Corps of Engineers and the University of California. The significant reports of previous investigations are listed in the Bibliography.

Need and Authorization for the Study

Seepage occurs nearly every year along the Sacramento River system and may persist for extensive periods, causing considerable damage.

Furthermore, large water development projects are being planned and constructed to sustain the rapid increase in water demands throughout California. These water development projects will alter the flows in the Sacramento River system which, in turn, will alter the amount of seepage and seepage damage which may occur in the future. Landowners in the Sacramento Valley have expressed considerable concern about both present and possible future seepage and its effects.

Because of this concern and the extensive seepage damage which resulted from the high flows that occurred during the spring of 1958, the Legislature in 1959 added to the California Water Code two significant sections concerning seepage. Section 12627.3 established state policy that the costs of solving seepage problems which arise or will arise from construction and operation of a water project shall be borne by the project. Section 12627.4 enjoined the Department to anticipate seepage problems which may arise from future construction and operation of water projects and to include plans for the solution of seepage problems as part of the project development. The Legislature also authorized this investigation and appropriated funds to initiate the investigation. Work was started in October 1959.

As is required by Section 12627.4 of the Water Code, a substantial portion of this investigation was conducted as an integral part of the planning of the State Water Project to determine the seepage problems which may arise in connection with project construction and operation. The information and data obtained from this investigation will be invaluable in examining and evaluating any claims which may be made that the State Water Project is causing seepage problems.

Objectives of the Investigation

The Sacramento Valley Seepage Investigation was conducted for the following purposes:

1. To document seepage conditions along the Sacramento and Feather Rivers as they exist prior to operation of Oroville reservoir and other units of the State Water Resources Development System. This information will provide a basis for determining the effects of the Oroville facilities and subsequent water development projects on seepage.

2. To develop relationships between river stage and duration, and seepage conditions. This information will aid in determining the most advantageous criteria for coordinated operation of Oroville reservoir and subsequent projects, based on all project purposes including consideration of seepage.

3. To estimate the effects on seepage conditions of changed river regimen which could result from the operation of future water development projects.

4. To determine whether need exists for detailed studies that would lead to authorization of seepage mitigation measures and to indicate the reaches where these studies should be undertaken.

Area of Investigation

The area directly affected by seepage from the Sacramento River system generally extends as far out as one mile on each side of the rivers and bypasses.

The study area, as shown on Plate 1, "Area of Investigation", consists of continuous strips of land on the landward side of the river levees. The strips average about 2 miles in width measured from the levee on either side of the watercourse and were selected to extend beyond the actual seepage area. The entire area of investigation totals about 625 square miles.

The investigated area is bound on the north by Ord Ferry, about 11 miles southwest of Chico on the Sacramento River, and a point just north of Marysville on the Feather River. Very little seepage occurs north of the study area because the land generally lies well above river level. Seepage south of Walnut Grove is being studied as part of the comprehensive investigation of the Delta facilities of the State Water Project. Therefore, the southern boundary was established at Walnut Grove.

Lands bordering the Tisdale, Yolo, and Sutter Bypasses; the Colusa River Drain, and the Knights Landing Ridge Cut are also included in the study area, as are lands along the lower reaches of the Yuba, Bear, and American Rivers. Lands abutting the various channels in the Sacramento-San Joaquin Delta north of Walnut Grove are also included. Lands on the river side of the levees and within the bypasses were not studied, as these areas are inundated by flooding rather than by seepage during high river stages.

Conduct of Investigation

The dynamic influence of river and ground water conditions on seepage and the economic effects of seepage had not been studied in detail prior to this investigation. Therefore, new methods had to be developed for collecting and analyzing data on seepage and the economic effects of seepage. The early phases of the investigation were devoted to the collection and interpretation of basic information fundamental to the study. Analyses were conducted as the concluding phase of the investigation.

Information compiled during previous investigations was reviewed and a data collection program was developed. Many types of data were obtained, the most important being river and bypass flows; ground water levels near the watercourses; the location, areal extent, and duration of seepage; measurement of the relative potential of various areas along the watercourses to seep; and information concerning the economic effects of seepage.

Additional staff gages were installed along the watercourses in the valley and high flow stages were recorded. Staff gages along the Sacramento and Feather Rivers were placed on a common elevation datum so that water surface profiles could be correlated with ground water elevations.

Ground water observation wells and piezometers installed during prior investigations by the U. S. Bureau of Reclamation, U. S. Army Corps of Engineers, Department of Water Resources, reclamation districts, and county farm advisors were measured as a network to determine ground water levels.

The electrical resistivity of the subsurface strata adjacent to the watercourses was measured to determine the relative potential of the various areas to seep. The lateral boundaries of the seepage areas were delineated from this information.

A considerable quantity of economic information was compiled and used to determine the effect of seepage on the agricultural and urban economies.

Seepage adjacent to the Sacramento River system was field mapped during flows of high stage and long duration. During these periods, seepage was also recorded by aerial photographic methods using infrared film with various filter combinations to create contrast and to intensify the imagery of seepage areas. Photointerpretation techniques for identification of seepage areas were developed during the investigation. Seepage areas were delineated for six different seepage occurrences.

Statistical correlations between riverflow conditions and areas of seepage were developed. These correlations were based on measured riverflows and seepage areas that were identified on aerial photographs and verified by field observations. These relationships were used to estimate seepage under present and proposed future river operating conditions.

Because the area covered by the investigation is large, special areas were selected for detailed examination. Eight areas, referred to as physical study areas, each selected to represent conditions in a much larger portion of the area of investigation, were established. Detailed topographic, hydrologic and geologic measurements were obtained in these areas. This approach allowed concentration of study in a limited number of areas and also enabled detailed instrumentation and subsurface exploration to be carried out within the cost limitations of the investigation.

Eleven economic study areas were selected. Farmers, county and urban officials, and others in each economic study area were interviewed to obtain information regarding seepage damage. In addition, crop yield tests were taken in these areas to determine the reduction in yields caused by seepage. The physical and economic study areas are shown on Plate 2.

Studies were made to estimate the economic impact of seepage. Since approximately 90 percent of the area is utilized for agriculture, most of the effort was devoted to determining the influence of seepage on the agricultural economy. However, the influence of seepage on the urban economy also was investigated.

Guidelines were developed for evaluating the impact of seepage on a particular crop. These guidelines are based upon three factors: the time of the year of the seepage occurrence, the duration of the seepage period, and the susceptibility of the particular crop to seepage damage under the foregoing conditions.

Finally, information developed during the investigation was used to evaluate the effect on seepage and seepage damage of the operation of Oroville reservoir and of increased summer flows which could result from future projects that might utilize the Sacramento River to convey water to the Sacramento-San Joaquin Delta.

Conclusions

1. Seepage from the Sacramento River system now has an effect on the economy of the State. The effect on agriculture is greater than on the urban economy.

2. Operation of Oroville reservoir should greatly reduce the magnitude of seepage along the Feather River caused by high flows of short duration. It should moderately reduce the magnitude of seepage caused by high flows of intermediate duration. Seepage resulting from high flows of long duration should not be changed significantly by the operation of Oroville reservoir.

3. Operation of Oroville reservoir should greatly reduce the probability of seepage and seepage damage occurring along the Feather River during April and May. The probability of seepage and seepage damage occurring during December, January, February, March, and June should be moderately reduced by the operation of Oroville reservoir.

4. Summer flows in the Feather River should not be large enough to cause seepage. With Oroville reservoir in operation, the maximum summer flow at Nicolaus should be about 6,000 cubic feet per second and should occur in August. Seepage normally does not occur along the Feather River when the flow at Nicolaus is less than 14,000 cubic feet per second.

5. Seepage conditions should be documented for at least 5 years after the Oroville facilities are in operation. The additional data will establish, to a higher degree of accuracy than is now possible, the effect of the operation of the Oroville facilities on seepage.

6. The approximate maximum flows that can be maintained in the Sacramento River for long durations without causing seepage in the top 4 feet of soil are as follows:

Colusa Weir to Fremont Weir	9,000 cfs
Fremont Weir to American River	15,000 cfs
American River to Hood	19,000 cfs

7. Use of the Sacramento River channel to convey imported water supplies will not influence seepage and seepage damage during the winter. It appears, however, that any material importation would contribute to summer seepage and damage. Under foreseeable conditions, this should not occur prior to about 1990.

8. A drainage system adjacent to the Sacramento River appears to be the best method for controlling possible future summer seepage. Based on conveyance of an assumed importation of 9,000 cubic feet per second in the Sacramento River, a drainage system would have to have a benefit-cost ratio of approximately 2.5:1. Moreover, a drainage system would also provide additional benefits by controlling winter seepage and by making possible the use of seepage to irrigate crops during the growing season.

9. Routes other than the Sacramento River should also be considered as possible alternatives for conveying imported water through the Sacramento Valley from developments which will become operational after about 1990.

10. There appears to be no need at this time for the State to make detailed studies which would lead to authorization of seepage mitigation facilities in the Sacramento Valley. There are, however, a number of localized areas adjacent to the Sacramento River, particularly between Colusa and Knights Landing, and the Feather River downstream from Nicolaus, where seepage alleviation facilities should be given further consideration, either by individuals or local agencies.

Office Reports

Detailed information on which this report is based is contained in the following Department of Water Resources office reports:

Sacramento Valley Seepage Investigation
Data Collection and Analysis

Sacramento Valley Seepage Investigation
Geology

Sacramento Valley Seepage Investigation
Analog Modeling Study on Seepage in the Sacramento Valley
and Computer Predicted Hydrographs

CHAPTER II

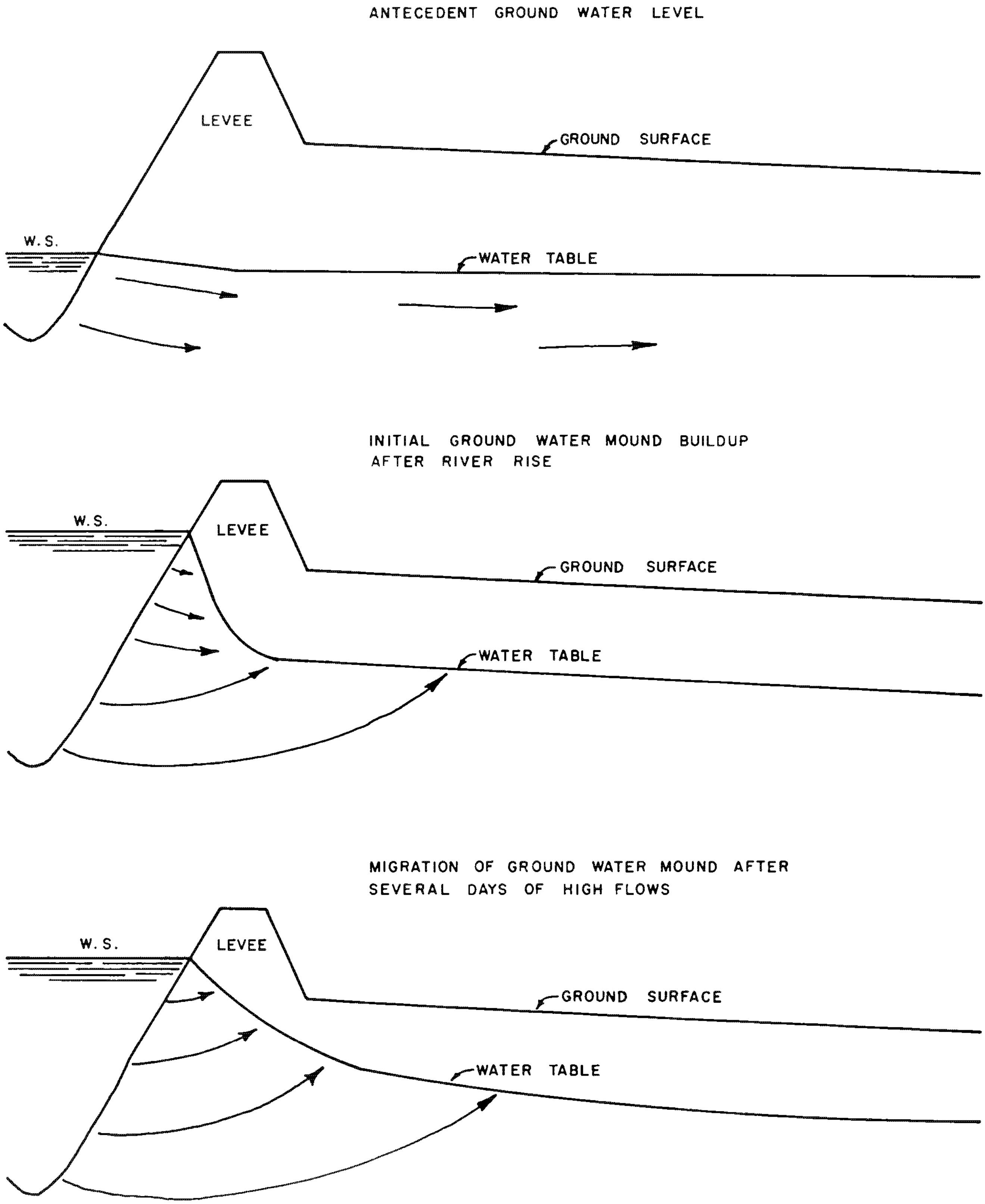
SEEPAGE AND SEEPAGE DAMAGE

There are many highly complex, interrelated and sometimes contradictory factors which affect seepage and seepage damage. The effects of some of these factors are understood, whereas others can only be surmised. Therefore, although generalizations can be made, each occurrence of seepage must be separately and individually considered in any detailed investigation of seepage and seepage damage. A discussion of these factors and their influence on seepage and seepage damage in the Sacramento Valley is included in this chapter.

Factors Influencing Seepage

Basically, seepage occurs when the differential head between the water surface in a leveed channel and the ground water table in hydraulic continuity with the water in the channel is maintained long enough to cause the ground water level to rise into the crop root zone.

Figure 2 shows how a ground water mound is formed causing seepage following a rise in water level in a river. During periods of relatively static low river stage, the ground water table is essentially at a constant level. That is, the amount of water entering the ground water body from the river is about equal to the amount of ground water flowing away from the river. As the river water surface rises above the ground water table, flow through or beneath the levee increases under the pressure of the steepened gradient and more water enters the ground water body than flows away. This causes the ground water table to rise rapidly



GROUND WATER MOUND BUILDUP

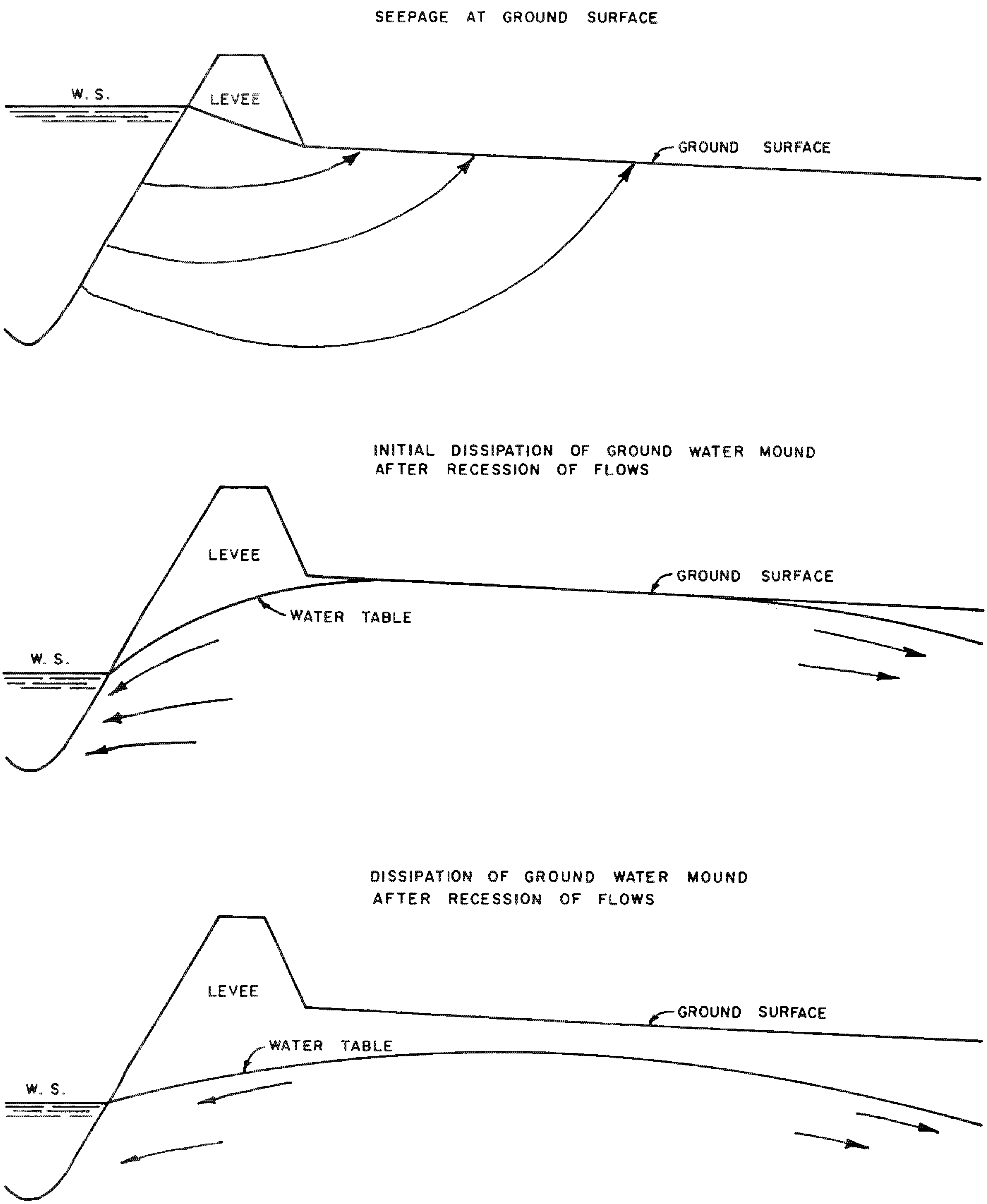
Figure 2

immediately adjacent to the channel. This wedge of water moves outward from the river, the height, distance, and rate of formation of the mound depending upon factors which are discussed later in this chapter. If the river remains high for a long period, the ground water will eventually reach a stable position. With a sufficiently high river stage, the ground water table could reach ground surface.

Figure 3 depicts the recession of the mound. When the river water surface drops, the ground water mound begins to dissipate. The ground water near the river starts flowing back to the river. The ground water at a greater distance from the river flows away from the river toward areas with lower ground water table elevations. The ground water mound dissipates fairly rapidly at first when the gradient is steep. As the mound flattens, with resultant reduced gradient, the rate of dissipation decreases. Eventually, the ground water table returns to a static level.

This idealized concept of the formation and dissipation of seepage is influenced by a number of factors. The six factors which have the greatest influence are the stage and duration of the river or contributory watercourse above a base level below which seepage does not occur; antecedent soil moisture conditions; topography of the land adjacent to the watercourse; geology and soils in the area; location and change in the ground water table; and drainage works in the area. These six factors are discussed in this chapter.

Other factors which influence seepage include the width and depth of the channel, height and width of the levee, agricultural practices in the seepage area, extent of the area covered by vegetation, and chemical quality of the seepage. Because these factors usually have only a minor influence on seepage, they are not discussed in this report.



GROUND WATER MOUND RECESSION

Figure 3

Since the factors affecting seepage are interrelated, variation in one or more factors will cause a change in others. Therefore, it is difficult to isolate the specific influence of any one factor on seepage. For this reason, the relationships developed during this investigation for estimating the occurrence and magnitude of seepage can be used as guidelines but should not be considered as exact.

Stage and Duration

The two most important factors affecting seepage are the stage or elevation of the water surface in the river above a certain critical base level below which seepage does not occur, and the duration of the stage above this level. The river must remain above this base level for a certain period of time before seepage starts. Both the stage and duration necessary to cause seepage are dependent upon a number of physical factors and vary throughout the area of investigation.

The stage of the river above the critical base level, called critical stage, is the force that pushes water through the soil. The higher the river stage, the greater the force and the greater the seepage.

The duration of the river stage determines how far out the water moves into the adjacent land and how much soil will become saturated. The longer the duration of a high river stage, the more time the water has to move out from the river, and the greater the area affected by seepage.

Studies made during this investigation indicate that at the onset of seepage, the seepage area depends primarily upon the height of the river surface above critical stage and the antecedent soil moisture and ground water conditions. The influence of these factors decreases during the seepage period. As the length of the seepage period increases, the influence of the duration of the river level above critical stage becomes increasingly more important on the magnitude of seepage.

The flow in the Sacramento River which averages about 15,376,000 acre-feet per year at Sacramento and 7,278,000 acre-feet per year at Colusa is closely related to the amount of precipitation over the watershed. Streams in the Sacramento River system reach their maximum stages during periods of heavy rainfall between November and April. Extremely high streamflow generally lasts for only a few days. However, moderately high flows fed by successive rainstorms and melting snow, may persist for many weeks or even months. After the spring snow-melt period, runoff in the rivers declines to a fairly steady base flow which slowly diminishes through the summer. An aerial view of the Feather River at Shanghai Bend during the December 1964 flood is shown as Figure 4. This figure illustrates the magnitude of flows which can develop in the Feather River. These flows average 5,590,000 acre-feet per year at Nicolaus. The arrows indicate the locations of pressure relief wells which were constructed to control deep seepage and protect the stability of the levee at Shanghai Bend.

River levels in the Sacramento River Basin are greatly influenced by the operation of the Sacramento River Flood Control Project and the larger water conservation projects in the Sacramento Valley. The influence of these projects on river stage and duration is discussed in the following sections.

Sacramento River Flood Control Project. The Sacramento River Flood Control Project consists of a system of levees, weirs, and bypasses designed to convey flood waters through the valley with a minimum of damage to agricultural and urban lands.

Figure 4. Feather River near Shanghai Bend during flood stage in December 1964.

The principal physical features of the project are depicted on Plate 1. The physical works include levees along the Sacramento, Feather, Yuba, Bear and American River channels; leveed bypasses through the Sutter and Yolo Basins; relief bypasses from the Sacramento River to the Butte Basin at Moulton and Colusa Weirs; a relief bypass from the Sacramento River at Tisdale Weir to the Sutter Bypass; a relief bypass from the Sacramento River at Sacramento Weir to the Yolo Bypass; a spillway structure or weir at each point where water is allowed to overflow from the river channels; and the widening and deepening of the Sacramento River channel from Cache Slough to its mouth.

When a flood discharge exceeds the carrying capacity of the river channels, the overflow weirs act as safety valves, diverting the peak floods into the bypasses and safely through the valley. The maximum capacity of the project is 579,000 second-feet. The project provides protection from floods to about 800,000 acres of highly productive agricultural lands and the cities of Marysville, Yuba City, and Sacramento as well as numerous smaller communities.

The Sacramento River Flood Control Project has a marked effect on seepage conditions. Before the bypasses were built, floodwaters overflowed into the flood basins which generally parallel the rivers and caused considerable general flooding. Confinement of floodflows by levees has resulted in higher water stages with consequent occurrences of seepage in some locations adjacent to the bypasses. The diversion of water from the rivers through the bypasses has, however, reduced river stages, thus reducing seepage adjacent to the rivers.

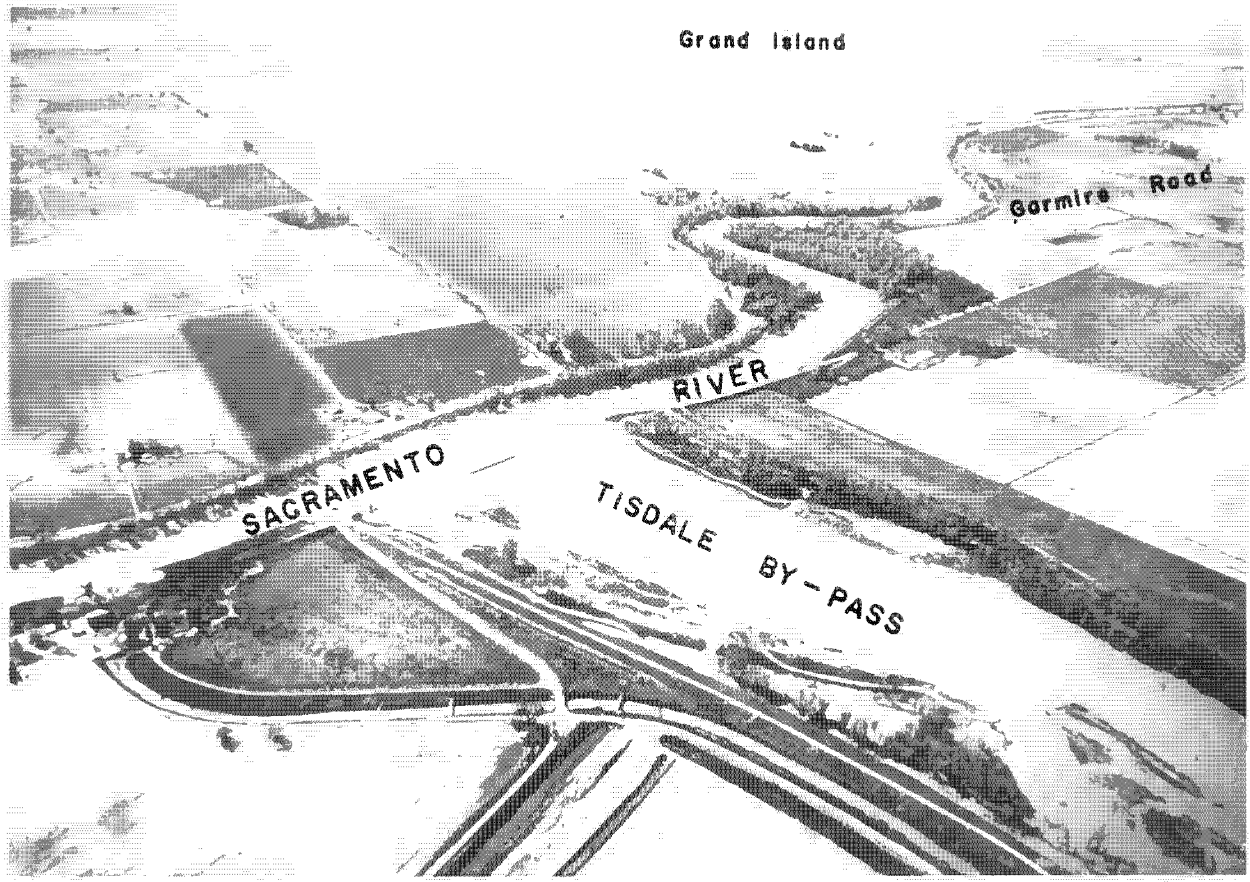
Oblique aerial photographs taken during the April 1963 floodflow period (Figure 5) show two features of the Sacramento Valley Flood Control Project in operation.

> Upper photo - Tisdale Weir is shown spilling high-stage floodflows over the weir and into the Tisdale Bypass. These flows travel easterly along the bypass and commingle with the flows in Sutter Bypass which originate in the Butte Basin area. These combined flows travel southerly along the bypass and Feather River to Fremont Pool, which is in the vicinity of Verona and the junction of the Feather and Sacramento Rivers. Tisdale Weir lowers the stage in the Sacramento River between the weir and Knights Landing, thus reducing flood danger and seepage along this narrow and restricted reach of river channel.

> Lower photo - Fremont Weir is shown spilling floodflows over the weir and into the Yolo Bypass. Flows travel southerly in the bypass and reenter the Sacramento River above the city of Rio Vista reducing flood danger and seepage along the lower reaches of the Sacramento River. The spill over Fremont Weir is a combination of floodflows from the Sutter Bypass, the Sacramento River, and the Feather River. The capacity of Yolo Bypass at the intake (Fremont Weir) is 343,000 cubic feet per second.

Existing Water Conservation Projects. Many water conservation projects in the Sacramento River Basin affect the flows in the rivers within the study area. Reservoirs have the most significant influence as they regulate the flows of the various rivers. Shasta and Folsom Reservoirs presently have the greatest influence on streamflow regimen in the Sacramento Valley. Oroville reservoir should control flows of the Feather River starting in the later part of 1967.

Generally, peak floodflows are stored temporarily in flood control or multiple-purpose reservoirs and later released at rates which will not cause downstream flooding. The effect of these reservoirs is to reduce peak flows which tends to reduce seepage during flood periods. These reservoirs, however, usually extend the flood releases over longer



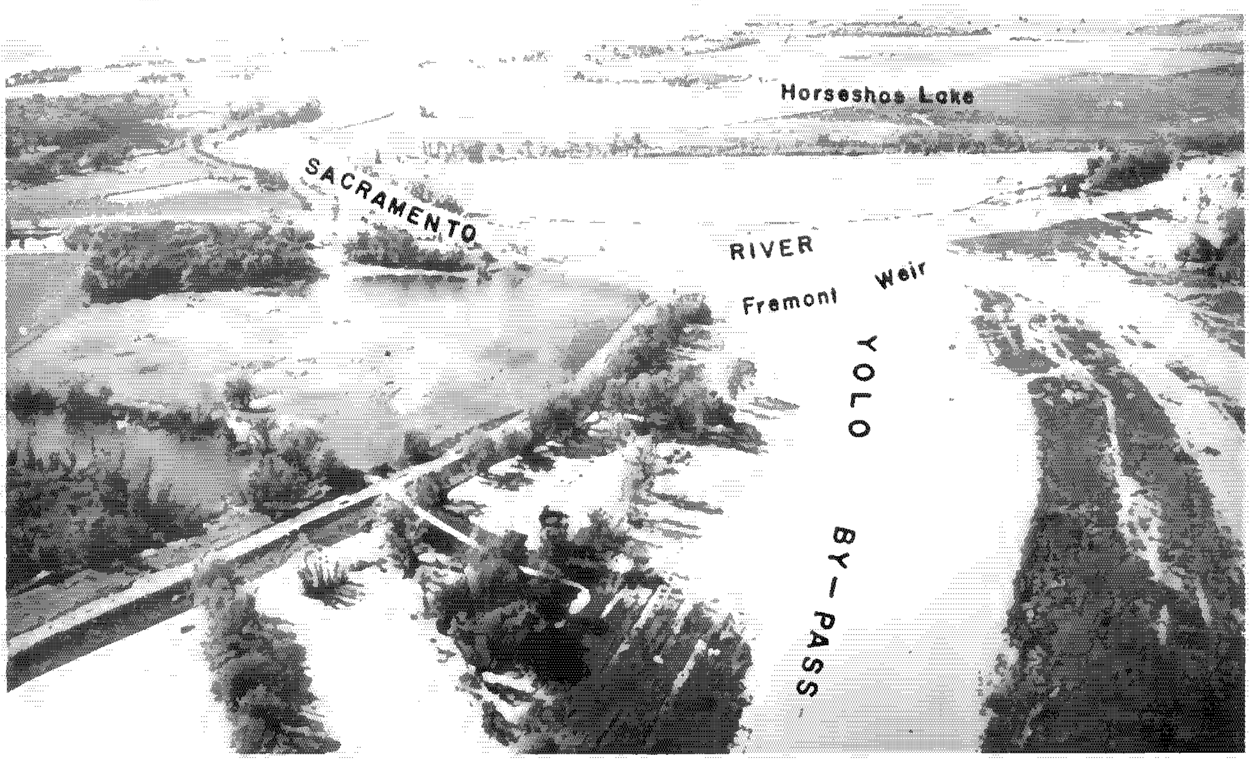


Figure 5. Tisdale and Fremont Weirs overflowing during the April 1963 seepage period

periods, which could extend the duration of seepage. The net effect of water conservation projects on seepage depends both on the storm conditions and the manner in which the reservoirs are operated.

Antecedent Soil Moisture Conditions

Studies made during this investigation indicate that antecedent soil moisture conditions have an important influence on seepage.

The rate at which seepage appears is related to the initial soil moisture content because less seepage is required to bring an already moist soil to saturation. Therefore, the wetter a soil before the river rises above critical stage, the sooner seepage should appear.

The soil moisture content at the time seepage occurs is primarily dependent upon two factors, the amount of rainfall occurring shortly before the river rises, and the ground water level prior to the occurrence of seepage.

The amount of moisture in the soil at the time a watercourse rises above critical seepage stage can vary over a wide range. This accounts for the considerable difference in the rapidity with which seepage may occur and in the magnitude of the seepage area under differing soil moisture conditions. Soil moisture conditions tend to stabilize during a seepage period and consequently the influence of soil moisture decreases with time.

The influence of antecedent soil moisture conditions can be quite pronounced. Seepage which would cover many acres of land if antecedent moisture conditions were high, may not even occur if antecedent soil moisture is low. Furthermore, a slight rise in river level above critical stage may very rapidly cause a considerable amount of seepage if the antecedent soil moisture is high. This explains why the first seepage of a season is usually smaller in areal extent and slower to occur than those later in the season when the soil moisture is higher.

Ground Water

The configuration and slope of the ground water table within the study area is largely influenced by the river system, and varies throughout the area and changes throughout the year. The elevation of the water table normally ranges from ground surface to 20 feet below. The water table immediately adjacent to the river is usually hydraulically connected to the river. Thus, ground water either percolates to or from the river depending upon the relative stages of the river and the adjacent water table. The ground water basin is also naturally recharged by direct percolation from precipitation and from downward movement of applied water on the land surface. The water table is generally drawn down in the spring and summer by the large amount of ground water which is pumped for agricultural use.

North of Colusa the water table generally slopes downward from the foothills to the river. South of Colusa the water table usually slopes from the foothills and the Sacramento River downward to the flood basins on either side of the river.

The timing and ultimate area of seepage are directly related to the depth and slope of the ground water table. If the water table is initially near ground surface and there is a good hydraulic connection

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to the river, it takes little time for a rise in river stage to cause seepage. Conversely, where there is a deep ground water table, the same increase in river stage may not cause seepage, or it may take a much longer time for seepage to appear. Therefore, where the ground water table is initially low, seepage from a short-duration flood may not affect surface conditions, whereas the same situation at a location with a high water table may have a marked surface effect.

In most of the irrigated agricultural lands adjacent to the Sacramento and Feather Rivers, the water table is closely controlled by surface and subsurface drains. When a long-duration flood occurs, these facilities sometimes become overtaxed and allow the ground water table to rise to the ground surface. Thus, the position, action, and control of the ground water table influence both how fast seepage appears and the extent of the seepage area.

<u>Topography</u>

Topography has a very important bearing on seepage and seepage damage. In areas where the ground surface is always higher than the highest river water surface, seepage is seldom a problem. Where the ground surface is below river water surface at all times, seepage may occur the year around if the proper combination of other physical factors is present and if physical works for seepage control have not been provided. Where adjacent lands are above river water surface most of the time but are below the water surface at moderate to high riverflows, seepage can occur intermittently, if the proper combination of the other factors is present and no physical control exists. Seepage also appears sooner, occurs in greater quantity, and lasts longer where the difference in head between the river and ground water surface is the greatest.

The floor of the Sacramento Valley slopes southward from an elevation of about 300 feet at its northern extremity to below sea level in the Sacramento-San Joaquin Delta. Lands at the upper end of the valley slope from the foothills to the river. In the vicinity of Butte City, the valley floor starts to level out with the result that the rivers have built up broad, low floodplains and natural levees adjacent to the channels through deposition of material during flood periods. The floodplains and natural levees slope gently away from the rivers to lower areas or flood basins parallel to and on each side of the rivers. In the vicinity of Sacramento the natural levees reach a maximum height of from 10 to 15 feet above the adjacent flood basins. The flood basins are identified as the Colusa Trough on the west side of the Sacramento River as far south as Knights Landing, and as the Yolo Basin from there south. The Butte, Sutter, and American Basins are the principal flood basins on the east side of the Sacramento River.

Man has constructed levees on both sides of the river in the study area. These levees are from 15 to 30 feet high and have generally been constructed on top of the natural levees. Thus, the Sacramento River below Hamilton City and the lower reaches of the Feather River flow in broad, elevated trenches, flanked on either side by low-lying flood basins.

Land leveling alters the topography, thus affecting seepage. If the land elevation is lowered, the amount of seepage should increase. Furthermore, seepage will generally appear first in low spots and depressions where the difference in head between the river water surface and ground surface is greatest. Local runoff also tends to collect in these depressions, contributing to waterlogging (soil saturation).

An example of ponded seepage is shown on Figure 6. The sequence of photographs was taken in April 1963. The depressed area long the right bank of the Sacramento River above Fremont Weir is normally above the level of the river except during flood periods. Seepage flows away from the river and ponds in swales and against the lower part of the field at the edge of the natural levee and county road. In April 1963, the field was being graded and leveled to remove the swales and raise the elevation of the lower portion of the field. This operation made the field more adaptable to farming but will not solve the seepage problem. In this case, the land leveling increased the area affected by seepage. Before the leveling, seepage was concentrated in the low portions of the field between the levees. However, leveling lowered the higher areas and increased the effective head which causes seepage, thereby increasing seepage over a greater portion of the area.

Geology and Soils

Sediments deposited along the river channels in the study area have been generalized into three types: (1) stream deposits--a gray, loose, gravelly sand of high permeability; (2) floodplain and natural levee deposits--brown, soft, clayey silts and fine silty sands of high to low permeability; and (3) flood basin deposits--a gray, stiff clay of low permeability. A typical geologic cross section is shown on Figure 7. Seepage flows through the permeable stream deposits and floodplain and natural levee deposits. The flood basin deposits formed fine-textured

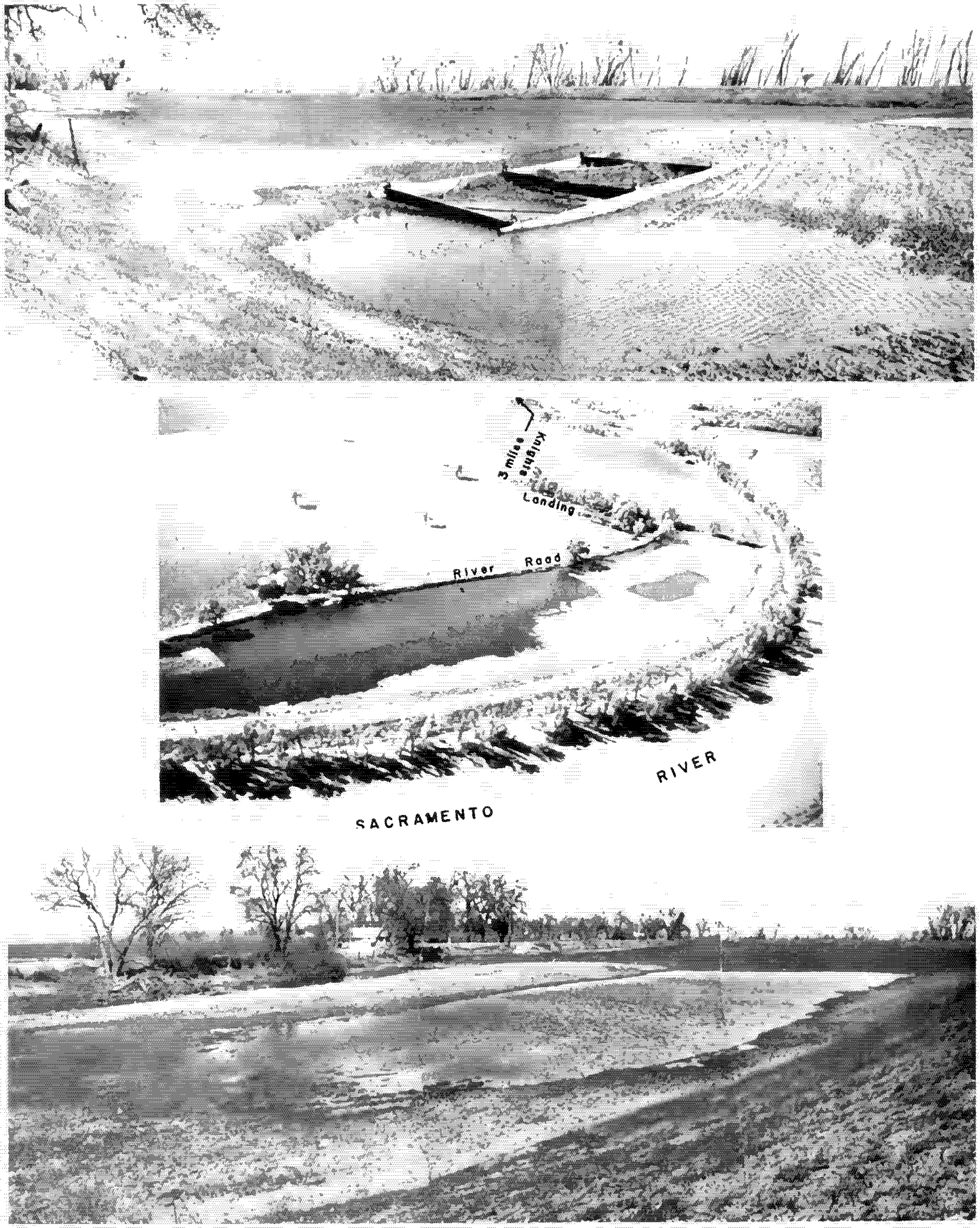
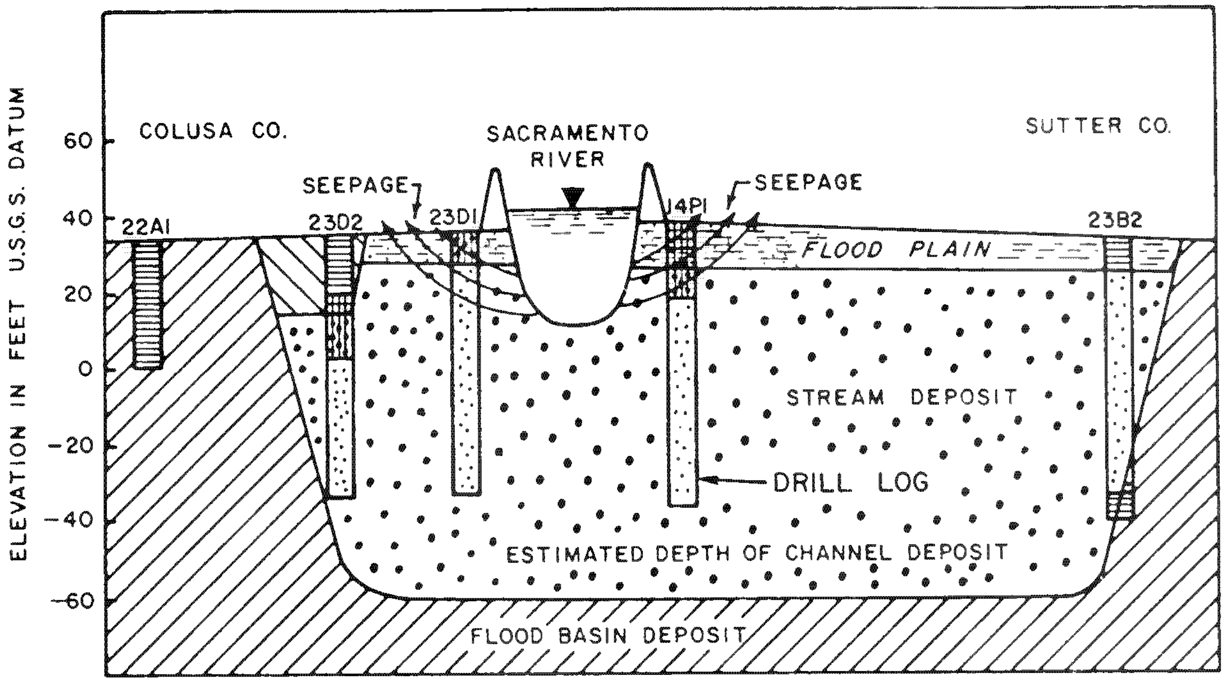


Figure 6. Ponded seepage between river levee and natural levee.



DIAGRAMATIC CROSS SECTION WITH GEOLOGIC ANNOTATIONS
MILLERS LANDING

VERTICAL SCALE IS 10 TIMES THE HORIZONTAL SCALE

DRILL HOLE NUMBERS ARE SHOWN ABOVE DRILL LOG

TYPES OF DEPOSITS

NATURAL LEVEE OR FILL
SILT, FINE SAND, CLAY; LOW PERMEABILITY

FLOOD PLAIN DEPOSIT
FINE SAND, SILT, CLAY; VARIABLE PERMEABILITY—LOW TO MEDIUM. DOTS ON SYMBOL INDICATE MEDIUM PERMEABILITY FLOOD PLAIN DEPOSITS

ABANDONED CHANNEL DEPOSIT
CLAY, SILT; LOW TO VERY LOW PERMEABILITY

STREAM DEPOSIT
SAND AND GRAVEL; HIGH PERMEABILITY

FLOOD BASIN DEPOSIT
GENERALLY CLAY, SILT; LOW TO VERY LOW PERMEABILITY

DRILL LOG SYMBOLS

SILTY SAND

SAND AND GRAVEL

SANDY SILT

CLAYEY SILT

CLAY

Figure 7

clayey soils which, because of low permeability, generally restrict the flow of seepage and act as impermeable boundaries.

The stream deposits were formed during the early post-Wisconsin glacial stage when stream gradients and velocities were very high. Highly permeable sands and gravels were deposited in the deep, wide channels which had been formed during the Wisconsin glacial stage (see Figure 7). The stream deposits extend vertically to a maximum depth of approximately 100 feet and laterally about 1 mile. Most of the seepage flows through the stream deposits because these soils are generally hydraulically connected with the rivers and are highly permeable. Figure 8 shows seepage which has saturated pervious soils next to the Sacramento River.

The floodplain and natural levee deposits were formed over the stream deposits during the later post-Wisconsin glacial stage when the rise in sea level reduced the stream gradients and velocities along the Sacramento and Feather Rivers. This caused the deposition of finer grained material such as fine sand, silt, and clay. The rise in sea level and the lowering of the stream velocities also increased the meandering of the rivers which accounts for the high variability of these soils, ranging from sand to clay, and the existence of abandoned channels. Generally, the relatively coarser grained soils were deposited adjacent to the main river channels and the finer grained soils were deposited farther away. The vertical thickness of the floodplain deposits ranges to 30 feet, and averages about 15 feet. At present, the natural and man-made levees are relatively impermeable because of the fine suspended sediment of silt and clay which was deposited on the levees

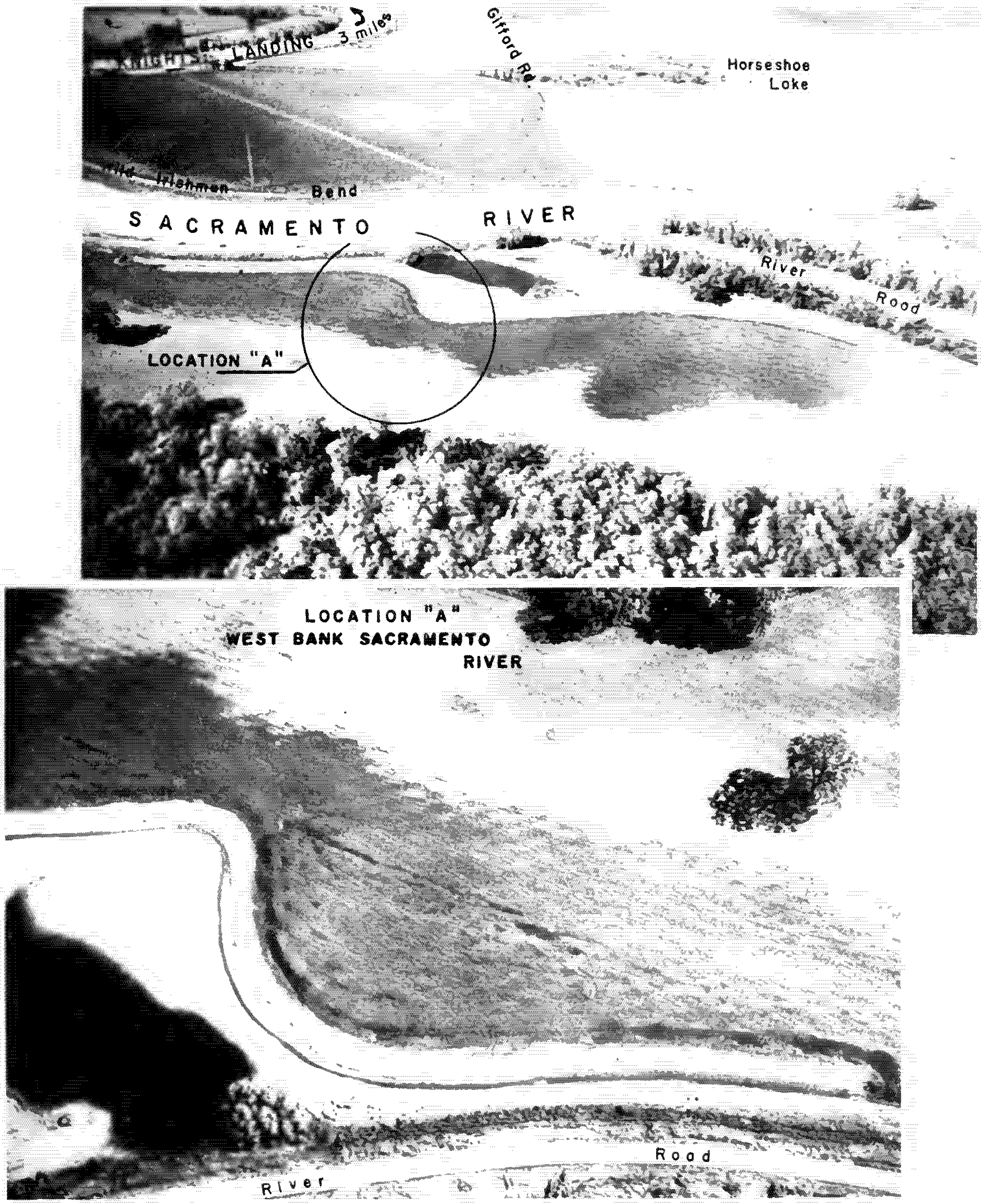


Figure 8. Seepage along the west bank of the Sacramento River above Fremont Weir.

The oblique aerial photographs taken during the April 1963 seepage period define the seepage pattern and show the gradation of saturation landward from the levee. Seepage in this area drains into an abandoned oxbow landward from the row of oak trees at the bottom of the upper photograph. This results in dewatering the area near the grove of trees surrounding the oxbow.

during the recession period of the high flood stages. The quantity of seepage which flows through the floodplain deposits varies because of the irregular deposition and varying permeability of these soils.

The flood basin deposits consist of clayey soils which were formed largely prior to the deposition of the stream deposits and floodplain and natural levee deposits. Many of these basin soils are underlain by a hard, impervious substratum. Before the rivers were confined by permanent levees, flood basin soils were repeatedly deposited during overflow periods in the low areas such as the Colusa and Sutter Basins. The high clay content of the flood basin deposits limits the quantity of seepage transmitted through these deposits.

The most significant soil characteristics influencing the occurrence and magnitude of seepage are the vertical and lateral extent and permeability of the various soil deposits. The width of natural levees also has a bearing on seepage.

The vertical and lateral extent of seepage is limited by the location of the impermeable flood basin deposits which underlie the stream deposits and laterally border both the floodplain and stream deposits. The geologic sections on Plates 12 through 18 show the limit of the potential seepage zone along cross sections at selected locations in the study area. The electrical resistivity maps on Plates 19 through 29 show the lateral extent of the potential seepage zones at 11 locations within the area of investigation. It was found that the stream deposits have a fairly consistent depth, but that the floodplain deposits vary considerably in depth. Generally, more seepage is transmitted where the floodplain deposits are very permeable or thinner than the permeable stream deposits.

Vertical permeability of the floodplain deposits ranges from approximately .001 to 5.0 feet per day, and the vertical permeability of the stream deposits varies from 1.0 to 30.0 feet per day. The large range in the permeability of the floodplain deposits is due not only to the irregular deposition of soils, but also to structural features such as small root holes and cracks which affect permeability more than does the grain size distribution. These holes and cracks were frequently found in soil located above the normal water table and in fine-grained soils. This large variation in permeability accounts in part for the nonuniform occurrence of seepage.

Anisotropy, the ratio of vertical permeability to horizontal permeability, affects the rate of seepage flow. In this investigation, the anisotropic ratios of the stream deposits were generally found to be close to unity. In areas where the anisotropic ratio is lowest seepage is usually distributed further inland. In a typical case where the less permeable floodplain deposits overlie the highly permeable stream deposits, the rate of seepage flow increases with an increase in the anisotropic ratio.

The widths of the natural levees are highly variable because of the nonuniform method of deposition, river meander, variable sediment load, past levee breaks, scours, and overflows. The natural levees are generally broad, but man has raised the levees and leveled the abutting lands to fill in low areas such as abandoned channels. Thus, the shape of the present levees are somewhat modified from the natural form. Generally, with other conditions the same, the wider the levee the less the rate of seepage flow.

Old river channels which have been cut off from the present channels either naturally or by the action of man in constructing river levees, have a small, localized influence on the location of seepage. Although the type of material varies considerably, abandoned channels are generally filled with fine-grained materials. Where these old river channels are hydraulically connected to the stream deposits, they readily transmit seepage upward during periods of high river stage.

This investigation showed a general similarity in arrangement of the floodplain and stream deposits in the area of investigation. However, the continual deposition and erosion caused by the meandering streams have created an area which is highly complex. Each area is unique and must be so treated in a detailed study of seepage or drainage.

Drainage Works

Waterlogging problems in the area of investigation result almost entirely either from precipitation or from seepage from the rivers or bypasses or both.

The location and operation of drainage facilities greatly influence the area affected by seepage. This influence is exerted by the ability of drainage facilities to control the height and fluctuation of the water table.

Properly designed and operated drains allow the water table to be maintained below the root zone in agricultural areas and to be maintained below the foundation of buildings, roadways, and airport runways in urban areas.

Drainage ditches and tile drains are the most common types of drainage facilities in the study area. Relief wells have been used in several locations. The type of drainage facility which is most effective depends primarily upon local soil and drainage conditions.

In most instances, open drainage ditches are probably the best and most economical facilities. Two types of open drains are extensively used in the study area--toe drains along the landward toes of the levees and ditch systems consisting of main drains, laterals, and sublaterals in the fields adjacent to the rivers and bypasses. The toe drains are limited to alleviating near-surface seepage and seepage through the man-made levees, whereas the lateral systems, if properly designed and operated, can usually alleviate seepage anywhere within the crop root zone in fields near the watercourses.

Tile drains placed underground offer a permanent method of draining land. A single tile line paralleling the levee would control only near-surface seepage, whereas a tile drainage system, including laterals, can effectively control seepage at considerable distances from the levees.

Relief wells reduce the hydrostatic pressure at or near the landward toes of levees by providing outlets for seepage from underground strata. Relief wells are therefore most effective in controlling deep seepage and in protecting levee stability at specific locations. However, they cost considerably more than either open or tile drain systems.

Pumping plants are usually constructed with each type of drainage system to pump the drainage flows back into the rivers or bypasses.

Drainage facilities also intercept drainage from local rainfall. This is important, as seepage generally occurs after heavy or prolonged periods of rainfall.

Drainage facilities in the Sacramento-San Joaquin Delta are quite extensive and are very effective in controlling seepage, except during the most severe seepage periods. South of Clarksburg, the lands are drained by an intricate system of ditches and some tile drains which intercept and remove large quantities of seepage. The agricultural areas north of Clarksburg are not as extensively covered by drains and are usually served by large reclamation district drainage ditches or by tile drains installed by the landowners. Figure 9 shows two examples of seepage being collected in open drains.

A seepage relief well system, constructed by the U. S. Army Engineers, controls deep seepage and protects the right levee of the Feather River near Shanghai Bend. Three relief wells were constructed by the Department of Water Resources to protect the levee near Old River at the west end of Fremont Weir.

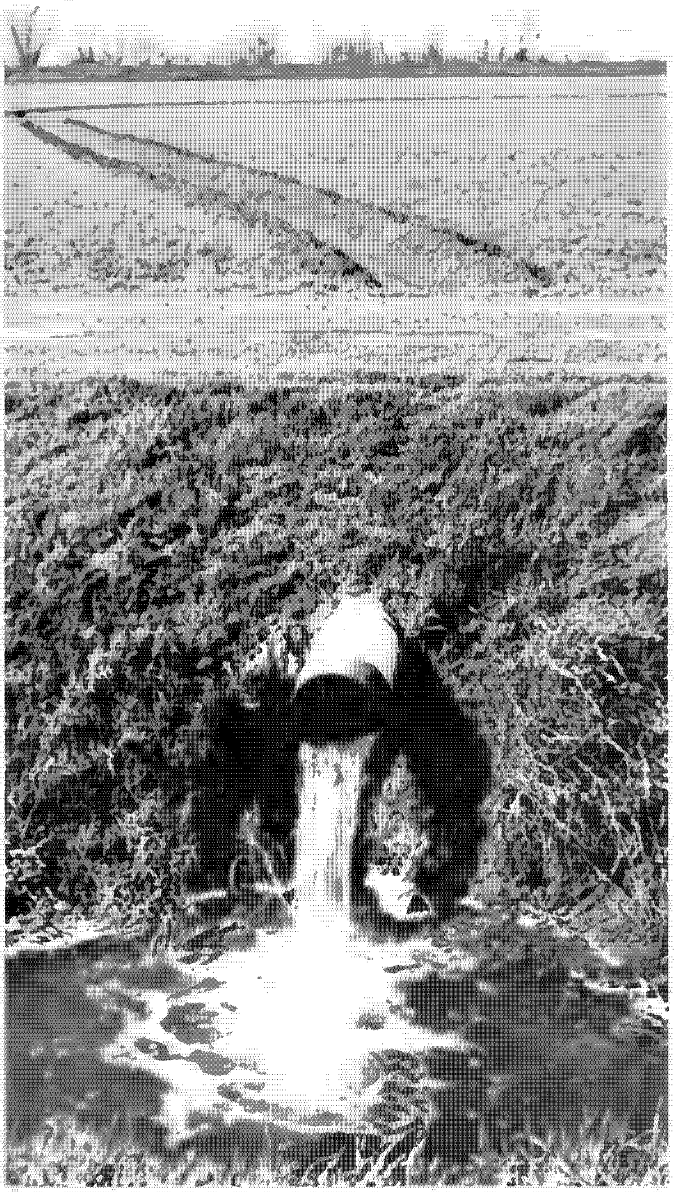
The larger urban centers such as the City of Sacramento generally have adequate underground drainage facilities. In addition, drainage facilities are constructed to protect buildings, roads, railroads, and airports from high water table conditions and damage.

Seepage Damage

The Sacramento Valley is one of the principal agricultural areas in the country. Practically every crop grown in California can be found in some part of the valley and the adjacent foothills.

Agriculture and allied services are the principal economic activities in the study area. Most of the agricultural lands are planted to field crops and grain with the remainder in orchards. The field crops

Seepage flowing down the cut-bank of drainage ditch about 1/2 mile away from the Sacramento River on the River Farms property north of Knights Landing.



A 12-inch outfall pipe spilling seepage collected from field drain adjacent to the Sacramento River on the Van Ruiten ranch upstream from Kirkville. The flow at the outfall was estimated to be 0.25 cfs.

Figure 9. Seepage collected by drainage works.

include barley, sugar beets, beans, milo, tomatoes, rice, alfalfa, pasture, safflower, and a negligible acreage of other crops. The orchards are mostly walnuts, pears, peaches, and prunes. Because agriculture is the most important economic activity in the area, the effects of seepage on the agricultural economy are more significant than on the urban economy.

The present urban areas are largely confined to the higher ground along the rivers and have fairly adequate drainage facilities. Thus, urban areas do not experience seepage to the extent that the agricultural areas do.

Seepage can have both beneficial and detrimental effects on the economy. Seepage recharges the ground water body and is sometimes used as a source of water for subirrigation and for leaching agricultural lands, particularly in the Sacramento-San Joaquin Delta. Seepage is also used as a source of water for duck ponds and has other beneficial effects. The primary effect of seepage, however, is usually detrimental.

In agricultural areas, seepage prevents or delays the use of lands to their full economic potential, delays or prevents planting of crops, reduces crop yields, kills orchards and annual and perennial crops, forces undesirable salts upward into the root zone of crops and trees, and otherwise interferes with farming operations. Seepage also necessitates the construction, operation and maintenance of drainage facilities on agricultural lands.

Seepage delays development in some urban areas and requires the installation and operation of drainage facilities for buildings, roads, and airports in these areas.

Types of Agricultural Damage

There are two primary types of seepage damage to the agricultural economy. These are direct damage to crops, and indirect damage due to limitation on land use. The most obvious type includes the inability to plant crops at the optimum time, total to partial loss of crops, the inability to double crop, decreased crop yields, loss of trees and perennial plants, and miscellaneous damages such as additional cultivation and loss in effectiveness of fertilizer.

In addition to direct damage, seepage often imposes a limitation on the type of crops which can be grown. In many areas, an increased intensity of use or an entirely different cropping pattern yielding a higher net income could be established if seepage were not prevalent.

Crop Damage. The direct impact of seepage on a particular crop is basically attributable to three factors: (1) the time of occurrence of seepage, (2) the duration of seepage, and (3) the susceptibility of a particular crop to seepage damage.

The time of occurrence of seepage is critical with respect to the type of crop and the state of crop growth. If seepage occurs during the period a crop is dormant or during a cool period, a crop is less susceptible to damage than during the crop growing season or during a warm or hot period. Also, in the case of annual crops, seepage may occur before the crops are planted, thus causing little or no damage. Generally, the economic effect of seepage on a crop increases up to the time of harvest.

An example of seepage damage to orchards is shown on Figure 10. This photograph shows the typical visual effects caused by seepage. The center photo on this figure shows a portion of an orchard pruned back because of root damage from seepage.

Waterlogged, stunted, and a few toppled walnut trees caused by seepage along the Feather River south of West Catlett Road, February 1962.

Prune orchard near Princeton on Keller Ranch, April 1954, severely pruned back because of seepage damage to roots.

Young pear orchard along the Feather River north of the Bear River, waterlogged from seepage with many of the trees blown over by the high winds in October 1962.

Figure 10. Orchard damage attributable to seepage.

The duration of seepage has a direct effect on the amount of damage to crops, regardless of when seepage occurs. However, the amount of damage resulting from a specific duration increases considerably late in the growing season when the plant nutrient and water requirements are high. Since plant growth is dependent upon the functioning of the root system, an interruption of the normal functions of the roots disrupts the flow of nutrients to the detriment of the plant in general. During the cooler portion of the year, plants can survive longer periods of seepage than during warmer periods when growth is more active.

Some crops are less susceptible to damage from seepage than others because they are more salt tolerant or less susceptible to damage from an oxygen deficiency. Thus, seepage of a specific duration at a given time may severely damage or completely destroy one crop, while another crop may suffer only slight or moderate damage.

Limitation on Land Use. Seepage limits the use of land in some agricultural areas. Without seepage control, the type of crops which can be grown is limited in areas which frequently have seepage. Crops which are tolerant to water in the root zone and/or shallow rooted are often planted in these areas, even though they yield a relatively low economic return. Repeated occurrences of seepage will cause an area to be less intensively farmed.

An increased intensity of land use or an entirely different cropping pattern yielding a higher net economic return could be established in some areas if seepage were controlled. If the economic return from the land is increased, the market value of the land could normally be expected to appreciate. Thus, the restriction on land use imposed by seepage reduces the market value of agricultural land.

Factors Influencing Agricultural Damage

A basic knowledge of soil moisture conditions and the ecological factors affecting plant growth are essential to the evaluation of the economic effects of seepage on the agricultural economy. Optimum plant growth occurs under ideal conditions when the soil temperature and the quantity of oxygen available to the root system are in balance with the normal requirements of the crop. Any deviation from the optimum growing conditions as a result of seepage can result in an economic loss due either to decreased crop yield or reduced quality of a crop or both. Seepage damage to grain crops planted along the Sacramento River is shown in Figure 11.

Available Oxygen. Oxygen in the upper strata of the soil is essential for optimum root growth and the subsequent development of plants. When the soil is saturated, as it is when seepage is present in the form of a high water table, oxygen is not present in the root zone and growth is inhibited, usually decreasing crop yield and/or crop quality.

In describing and discussing the effects of seepage, it is necessary to distinguish between moisture from seepage and moisture from other sources. Seepage differs from applied irrigation water and rain-water in the manner in which it enters the soil. Seepage movement occurs primarily when the soil is saturated and can be horizontal, upward, or a combination of both. This movement drives the oxygen necessary for plant growth from the pores of the upper soil strata. Seepage can also carry

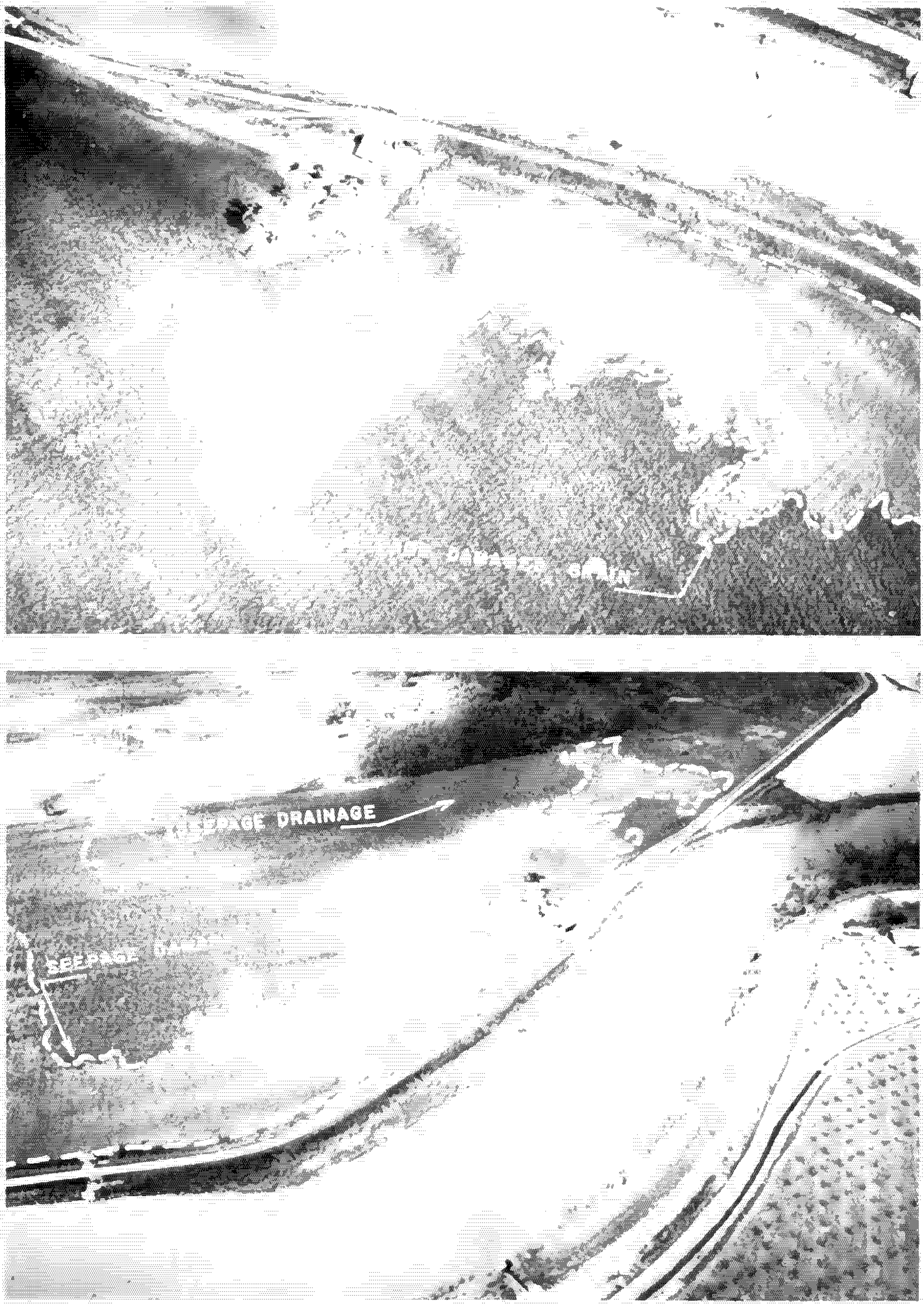


Figure 11. Crop damage from seepage along the left bank of the Sacramento River above Missouri Bend.

undesirable salts upward into the crop root zone. In contrast, irrigation and rainwater percolate downward without saturating the soil, and bring in oxygen and carry away excess salts.

Although the roots of crops are exposed to nearly saturated soil conditions for a short period of time during irrigation, particularly by the flooding method, growth is not inhibited and the plants are not damaged as is the case with seepage. This contrast in what appears to be similar circumstances is due to three factors. The short time of near-saturation is the primary difference. Second, irrigation water contains more oxygen than does seepage. Third, as irrigation water percolates downward through the soil, it draws in fresh air and also dissolves carbon dioxide and leaches it from the root zone.

Roots respire just as do other parts of the plant, and are injured if an adequate supply of oxygen is not available. Since respiration is most rapid during the plant growing season, seepage damage is likely to be greater during the growing season than in the dormant season. In general, total root growth and the rate of growth decrease with a decrease in oxygen supply and an increase in carbon dioxide in the soil.

Soil Temperature. Soil temperature, an important factor for crop germination and growth, is lower in saturated than in unsaturated soils. Some crops such as cereal crops will sprout when the soil temperature is about $45^{\circ}F$, but soil temperatures from 70 to 90 degrees are more favorable for both germination and plant growth. Soil bacteria which create plant food are also less active at lower temperatures than at temperatures ranging between 80 and 95 degrees.

Experiments reveal that low soil temperatures reduce the absorption oı water by the plant roots. Under certain circumstances, this causes wilting of plants because the uptake of water does not correspond to the quantity of water lost by transpiration.

Thus, the effect of seepage in reducing soil temperature can decrease farm income by delaying the period of crop germination and harvest, and by decreasing the crop quality and yield.

Decreased Respiration. Respiration is the process by which plants absorb oxygen and give off products. Plant pathologists have determined that the energy released by respiration is essential for the movement of solutes (the elements necessary for plant growth) into the plant cells. If respiration of actively accumulating tissue is decreased by chemical inhibitors, low temperature, or inadequate oxygen, the accumulation of solutes is invariably decreased or stopped. If, under prolonged seepage conditions, plants do not receive the solutes necessary for proper growth, they will suffer and eventually die. The damage from reduced respiration is directly related to the proportion of the total root system of the crop which is exposed to seepage and the duration of the inundation by seepage.

Crop Rooting Characteristics. Some knowledge of the rooting characteristics of crops which are grown in the study area is essential to proper evaluation of the effects of seepage. The maximum depth to which the roots of a crop will penetrate varies considerably, even in well-drained soils. There also is a minimum depth to the water table that is considered essential for proper plant growth.

According to information published by the University of California, the crops listed below will exhaust the available water supply to the following depths when grown in deep, well-drained soils under average conditions.

Crop	Depth in Feet	Crop	Depth in Feet
Alfalfa	8 to 12	Milo	6
Almonds	6 to 9	Peaches	6 to 9
Asparagus	10	Pears	6 to 9
Beans (bush)	1-1/2	Prunes	6 to 9
Beets (sugar)	5 to 6	Rice	1 to 1-1/2
Corn (field)	5 to 7	Safflower	7
Grain	5	Tomatoes	6 to 10
Permanent pasture	1-1/2 to 3	Walnuts	12 to 18

Since crops in the study area are not usually grown in deep, well-drained soils, it is essential to know the depth at which most of the roots grow. These depths are as follows:

Crop	Depth of Dense Growth
Field and truck crops	3' to 3-1/2'
Orchard	4' to 6'
Small Grains (barley)	24" to 30"
Sugar Beets	12" to 48"
Corn	18" to 20"
Alfalfa	36"
Pasture:	
Clover	24" to 48"
Kentucky bluegrass	18" to 20"
Ladino clover	6" to 12"
Vegetables:	
Beans	12"
Tomatoes	24"

If the soils and soil water are relatively free of alkali, the following crops require a minimum depth to water as shown:

Crop	Depth to Water in Feet
Pasture	2 to 3
Field and grain	3 to 5
Orchards and alfalfa	5 to 8

If there is an excessive amount of alkali present, almost any crop will require a minimum depth to the water table of 4 feet in coarse sandy soils, 6 feet in sandy loam soils, and 8 feet in clay loam soils.

For purposes of this investigation, a minimum depth to water table which each representative crop grown within the area of investigation would endure over a prolonged period was estimated. The minimum for any crop was considered to be 36 inches, because some irrigation is necessary to leach out the undesirable salts accumulated in the root zone. These depths are shown below:

Crop	Minimum depth to water in feet	Crop	Minimum depth to water in feet
Alfalfa	3	Melons	3
Almonds	6	Milo	3
Asparagus	4	Peaches	6
Beans (bush)	3	Pears	6
Beets (sugar)	3	Prunes	6
Corn (field)	3	Rice	3
Grain	3	Safflower	3
Permanent Pasture	3	Tomatoes	3
		Walnuts	8

Urban Damage

Population is relatively sparse throughout much of the study area. The principal urban centers in the area of investigation are Sacramento, Yuba City, Marysville, Linda, Olivehurst, and Colusa. The small towns and farmsteads bordering the river occupy a small portion of the area of the investigation.

When the urban areas were originally developed, buildings generally were located on high ground near streams to avoid flooding but to be near enough to the river to have cheap transportation and a water supply. Most of these buildings had basements which acted as sumps to keep the water, both drainage and seepage, from the wooden substructure during prolonged wet periods. Newer buildings, particularly residences, are constructed without basements. Seepage, if allowed to stand in contact with the building structure can warp, buckle or crack floors and walls, cause dry rot, and is a nuisance.

Since urban development in the area of investigation is presently confined largely to areas of higher ground, it is not appreciably affected by seepage at this time. However, urban development is beginning to encroach into seepage areas. This encroachment is certain to continue as the more desirable lands are utilized and as urban growth continues.

An example of urban encroachment into a seepage area is shown on Figure 12. The Rio Ramaza subdivision is located in a low-lying area just north of the Sacramento-Sutter county line. Drainage works were installed within the subdivision to control seepage and drainage, but during February 1965 the drainage facilities were overtaxed and did not keep ground water levels below ground surface. At the time the photograph was taken, seepage was present throughout the subdivision which is located in the bottom part of the figure. The darker areas in the subdivision are areas with standing water or where the soil is saturated or nearly saturated.

In a few instances, notably Southside and Bahnfleth Parks in Sacramento, severe seepage conditions have resulted in areas being used for park purposes rather than as building sites.

Figure 12. Rio Ramaza subdivision located in a seepage area north of the Sacramento-Sutter county line.

Examples of seepage in an urban area and at Bahnfleth Park are shown in Figures 13 and 14. Figure 13 is a composite of two oblique aerial photographs taken in April 1963. It shows seepage along the Sacramento River near Chicory Bend in south Sacramento. This area seeps almost every time the Sacramento River rises above ground surface. Most of the seepage is under levee seepage and usually causes high ground water conditions within a few blocks of the river levee. Bahnfleth Park, which is the undeveloped area in the upper photo, is a collection point for most of the seepage. The park has been graded to form a depression and is equipped with a sump pump and a drainage system to keep the park from becoming a lake during seepage periods. All storm drains in this area have bypass outlets, which are gated, to allow excess drainage and seepage to flow into the park. Seepage in this area is so severe that at times, even with the drainage system in operation, the park floods.

Figure 14 shows three photographs of seepage in the Chicory Bend area during February 1965. These photographs are keyed to the oblique aerial photographs in Figure 13 with annotations to show their location. Seepage shown on these photographs forms about the same pattern each time the river rises above ground surface from long-duration high flows. Seepage conditions depicted at the two locations are described below:

> Location 1 - Looking southerly down Riverview Court in the Chicory Bend area toward the Sacramento River levee. Note seepage flowing through cracks in the driveways and sidewalks, and also being forced up through the asphalt pavement on the street. This action causes some failure to take place in the street subbase, and when seepage recedes, a pumping action takes place and can cause large cracks in the pavement.

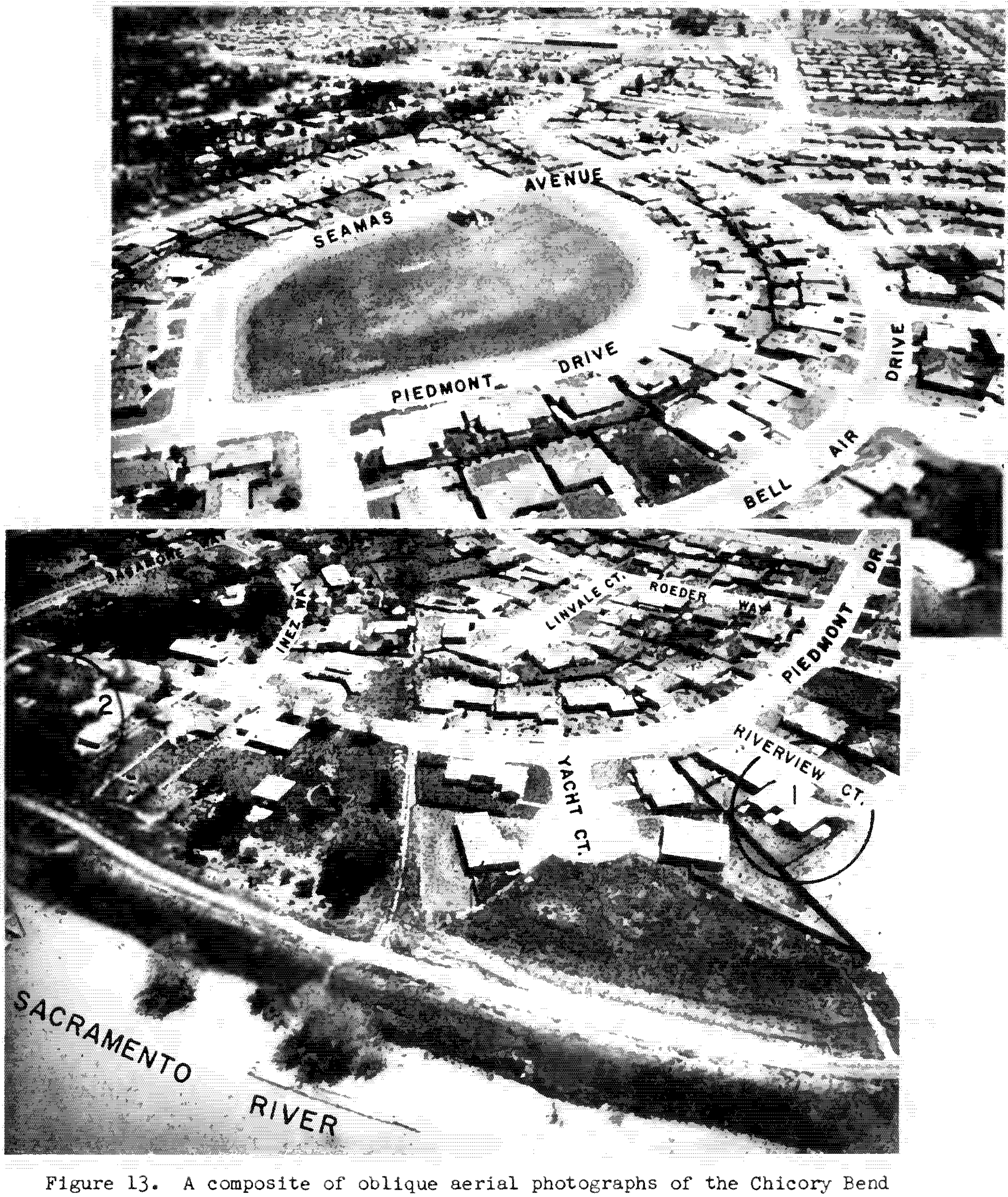


Figure 13. A composite of oblique aerial photographs of the Chicory Bend area showing seepage locations and Bahnfleth Park. (See Figure 14 for closeup views of circled areas 1 and 2)

(Location 1) Seepage flowing through sidewalks and lawns along Riverview court.

(Location 2) Seepage between levee and Piedmont Drive.

(Location 1) Seepage ponded on and flowing out of pavement on Riverview Court.

Figure 14. Seepage conditions along the Sacramento River near Chicory Bend in the South Sacramento area.

Location 2 - Looking northeast from the Sacramento River levee into the back yard of a home along Piedmont Drive in the Chicory Bend area. Seepage has created a small lake and is draining around and under the house into the street gutters. This condition can cause damage to the house and overloads the storm drains which also receive seepage through small cracks and joints.

Location 1 - Another photograph on Riverview Court showing seepage conditions in this area. Note seepage being forced up through the driveway and lawn, then ponding in the street and gutters.

The increased demand for building sites is naturally for land which has the least drainage problems, when all other factors are relatively the same. Consequently, urban development in seepage areas is lagging behind that in the nonseepage areas, even though the seepage areas may be closer to the places of employment and the downtown shopping centers and have other advantages.

Officials of the Federal Housing Administration recognize the problems created by seepage and drainage under and near homes. To protect the homeowner and the lending institution, their policy requires adequate proof that the water table can be maintained 2 feet or more below the foundation of the structures on which loans are authorized.

The need for drainage facilities does not preclude urban development, but it does delay development. The delay depends on the demand for land suitable for urban uses outside the seepage areas. Sacramento real estate appraisers have indicated the price of lands subject to seepage generally is less than lands suitable for comparable development outside the seepage areas, the difference being the costs of drainage facilities necessary to make the seepage land as desirable as the nonseepage land.

Effects of Drainage on Seepage Damage

By reducing or preventing seepage, drainage works greatly reduce the magnitude of economic damage resulting from seepage. Properly operated drains reduce the excess water in the root zone, thereby providing a root environment that is suitable for maximum plant growth. This, in turn, increases agricultural production and income.

Drainage also allows lands subjected to spring seepage to be planted earlier. Equipment is less likely to mire down due to wet soil conditions. Also, fields can be cultivated with less delay and tractor cultivation is more efficient because the soil dries uniformly and it is not necessary to cultivate around wet spots or parts of a field. Furthermore, well-drained soils warm up sooner and can be cultivated earlier in the spring than wet soils. Seeds germinate earlier, which improves crop production.

In the areas where seepage brings undesirable salts upward to the surface or into the root zone, deep drains should lower the water table and result in a downward movement of salts in the soil. This should lower the salt concentration in the root zone and improve crop growing conditions.

Drainage also improves public health conditions by reducing the amount of standing water on which mosquitoes may breed.

In some instances drains, although not wholly effective in preventing seepage, will reduce damage by reducing the duration of water in the root zone. An adequate, properly maintained and operated drainage system may often mean the difference between having and not having a crop. Therefore, in some areas such as the area south of Sacramento, such a system is essential to the use of the land for agriculture.

Control of seepage in urban areas is also economically beneficial. Control of seepage by drainage facilities prevents dry rot, differential settlement, and cracking of buildings. It also has other benefits including prevention or reduction of subbase failure of pavements, thus preventing heaving and cracking of roads and airport runways. The nuisance effect of seepage is also reduced by concentrating it in drains and preventing its spread.

CHAPTER III

PRESENT SEEPAGE CONDITIONS

The present level of seepage and seepage damage must be known before the effects of future changes in flow regimen of the river system on seepage and seepage damage can be determined.

Although there have been several studies of seepage conditions in the Sacramento Valley prior to this investigation, little physical and economic data of the required accuracy and extent was available for this purpose. Generally, previous observation techniques did not permit accurate definition of seepage areas. Furthermore, only meager information existed on the physiological effect of seepage on plant growth, and on the relationships between seepage and seepage damage. Therefore, it was necessary to collect specific physical and economic data unique to this investigation.

Based on this data, relationships were developed between the major physical factors affecting the occurrence and magnitude of seepage and the seepage areas observed during this investigation. The present level of seepage was estimated based on these relationships and the riverflows which occurred during the period 1943-44 through 1964-65.

Similarly, relationships were developed between the major factors influencing seepage damage and the magnitude of observed damage. The present level of seepage damage was then estimated based on these relationships and the estimated seepage occurrences during the period 1943-44 through 1964-65.

The present level of seepage and seepage damage and the methods used to obtain this information are discussed in this chapter. The data which was compiled and used is discussed in greater detail in the office reports on this investigation.

Method of Determining Present Level of Seepage

The timing, areal extent and duration of a number of seepage occurrences were observed and measured during this investigation. In addition, the physical factors which influence seepage were measured and studied and their relationship, variation and relative significance on seepage were analyzed. Concurrently with these analyses, the relationships between the various influencing factors and the occurrence of seepage were investigated. After considerable study, graphical correlations were developed between the two most significant factors and the magnitude of seepage.

An electronic data processing program was developed for rapid computation of the area and duration of seepage which would result from any river conditions included within the limits of the correlation curves. This program was used to compute seepage areas and the duration of seepage for one subarea within the area of investigation for the historical period 1943-44 through 1964-65. Since there had been no appreciable change in river regimen during this time, seepage occurring during this period was considered to represent seepage which would occur under present conditions of development. The most significant of these studies is reported in this section.

Seepage Areas

The determination of the physical extent of seepage which occurred during this investigation was perhaps the most important phase of the study. Many procedures were employed to determine the occurrence, magnitude, and duration of seepage. Some were established procedures used in previous ground water investigations, others were offshoots of recent developments in agriculture, engineering, military photographic reconnaissance, and geophysical exploration and were combined and adapted for seepage monitoring purposes for the first time in this investigation.

Infrared vertical aerial photographs and field observations were the basic tools used to determine the extent of the seepage areas. Six sets of aerial photographs were taken during five seepage periods to define the areal extent of the major seepage occurrences which took place during the investigation. The photographs were taken February 21, 1962, February 26, 1962, October 18, 1962, February 22, 1963, April 24, 1963, and February 10, 1965. The photographs of February 21, 1962 were taken with panchromatic film; all others were taken with infrared film which increased the image contrast between the dry and waterlogged areas. The seepage areas obtained from the aerial photographs taken on April 24, 1963, and February 10, 1965, were the most extensive seepage areas recorded during the investigation and are shown on Plates 3 through 11. Two sets of photographs were also taken during nonseepage periods to aid in identifying drainage areas and crop damage.

Seepage areas which occurred both at these times and at others during the period of investigation were also delineated in the field. Observations and ground water level measurements were taken to determine whether the source of water in the inundated areas was seepage, drainage or combination of both. Lateral seepage boundaries were delineated from electrical resistivity studies of the subsurface strata or were defined by physical or topographic barriers or drainage works. The influence of time on the occurrence, duration and extent of seepage was determined by observation and by continuous recordation of ground water levels in selected areas.

Seepage area delineations obtained were far more accurate than those obtained with methods employed in prior seepage investigations. Figure 15 shows seepage and drainage areas identified on an infrared vertical aerial photograph. Figure 16 shows how electrical resistivity was used to define areas which are susceptible to seepage.

The acreages of seepage determined from the aerial photographs are shown by subareas in Table 1. The boundaries of each subarea were established as the locations where flows in the rivers or bypasses substantially change or where substantial flow changes could be anticipated in the future. The 15 subareas and their approximate north-south boundaries are shown below and on Plate 1.

Subarea	Stream	North Boundary	South Boundary
1	Sacramento River	Ord Bend	Moulton Weir
2	Sacramento River	Moulton Weir	Colusa Weir
3	Sacramento River	Colusa Weir	Tisdale Weir
4	Sacramento River	Tisdale Weir	Verona
5	Sacramento River	Verona	Sacramento Weir
6	Sacramento River	Sacramento Weir	Mid-"Pocket" Area
7	Sacramento River	Mid-"Pocket" Area	Hood
8	Sacramento River	Hood	Isleton
9	Sutter Bypass	Butte Slough Outfall	Tisdale Bypass
10	Sutter Bypass	Tisdale Bypass	Junction of Feather River
11	Sutter Bypass	Jct. of Feather R.	Karnak Pumping Plant
12	Feather River	North of Yuba City	Junction of Bear River
13	Feather River	Jct. of Bear River	Verona
14	Yolo Bypass	Fremont Weir	Putah Creek
15	Yolo Bypass	Putah Creek	Cache Slough

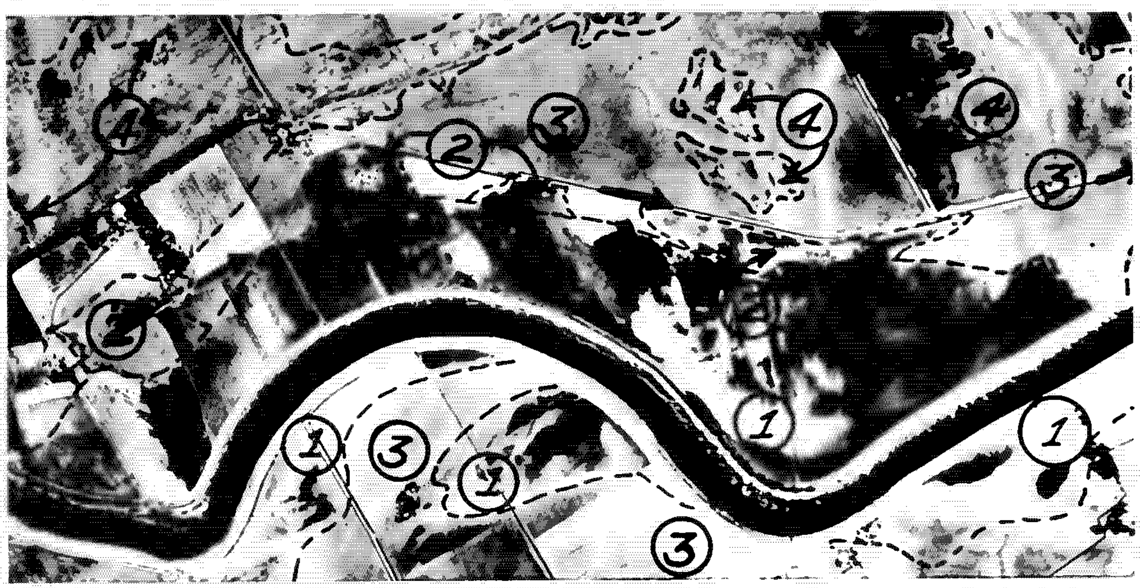


Figure 15. Identification of Seepage areas with Aerial Photography, Miller's Landing.

1. Seepage area

2. Drainage from seepage area

3. Saturated soil, possible seepage condition

4. Poor drainage, ponded water, and possible drainage from seepage

⟶ Direction of flow in drainage ditches

Infrared vertical aerial photography using a minus-blue filter taken on February 26, 1962. Heavy rainfall from February 6 through 19 saturated surface soils and caused drainage water to collect in depressed areas. The Sacramento River exceeded critical seepage stage from February 10 through 26; during this period seepage appeared in the Miller's Landing area. High ground water conditions persisted in the area until the end of March. Heavy seepage areas and ponded water appear dark on the aerial photographs. Saturated soil appears slightly less dark. Interpretation of the aerial photographs was complicated by the saturated soil conditions due to heavy rainfall prior to seepage stages of the river. Fields were observed during the period of greatest seepage in February, and the aerial photographs were interpreted in the field about one week after the exposures were made. The major seepage areas were still saturated at this time, and other areas where seepage had occurred were moist and identifiable with the aid of infrared aerial photography.

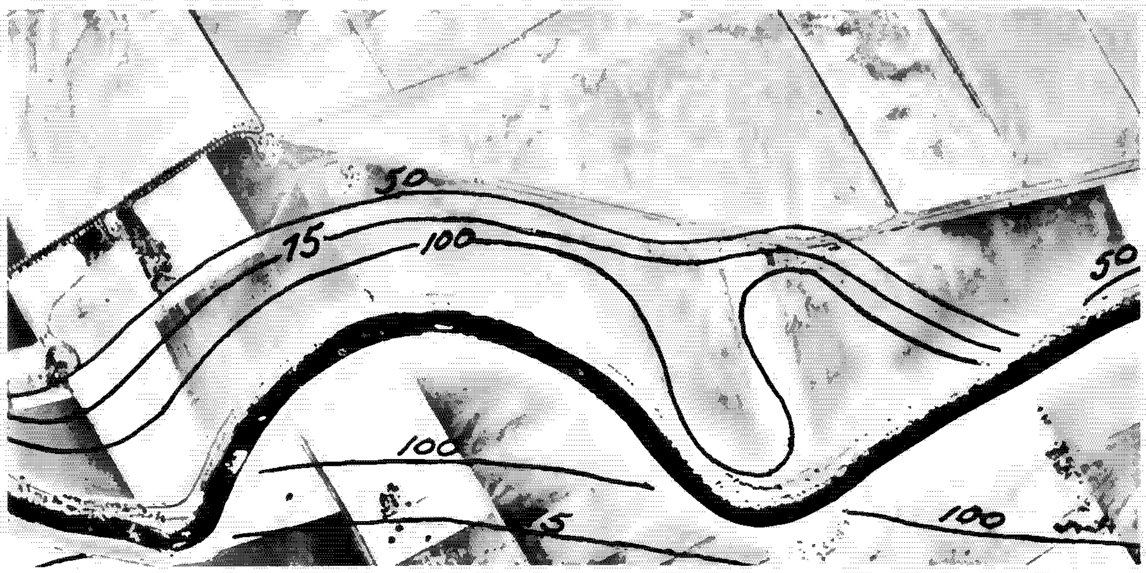


Figure 16.   Lines of Equal Electrical Resistivity Near Miller's Landing

100 ohm-feet and above, subject to seepage
100 to 75 ohm-feet, probable seepage
75 to 50 ohm-feet, little or no seepage
50 ohm-feet and below, no seepage

Lines of equal electrical resistivity are drawn on an infrared vertical aerial photograph taken with a minus-blue filter on May 30, 1962. No heavy rainfall had occurred during April or May and the Sacramento River was below critical seepage stage during this period. The darker areas on the photograph show areas under irrigation and depict surface soil characteristics. The electrical resistivity mapping in the Miller's Landing area, defined by lines of equal resistivity, indicate portions of the area which should be affected to various degrees by seepage during high river stages. Resistivity measurements were taken at numerous locations throughout the area to a depth of 20 feet, and correlated with drill logs to establish the representative conductivity of the various soil types. The location of the areas showing high resistivity compare favorably with the locations of the saturated areas shown in Figure 15. The combination of infrared photography and resistivity surveys can be utilized advantageously to classify questionable drainage and seepage areas.

TABLE 1

AREAS OF SEEPAGE DETERMINED FROM AERIAL PHOTOGRAPHS

Subarea (shown on Plate 1)	Date of Photograph					
	2/21/62 Area in acres	2/26/62 Area in acres	10/18/62 Area in acres	2/22/63 Area in acres	4/24/63 Area in acres	2/10/65 Area in acres
Sacramento River						
1	1,350	1,640	1,420	1,940	1,300	3,590
2	1,710	1,460	500	1,540	1,880	2,070
3	4,880	4,850	2,120	6,220	5,090	6,080
4	9,550	9,110	6,120	12,690	13,660	15,840
5	6,510	6,860	3,920	7,850	9,420	11,690
6	1,660	1,280	1,030	1,340	1,520	2,520
7	4,350	4,350	2,700	4,230	5,760	6,170
8	Insufficient Photo Coverage		6,770	14,020	29,770	19,590
Subtotal Sacramento River	---	-----	24,580	49,830	68,410	67,530
Sutter Bypass						
9	2,800	2,150	1,090	3,290	3,870	4,490
10	2,660	2,580	740	3,550	3,900	3,280
11	420	560	320	680	980	1,010
Subtotal Sutter Bypass	5,880	5,290	2,150	7,520	8,750	8,780
Feather River						
12	2,760	3,870	1,580	2,900	4,870	5,470
13	1,820	2,670	1,580	2,610	3,120	3,050
Subtotal Feather River	4,580	6,540	3,160	5,510	7,990	8,520
Yolo Bypass						
14	1,120	1,380	1,070	1,590	1,840	2,410
15	Insufficient Photo Coverage		330	1,810	1,880	1,960
Subtotal Yolo Bypass	---	-----	1,400	3,400	3,720	4,370
TOTAL, Study Area	---	-----	31,290	66,260	88,870	89,200

Factors Influencing Seepage

There are a large number of physical factors which influence seepage. These are discussed in Chapter II and include the stage and duration of the river surface above critical stage, antecedent soil moisture conditions, topography of the land adjacent to the watercourse, the geology and soils in the area, the location and change in the ground water table, drainage works in the area, width and depth of the river channel, the height and width of the river levee, agricultural practices in the seepage area, extent of the area covered by vegetation and the chemical quality of seepage. Field and office hydrographic, geologic, and physiographic studies were conducted both throughout the study area and in special test areas referred to as physical and economic seepage study areas which are shown on Plate 2 to isolate the effects of these variables.

A considerable quantity of information was necessary to evaluate the effects of the physical variables on seepage. The field observations, aerial photographs and electrical resistivity surveys used to delineate seepage areas were also used to study the effect of the physical variables on seepage. Additionally, ground water levels were measured at over 500 locations in the study area and were continuously monitored at approximately 90 locations within the study area; the physical seepage study areas were topographically mapped; subsurface geologic conditions and soil properties throughout the area of investigation were investigated by use of geologic drilling, logging and sampling plus field and laboratory testing of the soil properties; drainage works in several of the physical study areas were delineated and surface inflows and outflows in these areas were recorded; soil moisture conditions above the water table were measured in several of the physical study areas; cover crop and soil types were denoted; river stages were measured; and chemical quality of water in the inundated areas was tested to determine its source. Instrumentation in the Miller's Landing Physical Seepage Study Area is shown in Figure 17.

Figure 18 shows seepage conditions and several of the well recorders in the Miller's Landing Seepage Study Area in April 1963. Hydrographs of the Sutter Bypass and the water levels in four wells in the Karnak Study Area are shown in Figure 19. Geologic information obtained in the physical study areas is shown in Plates 12 through 18. Electrical resistivity surveys of the economic study areas are shown in Plates 19 through 29.

Relationship Between Influencing Factors and Seepage Areas

The relationships between riverflow conditions and seepage are extremely complex and depend upon a number of interrelated variables. Analysis of the relationships between the physical factors which cause seepage and the seepage areas was undertaken concurrently with the collection of basic data both to determine the nature of the information required and to assure the sufficiency of the data being collected. A number of alternative analyses were investigated. These included: (1) refinement of river stage-duration analyses developed in previous investigations; (2) seepage flow determinations, assuming a series of ground water wedges moving inland from the river; (3) development of empirical equations relating the level of water in a single ground water well to river conditions, with and without consideration of antecedent river conditions; (4) use of an electronic analog computer to model and

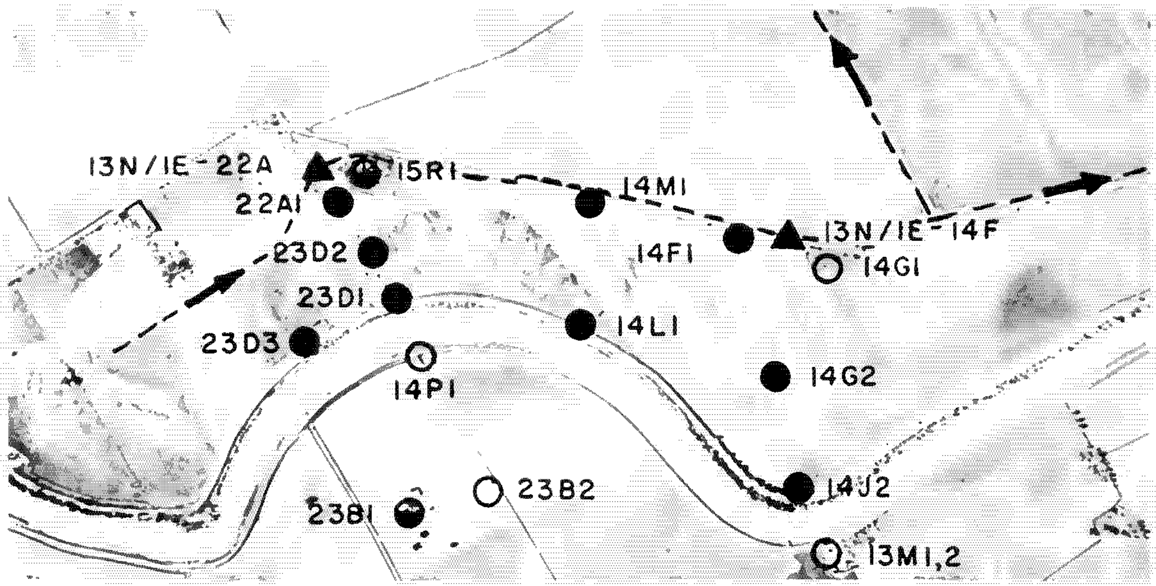
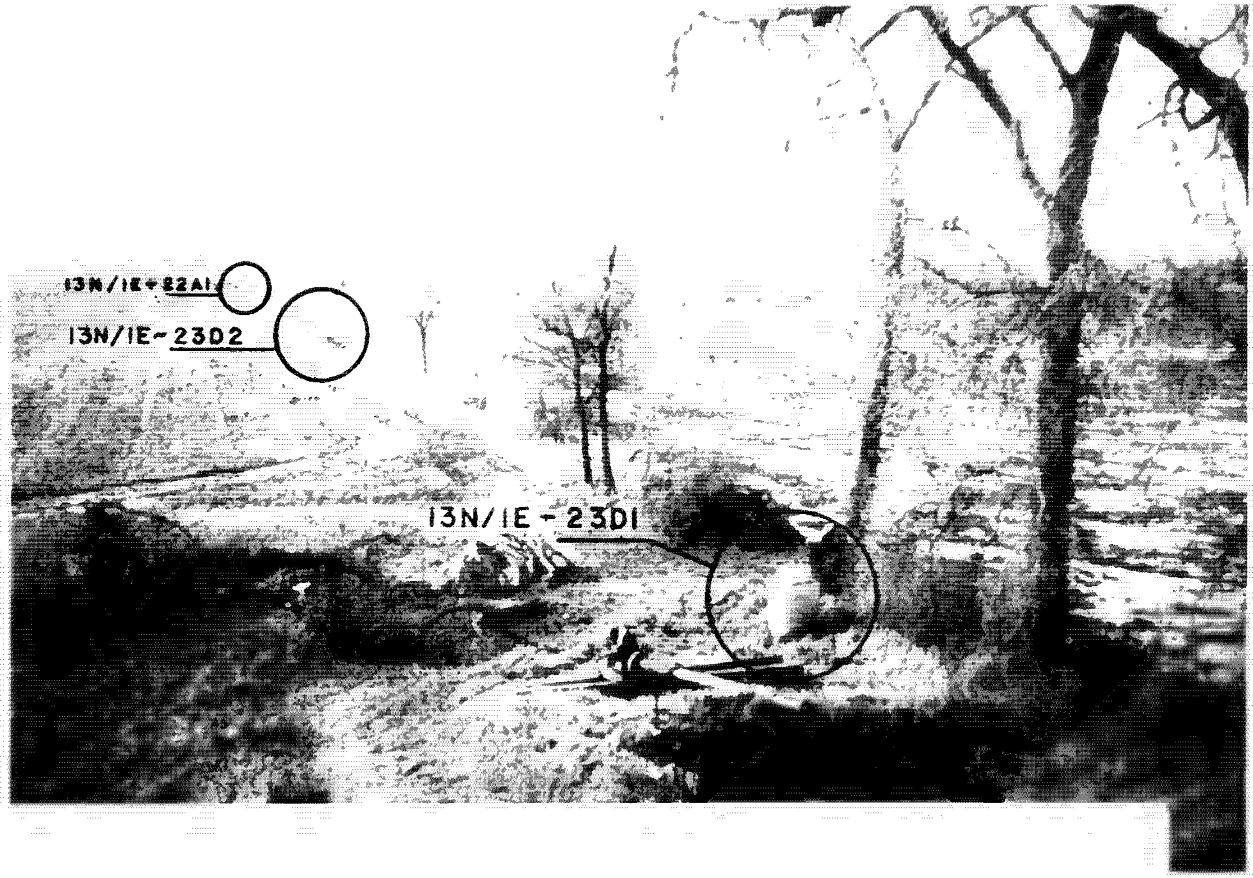


Figure 17. Instrumentation of the Miller's Landing Physical Seepage Study Area

- ▲ Drainage ditch stage recorder
- Domestic well
- ● Recorder well installation
- ○ Piezometer
- □ Neutron probe
- → Direction of flow in drainage ditches

This figure shows the instrumentation in the Miller's Landing area on a black and white vertical aerial photograph taken February 21, 1962. Recorder well and drainage ditch hydrographs were used to evaluate seepage in the study area and also gave some indication of the seepage flow from the Sacramento River into the area. Water levels in domestic wells and piezometers were measured frequently during the critical seepage periods and were correlated with recording wells in the area. Seepage conditions at the time the above photograph was taken were at a maximum; the black and white photograph does not give as much contrast between seepage areas and partially saturated soil conditions as does the infrared photograph shown in Figure 15. The numbers on the photograph identify the location of each piece of field equipment.



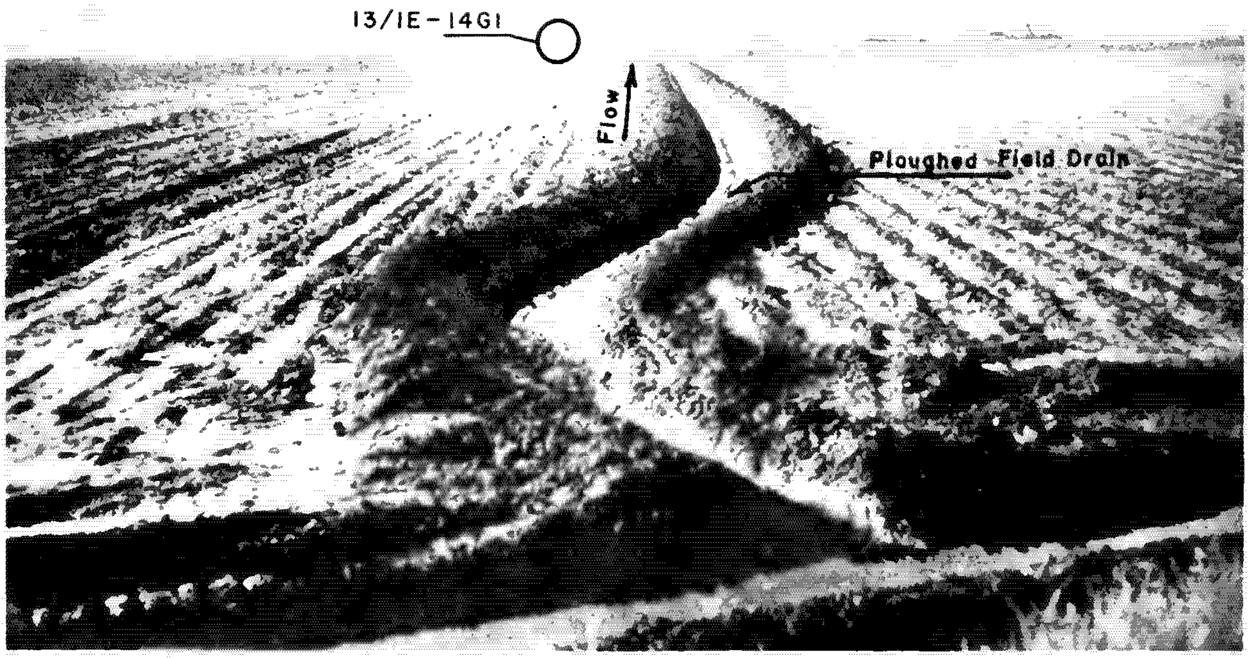
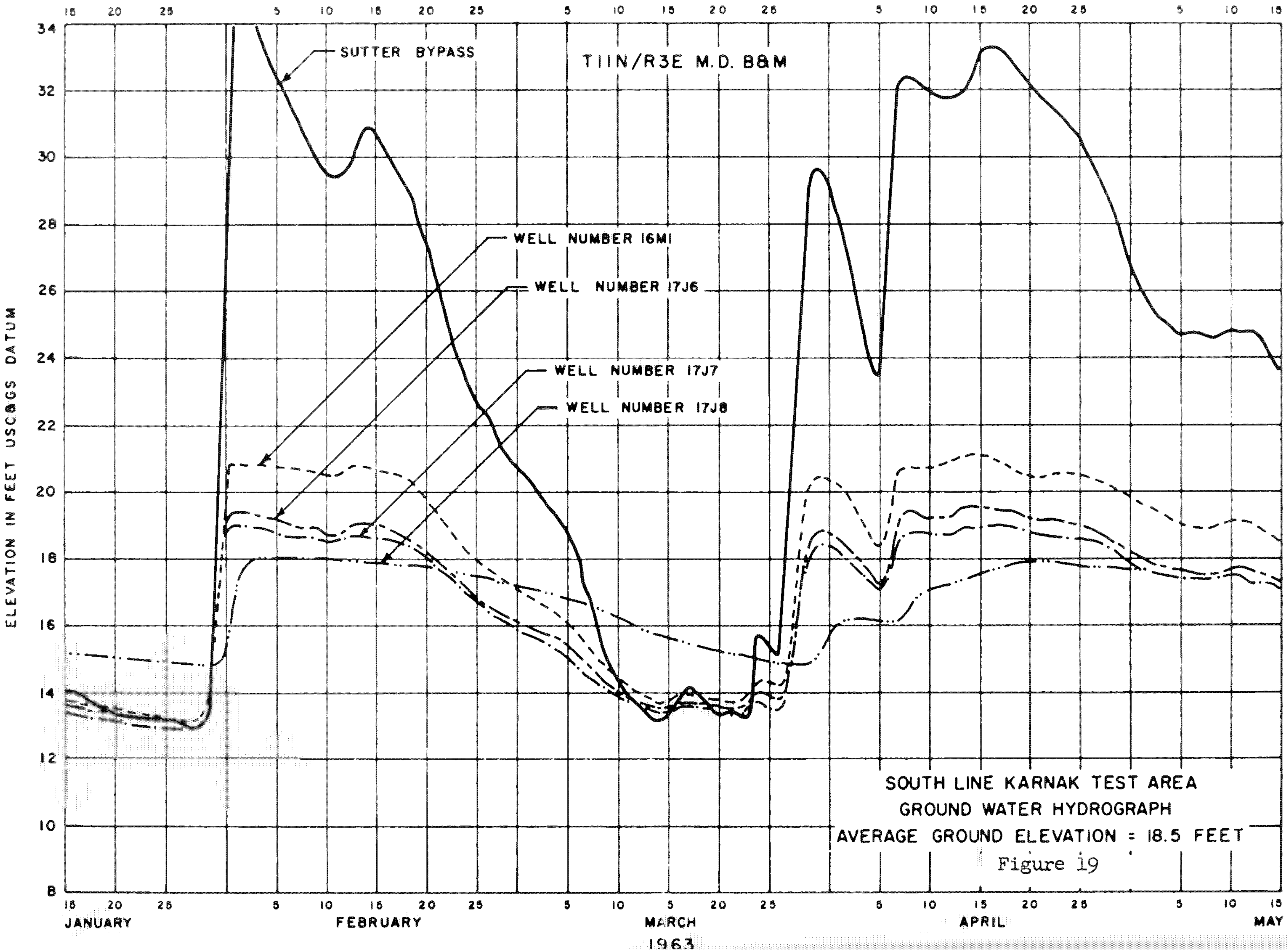


Figure 18. Seepage conditions within the Miller's Landing Study Area during April 1963.

The upper photograph defines seepage conditions along the southern well line in the study area. The lower photograph displays the type of field drain used in the field north of the northern well line. These shallow drains were effective for short duration floodflows causing mild seepage conditions. Heavy seepage inflow exceeded the capacity of the drains and made the ditches ineffective.



SOUTH LINE KARNAK TEST AREA
GROUND WATER HYDROGRAPH
AVERAGE GROUND ELEVATION = 18.5 FEET
Figure 19

study seepage conditions at a number of locations in the area of investigation; (5) multiple linear regression equations which statistically correlate the areas of seepage to riverflow conditions; and (6) empirical graphical correlations relating areas of seepage to riverflow conditions. Valuable insight into the factors which influence seepage and their relationship to seepage occurrences were evolved from these analyses.

The three most important factors affecting seepage were found to be the duration of the river above critical stage, the height of the river above this critical stage, and antecedent ground water conditions. However, because of the lack of data, only the first two of these factors were used to develop the final correlations used in this investigation. The effects of other factors such as soils and geology, topography and drainage facilities, are inherently included in the relationships since the magnitude of the seepage areas indicated on the aerial photographs is influenced by these factors.

Graphical correlation was selected as the most easily understood method of presenting the complex relationships between riverflow conditions and areas of seepage. To develop the correlations, the area of each seepage occurrence in each of the 15 subareas was correlated with the duration of the river above critical stage and the average height of the watercourse above critical stage. These areas are shown in Table I. River and bypass flow information was taken from daily hydrographs for gaging stations throughout the area of investigation. The resulting correlations for each subarea are shown on Plate 30 as seepage evaluation curves.

The following factors were considered in developing the correlation curves: (1) the time at which the aerial photographs of seepage were taken in relation with the duration of the river above critical stage; (2) the reliability of the acreage of seepage determined from each set of aerial photographs; (3) the comparison of the general shape of the correlation curve for one subarea with the shapes for the other subareas with similar characteristics; and (4) the direction and reasonableness of the slope of the correlation curves.

Soil conditions, topography and other physical and natural features vary throughout each subarea. Each curve was developed for average topographic conditions within the subarea. Therefore, the curves are not representative of conditions which occur on specific parcels of land within the subareas.

The curves also were developed for average antecedent soil moisture and ground water conditions which occurred during this investigation. The seepage areas would be less than indicated on the curves if antecedent soil moisture and the ground water table were low. Conversely, if the ground water table and soil moisture conditions were high due to previous rainfall, irrigation, or seepage, the seepage areas would be greater than indicated.

As additional drainage facilities are built and/or land leveling occurs, the relationships between river conditions and seepage areas as represented on the curves may change. However, the influence of changes in these constraints should not significantly affect the curves for a number of years.

The slopes of the curves are dependent primarily upon the soil conditions in the subareas. The greater the slope of a curve, the less permeable the soil and the slower the seepage area increases with time. Conversely, the flatter the slope, the more permeable the soil and the faster the seepage area increases with time.

The convergence of the family of curves as the duration of seepage increases, indicates that the influence of the duration of stage on the magnitude of the seepage area increases with time. Conversely, the minimum limit of the seepage area on each curve is dependent primarily upon the height of the river stage and the antecedent soil moisture and ground water conditions. The minimum limits of the seepage areas on each family of curves have a much larger range than the upper limits because (1) the river stage and soil moisture conditions have a more significant effect initially than after a prolonged period of seepage, and (2) the river stages and soil moisture conditions vary over a larger range initially than after an extended period of seepage.

The curves were not extended beyond the limits of the available data. Since there is a physical limitation on the magnitude of the total area of seepage which could occur in each subarea, the maximum area of seepage on each curve would be limited by a vertical asymptote representing the maximum possible seepage area. A seepage occurrence of this magnitude was not experienced during the investigation. Furthermore, the areas of the numerous small occurrences of seepage which happen on the average of several times per year in some locations were not measured as the economic effect of each of these occurrences is insignificant. As additional data becomes available, limits probably can be placed on the maximum possible areas of seepage and the time when seepage would begin.

The curves were drawn to best fit all measured conditions. In most cases, sufficient data was available to develop a family of curves; in others the limitation on data dictated that only a single curve be developed for a subarea. The points used to develop the curves are shown so that as additional data becomes available, the curves can, if necessary, be modified. Furthermore, with additional data, it will be possible to use an antecedent soil moisture factor in addition to the two factors already used. If further refinement is warranted, additional less significant factors can also be included.

The maximum deviation between a measured seepage area and the area of seepage determined from the correlation curves is approximately 50 percent. Most points are within a much closer tolerance. The accuracy of the curves can be improved when more data, particularly data over a wider range of conditions, becomes available.

Present Level of Seepage

The correlation curves were used to estimate the present level of seepage for Subarea No. 5, which is considered to be a typical subarea. The areas of seepage obtained in previous investigations generally included the area of all standing water, whether seepage, drainage, or both. Therefore, to obtain the level of seepage which occurred over a period of time considered representative of present conditions, it was necessary to use the correlation curves developed in this investigation to estimate seepage areas which may have occurred in the past, then to use those areas to estimate the present level of seepage.

Flow conditions for determining the present seepage level were based upon the measured daily flows which occurred during the period 1943-44 through 1964-65. This period was selected because the flow regimen of the river system did not change substantially during this time.

Using the historical riverflows, the area, duration and date of each seepage occurrence within the subarea were determined from the correlation curves by use of the electronic data processing program referred to earlier in this chapter. The average annual area of seepage for Subarea No. 5 was found to be approximately 7,365 acres. The average number of days of seepage per year for this period was 43 days. The results obtained for this area were assumed to be indicative of the results that would have been obtained for the other subareas. The initial date, duration and area of each seepage occurrence by year for the 22-year period and the maximum annual acreage affected is shown in Table 2.

Method of Determining Damage Under Present Level of Seepage

There are two types of damage which result from seepage; damage to agricultural areas and damage to urban areas.

As in the case of physical data on seepage, there was little existing information on the economic effects of seepage. Little data was available on the influence of seepage on plant growth. There were few measurements of the influence of seepage in limiting the use of land and of the resulting damages. Furthermore, the measurement of the influence of seepage on the urban economy had not been previously determined because it was difficult to differentiate between the economic effects of seepage and

SEEPAGE OCCURRENCES AND ACREAGES AFFECTED

SUBAREA NO. 5

TABLE 2

Water year	Seepage Occurrences: First: Initial day	First: Duration in days	Second: Initial day	Second: Duration in days	Third: Initial day	Third: Duration in days	Total number of days of seepage	Acreages Affected: First occurrence	Second occurrence	Third occurrence	Maximum acreage affected
1943-44							0				0
1944-45	2/2/45	17					17	6,030			6,030
1945-46	12/23/45	30					30	9,710			9,710
1946-47							0				0
1947-48	4/11/48	36					36	10,060			10,060
1948-49	3/4/49	24					24	6,840			6,840
1949-50	2/5/50	10					10	3,690			3,690
1950-51	11/19/50	10	12/4/50	26	1/13/51	58	94	5,030	9,370	12,230	12,230
1951-52	12/3/51	7	12/29/51	165			172	730	15,920		15,920
1952-53	12/30/52	38					38	10,570			10,570
1953-54	1/24/54	16	2/14/54	17	3/10/54	17	67 1/	5,390	6,900	5,360	6,900
1954-55							0				0
1955-56	12/20/55	55	2/22/56	22			77	12,020	7,840		12,020
1956-57	2/25/57	24	5/20/57	7			31	8,250	62		8,250
1957-58	1/27/58	125					125	14,940			14,940
1958-59	2/17/59	14					14	5,690			5,690
1959-60	2/8/60	9	3/8/60	8			17	4,060	860		4,060
1960-61	2/2/61	18					18	4,840			4,840
1961-62	2/10/62	17	3/7/62	7			24	6,910	60		6,910
1962-63	10/13/62	8	2/1/63	22	3/29/63	46	76	4,620	8,050	11,350	11,350
1963-64							0				0
1964-65	12/22	55	4/11/65	20			75	12,020	5,570		12,020
Average							43				7,365

1/ Fourth occurrence started on April 6, 1954 and had a duration of 17 days. It affected some 4,444 acres.

drainage. Therefore, it was necessary to gather economic data on the effects of seepage and to develop relationships between the magnitude and duration of seepage and those economic effects.

<u>Economic Data</u>

Economic data was compiled between 1960 and 1965. During this period literature was researched and crop specialists, urban officials, farmers, and others were interviewed to acquire pertinent data on seepage damage. Crop sampling programs were undertaken and land use and land classification surveys were conducted. This information was assessed on a preliminary basis concurrently with the collection of data.

The data collection program was refined as the study progressed. Eleven specific areas, referred to as economic seepage study areas, were selected on a random basis to avoid inadvertent bias of results. These areas are shown on Plate 2. Agriculturists in these areas were interviewed to obtain definitive data on seepage damages. This data, in conjunction with information in various technical publications, was used to develop relationships between seepage and seepage damage for each representative crop grown in the area of investigation.

A sampling program was undertaken to acquire specific information on the yield and quality of grain crops which had been exposed to seepage. Sampling was conducted at several locations in the area of investigation. Sampling at each location consisted of gathering grain as it was harvested in each of three parts of a field. Samples were taken from the most severe seepage area in the fields, from what appeared to be an average stand in the field, and from the best area. The sampling was continued through 1963 and this information was used along with other data, to develop the economic influence of seepage on the crops grown in the area of investigation.

The pattern of land use in the area of investigation was determined by a field survey conducted in the summer of 1961. A land classification survey was conducted in 1962. The standards utilized in the classification included soil texture, slope, drainage, and salinity conditions. These factors represent major determinants in the historic and potential use of land. The limitation of land use can be determined from a comparison of land use and land classification surveys and from comparisons of income from agricultural pursuits in areas with and without seepage.

Information regarding the impact of seepage on the urban economy was obtained through personal interview and from study of the added costs of constructing projects in the seepage areas. Statements from city engineers and planners, Federal Housing Administration officials, real estate appraisers, engineering consultants, and other available economic data for each urban locality were compiled. The resulting information together with crop damage information and the information on the limitation of land use due to seepage can be used to determine the total present economic effect of seepage.

Relationship Between Seepage and Seepage Damage

It was necessary to derive the economic relationships between seepage and seepage damage in order to assess the estimated damage from the present level of seepage.

Seepage occurs in both urban and agricultural areas. Therefore, its total economic effect can be estimated by measuring its effect on both the agricultural and urban economies.

Agriculture. Since agriculture is the most important economic activity in the area of investigation, agricultural damages are the most significant. There are two types of damage to the agricultural economy. The most obvious is direct damage which includes inability to plant at the optimum time, total or partial loss of crops, the inability to double crop, decreased crop yields, loss of trees and perennial plants, and miscellaneous damages such as additional cultivation and loss in the effectiveness of fertilizer. In one way or another these factors either increase the cost of production or reduce crop yields which, in turn, decreases crop income.

In addition to direct damage, seepage usually imposes a limitation on the type of crops which can be grown in areas frequently subjected to seepage. In many such areas, an increased intensity of use or an entirely different cropping pattern yielding a higher income could be established if seepage were not prevalent.

There are many factors which influence the extent of crop damage from seepage. Analysis indicated that the three most important factors are: (1) the time of year of the seepage occurrence, (2) the duration of the seepage period, and (3) the susceptibility of a crop to damage under the foregoing conditions.

Two curves were developed to express the impact of these factors on seepage damage. Once the seepage area, the time and duration of a seepage occurrence and the cropping pattern are known or can be projected, seepage damage to crops can be estimated using these curves.

The first set of curves indicates, for each representative crop grown in the area of investigation, the proportionate part of the crop normally planted at any specific time during the year. These curves, titled Crop Planting Curves, are shown on Plate 31.

The second series of multigraphic curves which are titled Crop Damage Curves, show the percentage deduction in yield for each representative crop grown in the area of investigation based upon the duration of seepage and the quarter of the year in which the seepage occurs. The Crop Damage Curves are shown on Plate 32.

Urban. Studies indicate that the price of land which is subjected to seepage is less than the price of land which does not experience seepage. The lands differ in price by approximately the cost of drainage facilities necessary to render the land with seepage as desirable as the land without seepage.

Estimates obtained from the Federal Housing Administration are that the cost of a drainage system, if not installed prior to construction of other improvements, ranges from $500 to $800 per lot in residential areas. If installed after the construction of residences, sidewalks and streets, the estimated costs increase to a range of about $1,200 to about $1,500 per lot.

In addition to the installed costs of drainage facilities, there are the annual costs of operation, maintenance and replacement of the drainage facilities.

The cost of an adequate drainage system which would make the seepage areas as functional as the nonseepage areas, plus the additional operating costs for pumping seepage can be used as the measure of seepage damage to urban areas.

Damage Under Present Level of Seepage

The present level of seepage damage was computed for Subarea No. 5 for the 22-year period 1943-44 through 1964-65. Since very little urban development exists within the subarea, only damage to the agricultural economy was estimated. Furthermore, damages to the agricultural economy were based on the present crop pattern. Therefore, only direct damages were included in the evaluation. It should be noted that had there not been seepage during this period, a different crop pattern yielding a higher income could have prevailed.

The present level of seepage damage was based upon the seepage areas and the time and duration of the seepage occurrences as shown in Table 1. The damages were based on the crop pattern prevailing in 1961, which was assumed to be representative of the crop pattern for the entire period between 1943 through 1965. The economic effect of seepage was measured as the difference in the financial return attributable to land with and without seepage.

The return attributable to land was determined by deducting from the crop gross income all variable and fixed costs of production except the interest cost on land. It was also based upon the price-cost relationship existing during the 1960-64 period. The estimated average return without seepage for each of the crops grown in Subarea No. 5 is shown in Table 3. The return for each crop in the subarea without seepage as a percent of the total in the subarea, and the weighted average return per acre for the subarea are shown in Table 4.

An electronic data processing program was developed so that the estimated damage for each seepage occurrence could be computed rapidly. This program computes average annual damage for each county and each subarea. This electronic data processing program operates in conjunction with the program that computes seepage areas and durations and which was described previously in this chapter.

The return attributable to land under conditions of no seepage was calculated as shown in the second, third, and fourth columns of Table 5.

Under seepage conditions the extent of seepage in the subarea varied from year to year. The return attributable to land affected by seepage is shown for each year in columns 5, 6, and 7 of Table 5. The return for the portion of the subarea not affected by seepage is shown in columns 8, 9, and 10.

The return attributable to land with seepage was determined as follows. The acreage, time of occurrence, and duration of seepage was taken from Table 1. The acreage planted to a particular crop at the time of each seepage occurrence was determined by referring to the crop planting curves, which indicate the proportionate part of the crop normally planted at a specific time of the year. Adjustments were made in the acreages obtained from the crop planting curves to account for variations from the normal planting schedule caused by rainfall or seepage.
The reduction in yield for each crop planted at the time of each seepage

TABLE 3

AVERAGE ANNUAL RETURN ATTRIBUTABLE TO LAND PER ACRE WITHOUT SEEPAGE
SUBAREA NO. 5
(1960-64 Base Period)

Crop	Unit	Yield	Price	Gross income	Less Costs				Return attributable to land 1/
					Variable	Fixed 2/	Management	Total	
Peaches	Ton	13.0	$ 62.00	$806.00	$464.15	$139.75	$80.60	$684.50	$121.50
Pears	Ton	10.0	82.50	825.00	461.30	159.20	82.50	703.00	122.00
Walnuts	Ton	.80	500.00	400.00	150.95	116.55	40.00	307.50	92.50
Asparagus-Tomatoes	Ton	25.0	25.00	625.00	374.30	120.70	62.50	557.50	67.50
Dry Beans	CWT	18.0	9.50	171.00	96.70	29.70	17.10	143.50	27.50
Milo-Corn	CWT	55.0	2.40	132.00	50.60	32.00	13.20	95.80	36.20
Sugar Beets	Ton	20.0	12.50	250.00	130.90	43.30	25.00	199.20	50.80
Rice	CWT	50.0	4.00	200.00	109.90 3/	35.10	20.00	165.00	35.00
Alfalfa	Ton	7.0	25.00	175.00	78.50	45.30	17.50	141.30	33.70
Pasture	AUM 4/	12.0	7.00	84.00	24.70	24.40	8.40	57.50	26.50
Pasture	AUM	6.0	7.00	42.00	15.65	12.80	4.20	32.65	9.35
Barley	CWT	30.0	2.30	69.00	28.75	22.50	6.90	58.15	10.85
Safflower	Ton	1.25	85.00	106.00	32.45	29.95	10.60	73.00	33.00

1/ Annual gross income minus all on farm production costs, exclusive of cost of land.
2/ Except land cost but includes land reclamation cost.
3/ Water cost assumed to be $2.50 per acre-foot for rice.
4/ Animal unit months.

TABLE 4

PRESENT CROPPING PATTERN AND AVERAGE ANNUAL RETURN
ATTRIBUTABLE TO LAND WITHOUT SEEPAGE
SUBAREA NO. 5

Crop	Return attributable to land per acre	Crop acreage in percent of total of subarea	Weighted return attributable to land by crop
Peaches	$121.50	.24	$ .29
Pears	122.00	.95	1.16
Walnuts	92.50	3.50	3.24
Asparagus	67.50	.54	.36
Tomatoes	67.50	10.03	6.77
Dry Beans	27.50	2.82	.78
Milo	36.20	12.02	4.35
Sugar Beets	50.80	11.43	5.81
Rice	35.00	9.16	3.21
Alfalfa	33.70	18.90	6.37
Pasture 12 AUM 1/	26.50	2.99	.79
Barley	10.85	17.43	1.89
Pasture 6 AUM	9.35	2.71	.25
Safflower	33.00	7.28	2.40
Total		100.00	
Weighted Return Attributable to Land Per Acre			$37.70

1/ Animal Unit months.

TABLE 5

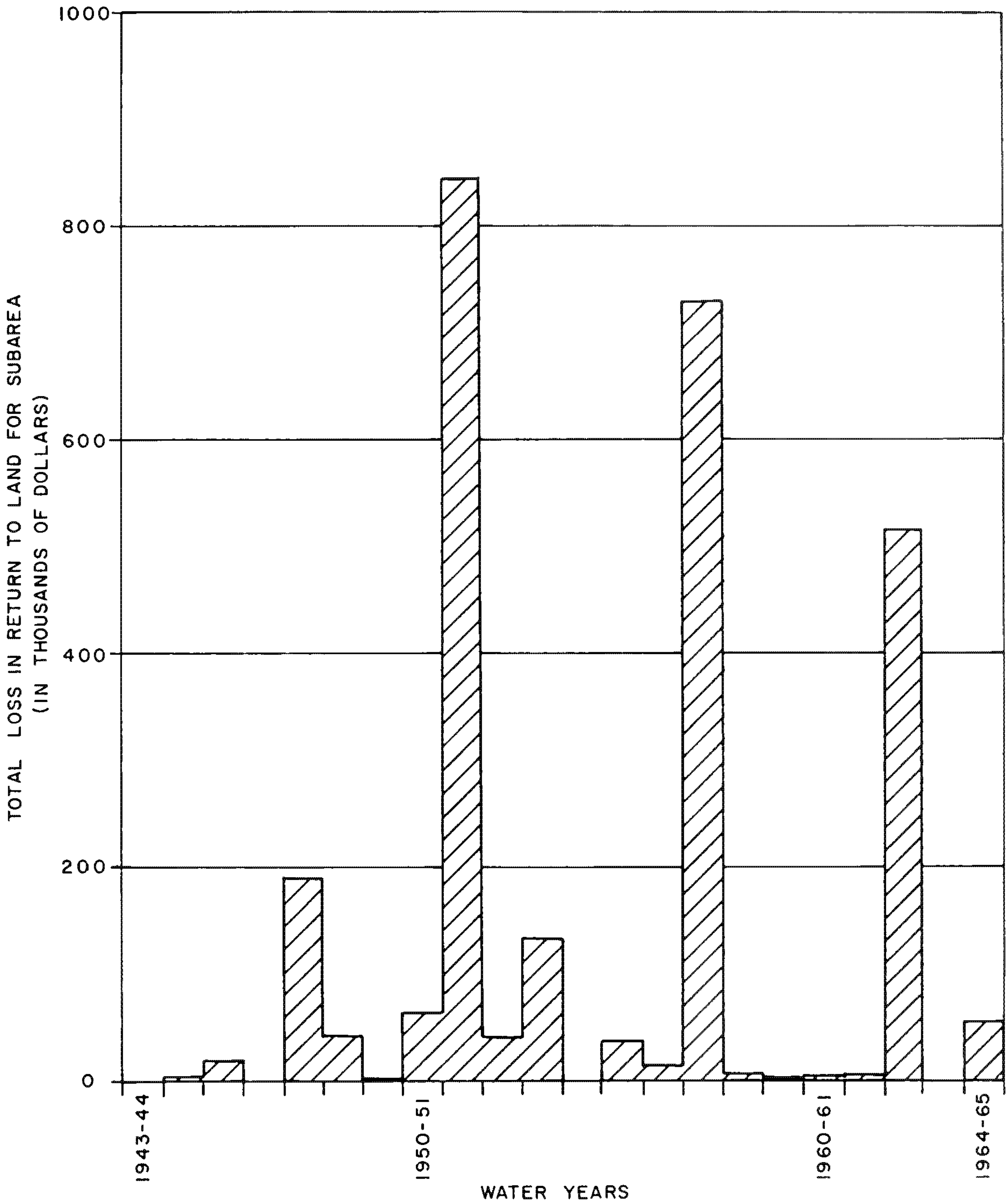
ECONOMIC EFFECTS OF SEEPAGE ON RETURN ATTRIBUTABLE TO LAND
SUBAREA NO. 5

Water year	Under Nonseepage Conditions: Net irrigable acreage 1/	Under Nonseepage Conditions: Return to land: Per acre	Under Nonseepage Conditions: Return to land: Total for subarea	Under Seepage Conditions: Seepage Area: Acreage	Under Seepage Conditions: Seepage Area: Return to land: Per acre	Under Seepage Conditions: Seepage Area: Return to land: Subtotal for subarea	Under Seepage Conditions: Nonseepage Area: Acreage	Under Seepage Conditions: Nonseepage Area: Returr to land: Per acre	Under Seepage Conditions: Nonseepage Area: Returr to land: Subtotal for subarea	Under Seepage Conditions: Total: Return to land: Per acre	Under Seepage Conditions: Total: Return to land: Total for subarea	Loss in return to land with seepage: Per acre	Loss in return to land with seepage: Total for subarea
1943-44	21,400	$37.70	$806,800	0	$ 0	$ 0	21,400	$37.70	$806,800	$37.70	$806,800	$ 0	$ 0
1944-45	21,400	37.70	806,800	6,030	36.90	222,500	15,370	37.70	579,400	37.50	801,900	0.20	4,300
1945-46	21,400	37.70	806,800	9,710	35.60	345,700	11,690	37.70	440,700	36.70	786,400	1.00	21,400
1946-47	21,400	37.70	806,800	0	0	0	21,400	37.70	806,800	37.70	806,800	0	0
1947-48	21,400	37.70	806,800	10,060	18.70	188,100	11,340	37.70	427,500	28.80	615,600	8.90	190,500
1948-49	21,400	37.70	806,800	6,840	31.20	213,400	14,560	37.70	548,900	35.60	762,300	2.10	44,900
1949-50	21,400	37.70	806,800	3,690	37.40	138,000	17,710	37.70	667,700	37.60	805,700	0.10	2,100
1950-51	21,400	37.70	806,800	12,230	32.50	397,500	9,170	37.70	345,700	34.70	743,200	3.00	64,200
1951-52	21,400	37.70	806,800	15,920	(15.30)	(243,600)	5,480	37.70	206,600	(1.70)	(37,000)	39.40	843,200
1952-53	21,400	37.70	806,800	10,570	33.80	357,300	10,830	37.70	408,300	35.80	765,600	1.90	40,700
1953-54	21,400	37.70	806,800	6,900	18.30	126,300	14,500	37.70	546,600	31.40	672,900	6.30	134,800
1954-55	21,400	37.70	806,800	0	0	0	21,400	37.70	806,800	37.70	806,800	0	0
1955-56	21,400	37.70	806,800	12,020	34.50	414,700	9,380	37.70	353,600	35.90	768,300	1.80	38,500
1956-57	21,400	37.70	806,800	8,250	35.80	295,400	13,150	37.70	495,800	37.00	791,200	0.70	15,000
1957-58	21,400	37.70	806,800	14,940	(11.10)	(165,800)	6,460	37.70	243,500	3.60	77,700	34.10	729,700
1958-59	21,400	37.70	806,800	5,690	36.50	207,700	15,710	37.70	592,300	37.40	800,000	0.30	6,400
1959-60	21,400	37.70	806,800	4,060	37.40	151,800	17,340	37.70	653,700	37.60	805,500	0.10	2,100
1960-61	21,400	37.70	806,800	4,840	36.70	177,600	16,560	37.70	624,300	37.50	801,900	0.20	4,300
1961-62	21,400	37.70	806,800	6,910	36.90	255,000	14,490	37.70	546,300	37.40	801,300	0.30	6,400
1962-63	21,400	37.70	806,800	11,350	(7.60)	(86,300)	10,050	37.70	378,900	13.70	292,600	24.00	513,600
1963-64	21,400	37.70	806,800	0	0	0	21,400	37.70	806,800	37.70	806,800	0	0
1964-65	21,400	37.70	806,800	12,020	32.90	395,500	9,380	37.70	353,600	35.00	749,100	2.70	57,800
Average Annual		$37.70	$806,800	7,400	$21.00	$154,100	14,000	$37.70	$529,100	$31.90	$683,200	$ 5.80	$123,600

1/ Gross irrigable acreage is 23,260
2/ Figures in parenthesis are negative values.

occurrence was determined by referring to the crop damage curves, which show the percentage reduction in yield for each crop based upon the duration of seepage and the quarter of the year in which the seepage occurs. The return attributable to land was calculated based upon the reduced yield. If seepage or rainfall would have prevented a particular annual crop from being planted, an alternate crop was assumed to be planted to the extent possible. Costs incurred for the first crop are included in the analysis.

The total return attributable to land under seepage conditions, which is shown in columns 11 and 12 of Table 5, was then deducted from the return under nonseepage conditions. The difference in return with and without seepage represents the direct effect of seepage on the agricultural economy in Subarea No. 5. This data is shown in the last two columns of Table 5 and graphically illustrated in Figure 20. The economic effects of seepage on limiting land use and on the urban economy are not included in the foregoing figures.



DIRECT AGRICULTURAL DAMAGE RESULTING FROM SEEPAGE
SUBAREA NO. 5

Figure 20

CHAPTER IV

FUTURE SEEPAGE CONDITIONS

Large water development projects are being planned and constructed in northern California to meet the growing need for water throughout the State. These projects will change the flow regimen in the Sacramento River system and these changes will alter the amount of seepage and seepage damage which may occur in the future.

Flows in the Feather and lower Sacramento Rivers will be influenced by the operation of Oroville reservoir which is currently under construction. The regimen of the Sacramento River will be affected by the operation of projects within the Sacramento River Basin and those outside the basin which may utilize the Sacramento River as a conduit for conveying imported water to the Sacramento-San Joaquin Delta.

The effect of the Oroville facilities and of increased levels of summer flow in the Sacramento River which could be caused by imported water were investigated. These studies are discussed in this chapter.

Estimated Effect of Oroville Reservoir on Seepage Conditions

For purposes of this investigation, an operation study of the Oroville facilities was developed. Using this study, the Oroville facilities were operated to provide 710 megawatts of power, the reservoir was operated for flood control purposes and releases were made to satisfy downstream water rights and to maintain fishlife in the river. Projected inflows and releases from the Oroville facilities were based on daily flows which occurred during the historic period 1943-1964. These were modified to reflect 1990 levels of development upstream from Oroville so as to be representative of conditions which will occur during the period the facilities are in operation. Using these flows, the duration, time of occurrence, and areas of seepage which would occur along the Feather River between Marysville and Verona were compiled from the seepage evaluation curves. The probability of seepage occurrences of 1, 5, and 15 days were determined.

The foregoing process was repeated assuming that Oroville reservoir was not in operation during the 21-year study period.

The estimated effect of Oroville reservoir on seepage conditions was then determined by comparison of the probabilities of occurrence of seepage with and without the Oroville facilities in operation for the 21-year study period.

Project Operating Criteria

The Oroville facilities include a large multipurpose dam and reservoir and two afterbay reservoirs with a combined storage capacity of 3,552,900 acre-feet. These multiple-purpose facilities will be operated for flood control, power generation, water supply, recreation, and fish and wildlife enhancement. Basically, water will be stored during periods of large inflow and released during dry periods to meet downstream demands.

The operation criteria for the Oroville facilities have not been completely established at this time. However, the operation study conducted for this investigation provides an estimate of flows under future conditions, and modifications in the operation will not materially change the results of the studies described in this chapter.

The operation study, titled "Oroville-Thermalito Reservoir Power Operation Study MD-1", tentatively determined the impaired downstream flows which could result from the operation of the Oroville facilities. The criteria used in the operation study were: (1) the inflows to Oroville reservoir during the period January 1928 through December 1964 were adjusted to account for the projected 1990 level of upstream development; (2) a total dependable generating capacity of 710 megawatts was obtained utilizing a pump-back and pump-storage operation; (3) the service area water demand in 1990 was assumed to be 938,500 acre-feet; (4) a 50 percent deficiency in reservoir storage was assumed during 1931 and 1933, the two driest years of the study period; (5) the flood control stage at the end of each day was based upon the U. S. Corps of Engineers' required flood control reservation in acre-feet; and (6) the minimum continuous fish releases in the river below Thermalito Afterbay were 800 cfs.

The flows without the Oroville facilities in operation were the same as the inflows described under (1) above, but were not modified by the influence of the Oroville facilities.

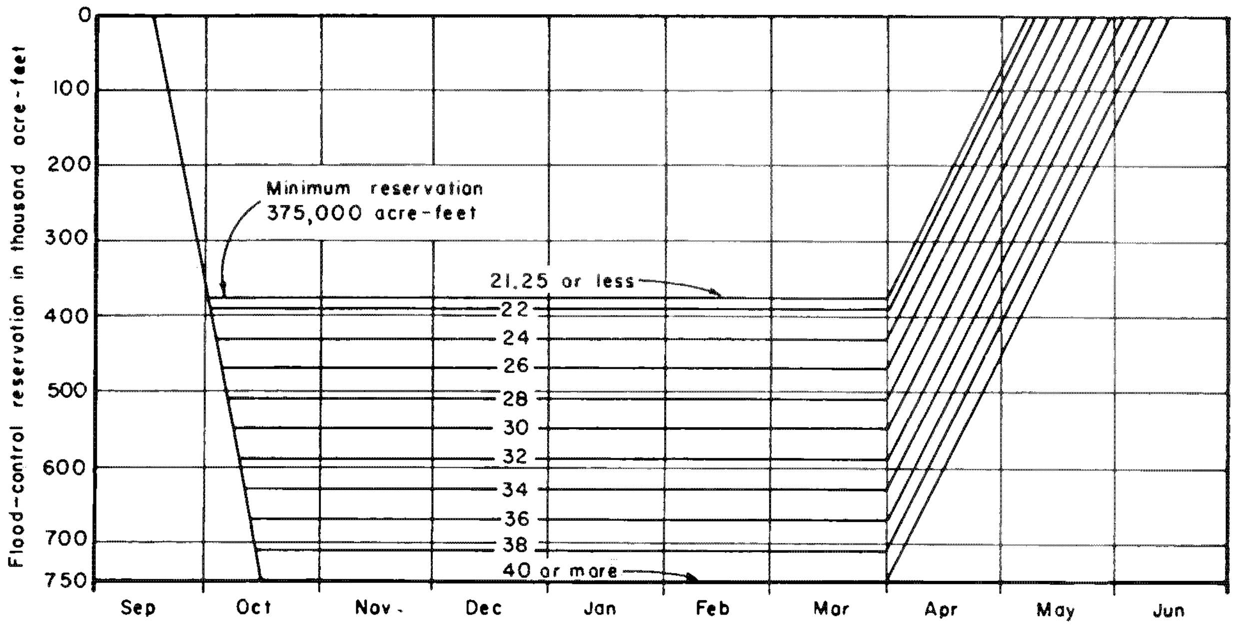
The flows entering the Feather River from the Yuba and Bear Rivers are minimal during the summer months and include historic diversions and accretions on the valley floor. For the purpose of this operation study, the winter flows in the Yuba and Bear Rivers were assumed to be unimpaired and equal to the historic flows because there is little flood control storage in the upstream water developments on the two rivers. Therefore, the flows in the Feather River below Shanghai Bend would reflect the flow from the Yuba River, and the flow at the gaging station at Nicolaus would incorporate all upstream flows plus contributions from the Bear River.

Operation for Flood Control. Oroville reservoir was operated for flood control under criteria established by the U. S. Corps of Engineers. In general, sufficient storage capacity will be reserved during the winter to provide for temporary storage of flood inflows for later release at rates within the capacity of the leveed downstream channel. The channel capacity of the Feather River below its confluence with the Yuba River is 300,000 second-feet.

The general plan of development for the Yuba River, with flood control storage at the proposed New Bullards Bar and Marysville Reservoirs, provides for a maximum flow of 120,000 second-feet in the Yuba River. Of the remaining 180,000 second-feet of channel capacity in the Feather River, 150,000 second-feet will be allocated for controlled releases from Oroville reservoir, and 30,000 second-feet will be reserved for local inflow between Oroville and the Yuba River.

The maximum flood control reservation for Oroville reservoir is 750,000 acre-feet. A lesser reservation may be maintained, depending upon the time of the year and the amount of rainfall during the preceding 60-day period. The flood control diagram for Oroville reservoir is shown on Figure 21.

As shown on Figure 21, operation of Oroville reservoir for flood control can be analyzed under three distinct periods. It is possible that during the first period, September 15 to October 15, 750,000 acre-feet of stored water would have to be emptied within a 30-day period, for an average release into the river of 12,500 second-feet. However, releases from the reservoir during the summer and autumn would normally reduce reservoir storage by September 15 to a level far below that required for flood control.



USE OF DIAGRAM

1. Parameters are preceding 60-day basin-mean precipitation expressed as a percentage of normal annual precipitation.

2. Except when releases are governed by the emergency release diagram, all storage in excess of that indicated by this diagram shall be released as rapidly as possible, subject to the following conditions:

   a. That releases do not exceed 50,000 cfs or maximum rate of inflow for the flood, whichever is greater.

   b. That releases do not exceed 150,000 cfs at any time.

   c. That flows in Feather River above Yuba River do not exceed 180,000 cfs at any time.

   d. That releases are not increased more than 10,000 cfs or decreased more than 5,000 cfs in any 2-hour period.

   e. After 31 March, reservation for any given parameter decreases 10,000 acre-feet per day.

NOTE: Taken from U.S. Corps of Engineers office report "Flood Control Operation Criteria for Oroville Reservoir, Feather River California", December 1958

OROVILLE DAM AND RESERVOIR PRELIMINARY FLOOD CONTROL STORAGE RESERVATION DIAGRAM

Figure 21

Therefore, adequate storage capacity should be available to reduce the peak and volume of runoff from the initial storms of the season and the downstream channel seepage should be reduced during the period from September 15 to October 15.

During the second period, October 15 to April 1, the flood control storage reservation in the reservoir will be maintained between a minimum of 375,000 acre-feet and a maximum of 750,000 acre-feet, depending upon antecedent rainfall. Floodflows will be stored temporarily and gradually released. This storage also should reduce the magnitude of seepage and seepage damage.

During the third period, April 1 through June 15, the reservoir can store inflow at a minimum rate of 5,000 second-feet, thereby reducing downstream releases and reducing or eliminating seepage.

Operation for Water Demand. The Oroville facilities were operated to satisfy downstream water rights and maintain sufficient flows in the Feather River for fish and wildlife as follows:

(1) local downstream service area water demands in 1990 were estimated to be 938,500 acre per year;

(2) the minimum continuous fish release at the Diversion Dam and from the Feather River outlet works were each assumed to be 400 second-feet, resulting in a combined flow in the river immediately below Thermalito Afterbay of 800 second-feet;

(3) additional water was diverted from the afterbay to meet the Sutter-Butte and Western Canal demands; and

(4) water required from June through September for export and Delta water quality control, was supplied from the power releases and from inflow into the river from the Kelly Ridge powerhouse.

The downstream releases for water demand were made on a continuous basis and reached a maximum of 6,000 second-feet in August.

Operation for Power Generation. The Oroville-Thermalito generating equipment was assumed to have a dependable capacity of 710 megawatts. The dependable electric power and energy output was based upon operation of the reservoir through the period of lowest runoff from January 1928 through December 1937. During this period, the onpeak hours each day were assumed to be the same during each week of the month, and a 50 percent deficiency in reservoir storage occurred in 1931 and 1933.

Power releases were made for onpeak and offpeak energy generation. The total yearly hours of onpeak and offpeak generation were 2,978 and 4,116, respectively. The combined Oroville-Thermalito plant factor was assumed to be 34 percent for onpeak loads. During offpeak hours, water not required to meet local service area demands or downstream use was pumped back into Oroville reservoir for regeneration. The total 10-year generation and pump energy demands used for Oroville-Thermalito were 2,235,432 and 799,170 megawatt hours, respectively.

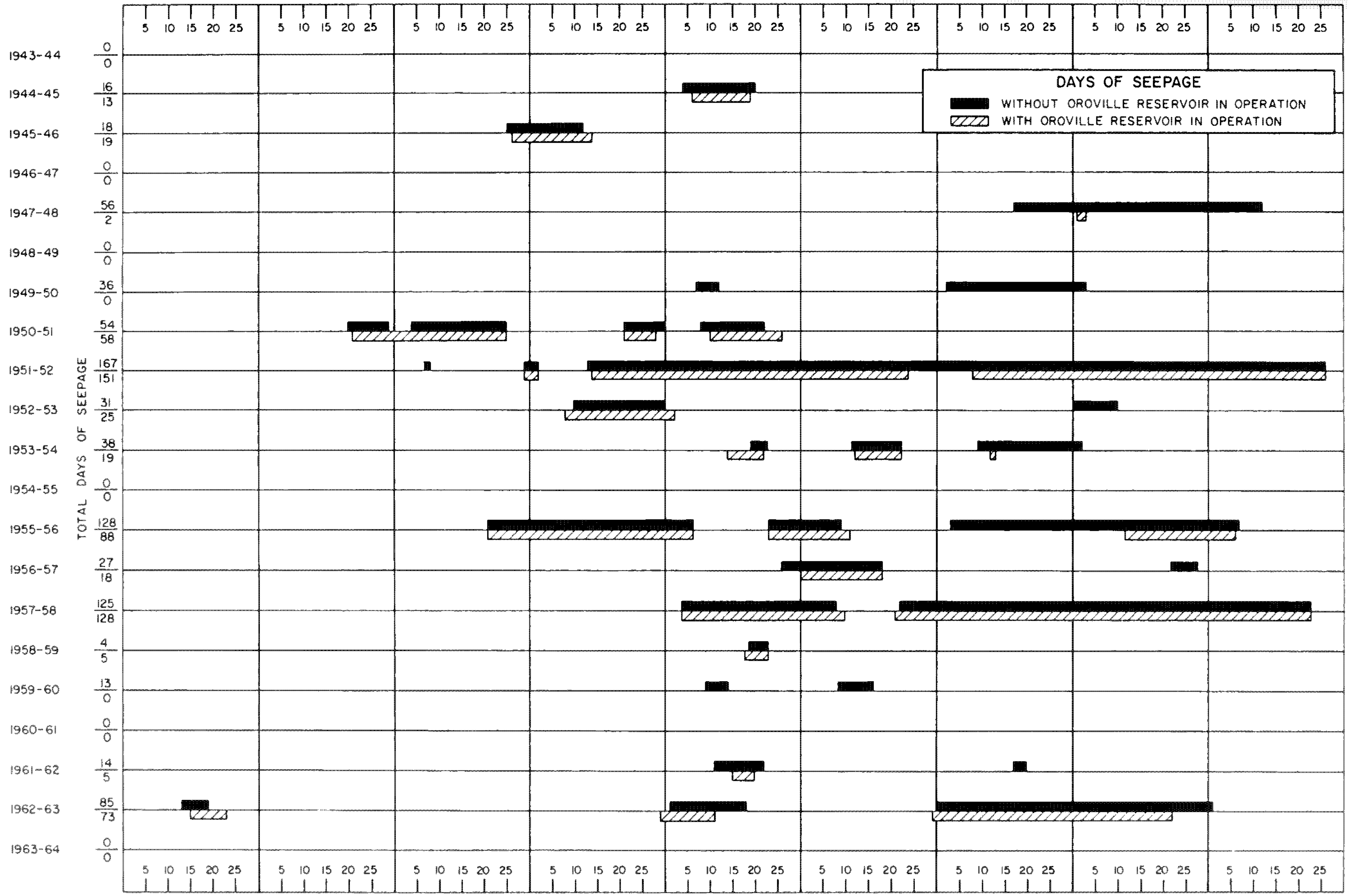
Analysis of Project Operations

Analysis of the effect of operation of the Oroville facilities on seepage was based on information obtained from the daily operation study. The analysis covered Subareas 12 and 13 which extend along the Feather River from Marysville to Verona. The reach upstream from Marysville is not subjected to seepage to any significant extent and this reach was not considered part of the study area.

Information developed from the daily operation study for the period October 1, 1943, to July 1, 1964, was used to compute flows and stages in the Feather River below Shanghai Bend and at Nicolaus. This period was selected because the stream regimen would reflect backwater effects caused by the Sacramento River with Shasta Reservoir in operation. The following were computed: (1) the daily flow below Shanghai Bend; (2) the daily river stage below Shanghai Bend and at Nicolaus; (3) the days the river would be above critical seepage stage at each of these locations; (4) the average height of the river above critical stage during each seepage occurrence; and (5) the days above critical seepage stage for each seepage occurrence by month and year.

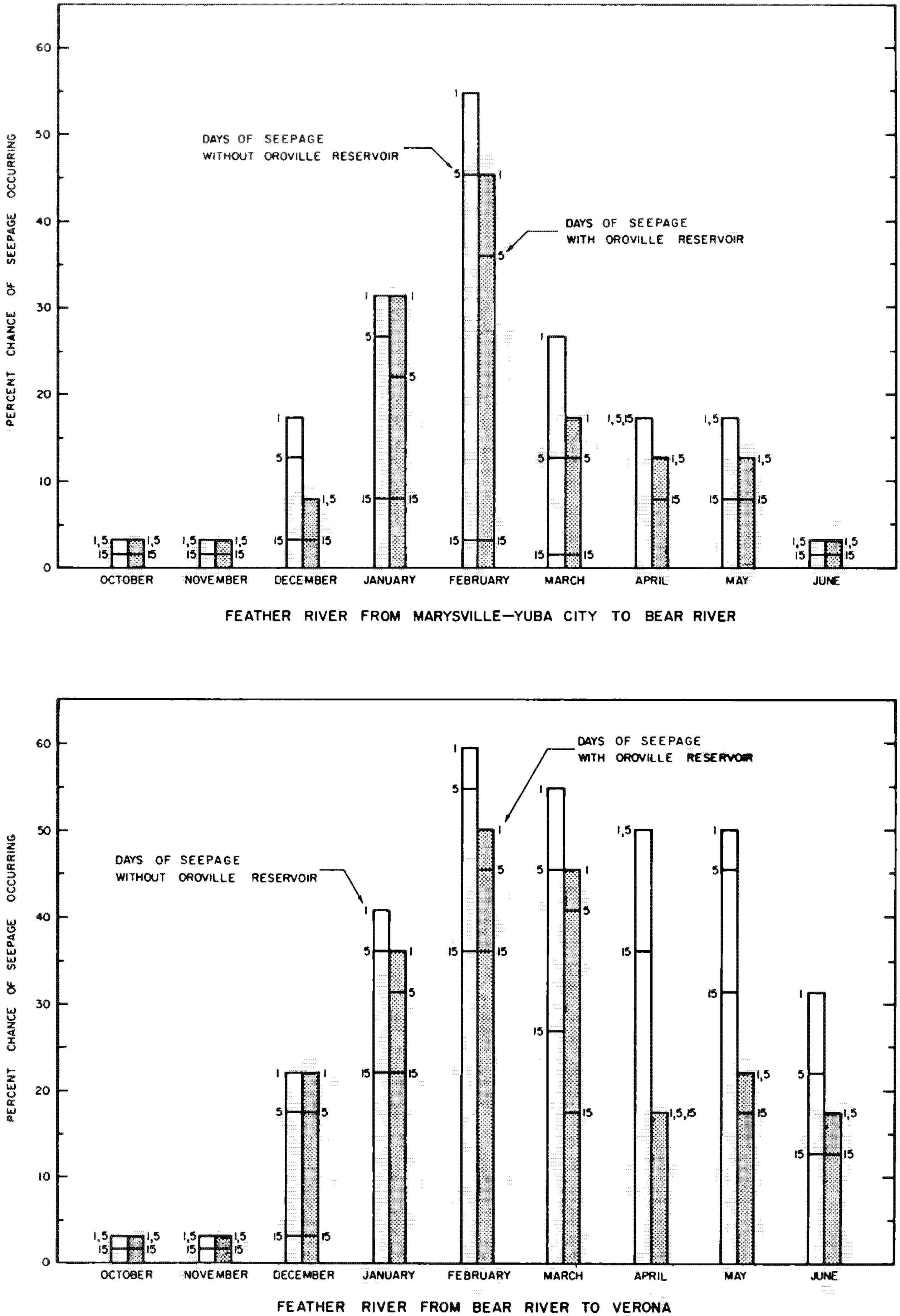
This data was used to construct a bar chart which shows the duration of seepage by day with and without Oroville reservoir in operation for each year of the 21-year study period. Figure 22 shows this information for the lower reach of the Feather River.

To determine the probability of the occurrence of seepage, a tabulation of days of seepage per month and year was made from the bar chart; the days of seepage per month were arranged in order of magnitude; an exceedence frequency was assigned for each 1-or-more, 5-or-more and 15-or-more-day seepage occurrence per month. Figure 23 was drawn to graphically display the probability of seepage occurring by month along the two reaches of the Feather River. The exceedence frequency for each seepage occurrence during each month was obtained from the plotting point tables in "Statistical Methods in Hydrology" by Leo R. Beard.



DAYS OF SEEPAGE
LOWER REACH OF FEATHER RIVER - SUBAREA NO. 13

Figure 22



EFFECT OF OROVILLE RESERVOIR ON SEEPAGE

Figure 23

Results of Analysis

The foregoing studies indicate that: (1) flood control releases should have the most significant effect on seepage conditions; (2) releases for other project purposes should not significantly increase and/or change flows which cause seepage; (3) large peak floodflows which cause seepage should generally be reduced by reservoir operations; and (4) during the summer when peak local service area and export demands occur, flows in the channel should not be sufficient to cause seepage downstream from the reservoir.

Interpretation of the data used to construct Figures 22 and 23 indicates that high flows which cause seepage will usually occur from October through June, which is the major rainfall and snowmelt period. The high flows can be classified into three groups of duration:

(1) High flow conditions of 10 days or less which produce a relatively small volume of water and occur more frequently than longer duration high flow conditions. The entire volume of runoff could be stored in the flood control reservation, enabling the reservoir to reduce the downstream flood peaks. The control of these peak flows should reduce or eliminate seepage.

(2) High flow conditions of 30 days or less. The flood control reservation available in the reservoir could store enough of the runoff caused by this type of storm to reduce the downstream floodflows in the Feather River. These reduced flows should, in turn, result in less seepage.

(3) High flow conditions of more than 30 days duration. A small portion of the inflow from long duration high flows could be stored in the flood control reservation. The high riverflows downstream from Oroville reservoir would not be changed to any significant degree by the operation of the reservoir, because the outflow from the reservoir would be almost equal to the inflow. Seepage conditions should not be changed essentially.

The analysis also showed that during the 21-year study period the number of occurrences of seepage along the Feather River in the lower reach south of the confluence with the Bear River would be reduced from 36 to 22 with Oroville reservoir in operation. Furthermore, the number of occurrences of seepage along the upper reach, between Marysville and the Bear River, would be reduced from 29 to 23.

The daily operation study indicates that the maximum summer flow in the Feather River at Nicolaus will be approximately 6,000 second-feet and will occur in August. Seepage does not normally occur along the Feather River until the flow at Nicolaus exceeds 14,000 second-feet. Therefore, the summer releases from the Oroville facilities should not approach the stage required to cause seepage.

The conclusion can be drawn that Oroville reservoir will generally reduce the peaks and durations of high flows in the fall, winter and spring, in turn reducing seepage and seepage damage. Also, the river stages in the summer should always be less than critical; consequently, there should not be seepage damage to crops planted adjacent to the Feather River in the summer. The studies also show that the largest reductions in seepage will occur in April and May. Seepage can cause major damage during those months. Therefore, Oroville reservoir will be very beneficial in reducing major seepage damage.

Estimated Effect of Imported Water on Seepage Conditions

Planning of projects which would import water into the Sacramento Valley is in the preliminary stage. Consequently, the magnitude of flows of imported water cannot be closely determined at this time. Therefore, three different levels of summer flows in the Sacramento River were selected as representative of probable future flow conditions, and their effect on seepage and seepage damage was projected. While the selected flows were necessarily arbitrary, the resulting analysis will be usable in future studies when more definitive riverflow information is available.

Possible seepage areas and damages along the Sacramento River which could result from each of the three selected flows were estimated. Curves were developed to relate riverflow conditions to the estimated area which would be affected and damage which could be caused by seepage.

Seepage could limit the use of lands to less than their full economic potential. The economic influence of seepage on the agricultural economy was measured as the reduction in the financial return attributable to land due to the projected limitation on land use which could result from seepage. The economic effect on the urban economy was considered as the estimated cost of installing and operating adequate drainage systems which would make the seepage areas as functional as the nonseepage areas. The total effect of seepage on the economy was considered to be the sum of the damage to the agricultural and urban economies.

Four alternative methods of controlling seepage were investigated and plans and costs of control were developed for each method. The plans were compared and the estimated capital and annual costs of the most favorable plan were compared with the total economic effect of seepage.

Operation of Import Projects

California's long-range planning recognizes that future water demands will require importation of water to and through the Sacramento Valley. The Department of Water Resources, U. S. Bureau of Reclamation, and U. S. Army Corps of Engineers are coordinately studying proposed developments which may utilize the Sacramento River as a natural conduit for this imported water.

Department of Water Resources Bulletin No. 136, "North Coastal Area Investigation" 1964, describes proposed facilities that would develop and transport waters from the North Coastal streams to points of need via the Sacramento Valley.

Recent studies by the Department of Water Resources as reported in Bulletin No. 160-66, "Implementation of The California Water Plan" indicate that importation of water may be required to supply needs of the State Water Project and the Central Valley Project beginning in the late 1980's. Because of the availability of surplus water in the Delta during the floodflow season, substantial imports of water will be largely limited to the summer and fall months. Imports should increase as the water demand continues to grow. Therefore, seepage directly attributable to imported water could occur in the summer and fall if imports reach a sufficient magnitude.

Since the magnitude of imported flows cannot be accurately established at this time, three different levels of flow considered representative of future flow conditions were selected and used in the analysis. The three flow conditions are:

Selected Flow Conditions

River Gaging Stations	Condition 1		Condition 2		Condition 3	
	Flow CFS	Stage USGS	Flow CFS	Stage USGS	Flow CFS	Stage USGS
Sacramento River						
at Colusa	10,000	42.6	14,000	46.1	18,000	49.4
below Wilkins Slough	10,000	30.2	14,000	34.7	18,000	39.0
at Knights Landing	10,000	18.8	14,000	21.5	18,000	24.5
at Verona	17,300	14.5	21,300	16.3	25,300	18.1
at Sacramento	18,300	5.8	22,300	7.2	26,300	8.6
near Freeport	---	----	22,300	5.2	26,300	6.4
at Snodgrass Slough	---	----	22,300	3.4	26,300	4.2
Feather River						
at Nicolaus	6,500	22.8	6,500	22.8	6,500	23.4

Flow Condition No. 1 assumes the importation of approximately 5,000 second-feet. Condition No. 2 is based on an importation of about 9,000 second-feet, and Condition No. 3 assumes an importation of approximately 14,000 second-feet.

Seepage Areas

The seepage areas which could result from each of the three flow conditions were estimated for the reach along the Sacramento River from Colusa Weir to Hood and along the lower reaches of the Feather River and Sutter Bypass. Studies indicated that the flows would not be sufficient to cause seepage north of Colusa Weir.

The study area along the Sacramento River was divided into three reaches--Colusa Weir to Fremont Weir; Fremont Weir to the American River; and the American River to Hood. Curves were developed to show the estimated seepage area and damage which would result from various flows in each of these reaches. The curves and their uses are described in the following section on seepage damage.

The higher summer flows in the Sacramento River would cause water to back up along the Feather River and along the Sutter Bypass. This backwater would cause summer seepage along the lower reaches of the Feather River and Sutter Bypass and flooding in the bypass. The projected seepage and flooded areas are included in the estimates for the reach from Fremont Weir to the American River.

The river stage which would result from each of the three flow conditions was calculated at each mile along the rivers and the Sutter Bypass. The flows and river stages were assumed to be constant for a minimum period of 30 days. The slope of the ground water gradient away from the river was estimated from studies of measured ground water gradients and analog model studies conducted during this investigation. The ground water levels which would occur at each of a number of representative wells which formed the ground water level monitoring grid in this investigation were estimated for each of the flow conditions. The ground water levels were then superimposed over 7-1/2 minute USGS quadrangles. The areas where the water table was estimated to be within 2 feet of the ground surface and from 2 to 4 feet below the ground surface were delineated on the maps. These areas were then adjusted based on soil maps in the 1955 report of the California Division of Water Resources titled "Seepage Conditions in the Sacramento Valley", the locations of rice fields and drainage ditches, and seepage areas observed during this investigation. Information obtained in the analyses used to develop the seepage evaluation curves and the electrical resistivity studies was also used to establish the seepage areas and seepage boundaries.

The critical river reach for possible summer seepage was found to extend from Colusa Weir to Fremont Weir. The maximum flow that can be maintained in this reach for long durations without causing seepage was estimated to be approximately 9,000 second-feet. The maximum flow which can be maintained between Fremont Weir and the American River without causing seepage was estimated to be about 15,000 second-feet. It was estimated that flows in the reach between the American River and Hood can be at least 19,000 second-feet without causing seepage.

Seepage Damage

Summer seepage resulting from imported water could cause some damage to agricultural and urban areas. Existing drainage facilities along the rivers could also be affected by higher summer river stages.

Agricultural damage could result from a limitation on the type of crops that could be grown in the seepage areas and from certain direct damages to crops which could occur during the transition period of changing from a crop pattern which could be grown with winter seepage, to one which could be grown under summer seepage conditions. Since transitional damages would be of a minor nature, only agricultural damage resulting from a limitation on the type of crops was considered in this analysis. The economic effect of summer seepage on the agricultural economy was measured as the difference in financial return attributable to land without summer seepage and the return with summer seepage. Damage to the urban economy was also included in the analysis.

The return attributable to land for each of the representative crops projected for the area was derived on the basis of the price-cost relationships existing during the 1960-64 period. An allowance was made for the irrigation water costs incurred during a normal crop year. The return attributable to land was determined by deducting from the gross income, all variable and fixed costs except the cost of land. The estimated average return for each crop assuming no summer seepage is shown in Table 6.

In order to estimate the agricultural damage, projections were made of six cropping patterns which would be expected to prevail in 1995 under various degrees of severity of seepage. Conditions in 1995 were selected on the premise that quantities of imported water would not be sufficient to cause summer seepage prior to that time. All cropping patterns were projected on the basis that present winter seepage conditions would continue. The return attributable to land for each of these cropping patterns was computed.

One cropping pattern was projected for 1995 conditions assuming that no water would be imported and hence no summer seepage would occur. This cropping pattern and the return attributable to land for that pattern are shown in Table 7.

Five cropping patterns were projected for 1995 assuming that the Sacramento River would be used as a conveyance channel for imported water. These cropping patterns are shown in Table 8. Each of these cropping patterns was predicted on an arbitrary percentage of the seepage study area where the water table would be within the top 2 feet of the ground surface, with the remainder between 2 feet and 4 feet. Crops which are tolerant of high water table conditions were used in the projections. The cropping pattern was increasingly limited to seepage tolerant crops as the proportion

TABLE 6

AVERAGE ANNUAL RETURN ATTRIBUTABLE TO LAND 1/
WITH NO SUMMER SEEPAGE
(1960-64 Base Period)

Crop	Unit	Yield	Price	Gross income	Less Costs: Variable	Fixed 2/	Management	Total cost	Return attributable to land
Almonds	ton	.75	$600.00	$450.00	$174.00	$126.00	$45.00	$345.00	$105.00
Peaches	ton	13.0	62.00	806.00	464.15	139.75	80.60	684.50	121.50
Pears	ton	10.0	82.50	825.00	461.30	159.20	82.50	703.00	122.00
Prunes	ton	2.0	300.00	600.00	285.60	137.90	60.00	483.50	116.50
Walnuts	ton	.80	500.00	400.00	150.95	116.55	40.00	307.50	92.50
Asparagus-Tomatoes	ton	25.0	25.00	625.00	374.30	120.70	62.50	557.50	67.50
Dry Beans	cwt	18.0	9.50	171.00	96.70	29.70	17.10	143.50	27.50
Milo-Corn	cwt	55.0	2.40	132.00	50.60	32.00	13.20	95.80	36.20
Sugar Beets	ton	20.0	12.50	250.00	130.90	43.30	25.00	199.20	50.80
Rice	cwt	50.0	4.00	200.00	109.90 3/	35.10	20.00	165.00	35.00
Alfalfa	ton	7.0	25.00	175.00	78.50	45.30	17.50	141.30	33.70
Pasture	aum	6.0	7.00	42.00	15.65	12.80	4.20	32.65	9.35
Pasture	aum	12.0	7.00	84.00	24.70	24.40	8.40	57.50	26.50
Barley	cwt	30.0	2.30	69.00	28.75	22.50	6.90	58.15	10.85
Safflower	ton	1.25	85.00	106.00	32.45	29.95	10.60	73.00	33.00

1/ Annual gross farm income minus all on-farm production costs, exclusive of cost of land.
2/ Except land cost but includes land reclamation cost.
3/ Water cost assumed to be $2.50 per acre-feet for Rice.

TABLE 7

PROJECTED CROPPING PATTERN AND
RETURN ATTRIBUTABLE TO LAND IN 1995
WITH NO SUMMER SEEPAGE

Crop	Return attributable to land per acre	Crop acreage in percent of total	Weighted return attributable to land by crop
Pears	$122.00	.20	$ .24
Almonds	105.00	.28	.29
Prunes	116.50	9.38	10.93
Walnuts	92.50	7.50	6.94
Asparagus-Tomatoes	67.50	13.45	9.08
Dry Beans	27.50	11.47	3.15
Milo-Corn	36.20	7.49	2.71
Sugar Beets	50.80	8.11	4.12
Rice	35.00	15.91	5.57
Alfalfa	33.70	7.84	2.64
Pasture 12 AUM 1/	26.50	4.29	1.14
Barley	10.85	5.07	.55
Safflower	33.00	8.92	2.94
Total		100.00	
Weighted Return Attributable to Land Per Acre			$50.30

1/ Animal Unit months.

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TABLE 8

PROJECTED EFFECT OF VARIOUS LEVELS OF SUMMER SEEPAGE ON CROPPING PATTERN AND RETURN ATTRIBUTABLE TO LAND IN 1995

Crop	Return attributable to land per acre	Cropping Pattern in Percent of Total Area Affected by Summer Seepage									
		100% of Land 2 to 4 feet to: Water Table		10% of Land 0 to 2 feet, 90% 2 to 4 feet to Water Table		35% of Land 0 to 2 feet, 65% 2 to 4 feet to Water Table		65% of Land 0 to 2 feet, 35% 2 to 4 feet to Water Table		90% of Land 0 to 2 feet, 10% 2 to 4 feet to Water Table	
		Percent	Return	Percent	Return	Percent	Return	Percent	Return	Percent	Return
Dry Beans	$27.50	9	$ 2.48	5	$ 1.38	0	0	0	0	0	0
Milo-Corn	36.20	15	5.43	15	5.43	10	$ 3.62	5	$ 1.81	0	0
Sugar Beets	50.80	15	7.62	10	5.08	5	2.54	0	0	0	0
Rice	35.00	19	6.65	15	5.25	10	3.50	5	1.75	0	0
Alfalfa	33.70	14	4.72	10	3.37	5	1.69	0	0	0	0
Pasture 12 Aum [1]	26.50	6	1.59	10	2.65	17	4.51	20	5.30	10	$ 2.65
Pasture 6 Aum	9.35	0	0	10	.94	35	3.27	60	5.61	85	7.95
Barley	10.85	7	.76	10	1.09	8	.87	5	.54	0	0
Safflower	33.00	10	3.30	10	3.30	5	1.65	0	0	0	0
Nonfarmed	0	5	0	5	0	5	0	5	0	5	0
Totals and Weighted Returns		100	$32.60	100	$28.50	100	$21.70	100	$15.00	100	$10.60

1/ Animal Unit months.

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of the area where the water table would be within the top 2 feet of the soil increased. The average annual return attributable to land per acre was computed for each of the five cropping patterns and is shown in Table 8.

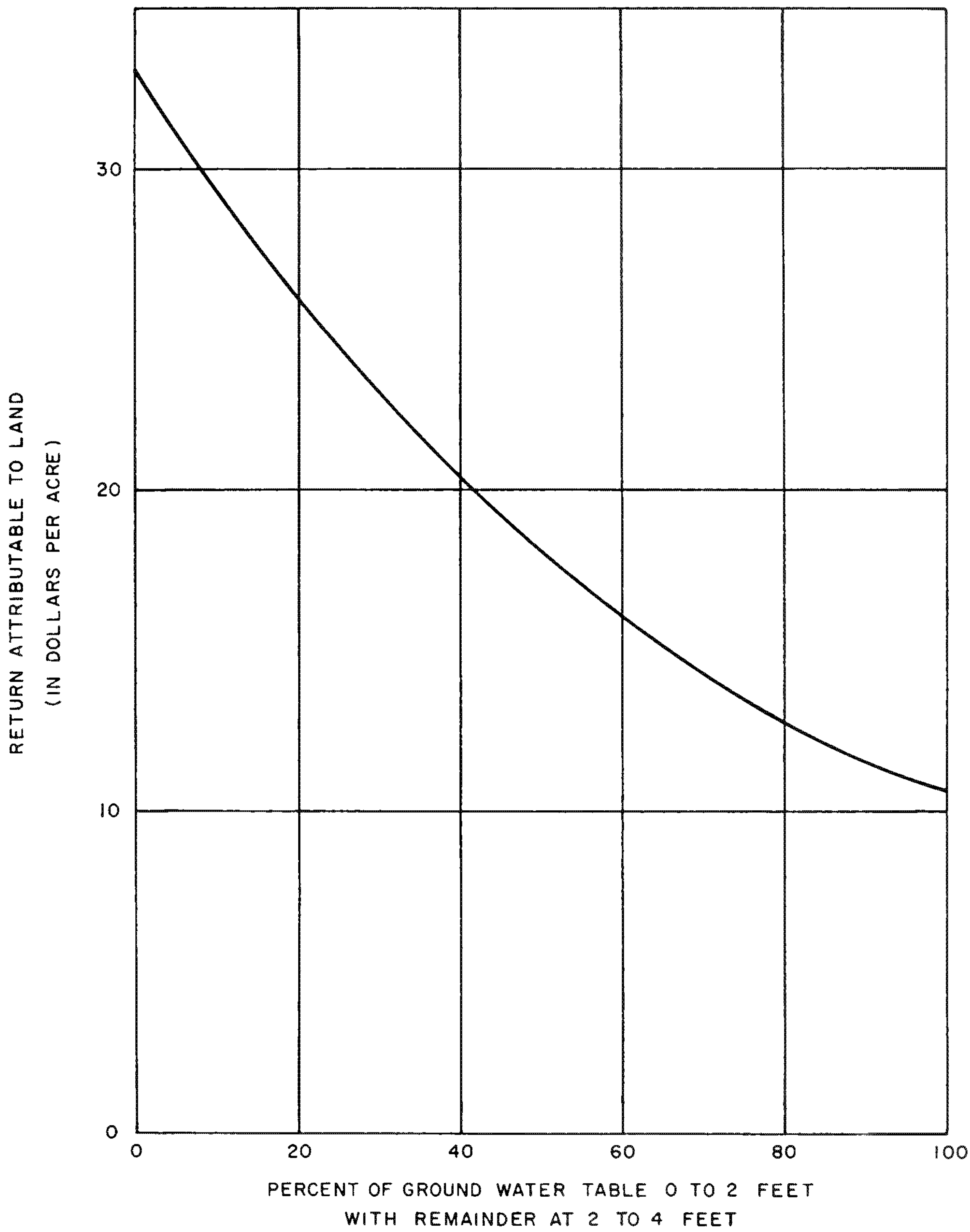
The return attributable to land for each of the five cropping patterns was used to derive Figure 24 which shows the effect of summer seepage on the return attributable to land. This information was used to determine the return which would occur under each of the three flow conditions previously described in this chapter.

The average return attributable to land for each of the three flow conditions for the river reaches between Colusa Weir and Hood is shown in Table 9. The flooded areas previously described are included in this table.

In addition to flooding, high summer flows in the river would cause several other problems. One of these would be the additional cost of pumping local drainage water into the river. Another would be the inability of water in the Colusa Basin Drain at the Knights Landing Outfall Gates and at the Butte Slough Outfall Gates to drain into the river by gravity flow. Pumping plants would be required at the outfall structures on the Sacramento River to prevent flooding along both drainage systems.

The seepage damage to urban areas was measured as the cost of an adequate drainage system, including operation and maintenance, which would make the seepage areas as functional as the nonseepage areas.

The on-farm damages attributable to summer seepage were estimated by computing the difference in return to land with and without seepage. The resultant total net decrease in the return to land plus the estimated



EFFECTS OF SUMMER SEEPAGE ON
AVERAGE RETURN ATTRIBUTABLE TO LAND

Figure 24

TABLE 9

PROJECTED RETURN ATTRIBUTABLE TO
LAND UNDER DIFFERENT FLOW CONDITIONS
IN 1995, COLUSA WEIR TO HOOD

Flow in cubic feet per second	Seepage 0 to 2 feet below ground surface: Acres	Seepage 0 to 2 feet below ground surface: Percent of total seepage area	Seepage 2 to 4 feet below ground surface: Acres	Seepage 2 to 4 feet below ground surface: Percent of total seepage area	Total summer seepage area	Return attributable to land per acre	Flooded area: Acres	Flooded area: Return attributable to land	Total seepage and flooded area	Average return attributable to land per acre
Colusa Weir to Fremont Weir										
10,000 cfs	2,693	33	5,388	67	8,081	$22.20	0	0	8,081	$22.20
14,000 cfs	21,475	58	15,485	42	36,960	16.50	0	0	36,960	16.50
18,000 cfs	40,676	81	9,609	19	50,285	12.60	0	0	50,285	12.60
Fremont Weir to American River										
17,300 cfs	166	80	41	20	207	$12.80	0	0	207	$12.80
21,300 cfs	669	23	2,232	77	2,901	25.00	418	0	3,319	21.90
25,300 cfs	3,646	30	8,713	70	12,359	23.00	1,050	0	13,409	21.20
American River to Hood										
18,300 cfs	0	0	0	0	0	$ 0	0	0	0	$ 0
22,300 cfs	3,938	49	4,057	51	7,995	18.00	0	0	7,995	18.00
26,300 cfs	7,235	67	3,635	33	10,870	14.40	0	0	10,870	14.40

1965 costs of pumping plants at Knights Landing Dam and the Butte Slough Outfall Gates and associated pumping costs, plus the urban damages gave the total damages for the three reaches under the three flow conditions. The computation of these total damages is presented in Table 10. A summary of the total annual damages under the three flow conditions for the total reach from Colusa Weir to Hood is:

Flow Condition No. 1	$ 270,600
Flow Condition No. 2	1,828,300
Flow Condition No. 3	3,023,300

The information in Table 10 was used to develop Figures 25 and 26 which can be used to determine the projected seepage areas and damages for various ranges of flow in the Sacramento River. These curves are shown for each of the three reaches--Colusa Weir to Fremont Weir, Fremont Weir to American River, and American River to Hood.

Methods of Controlling Summer Seepage

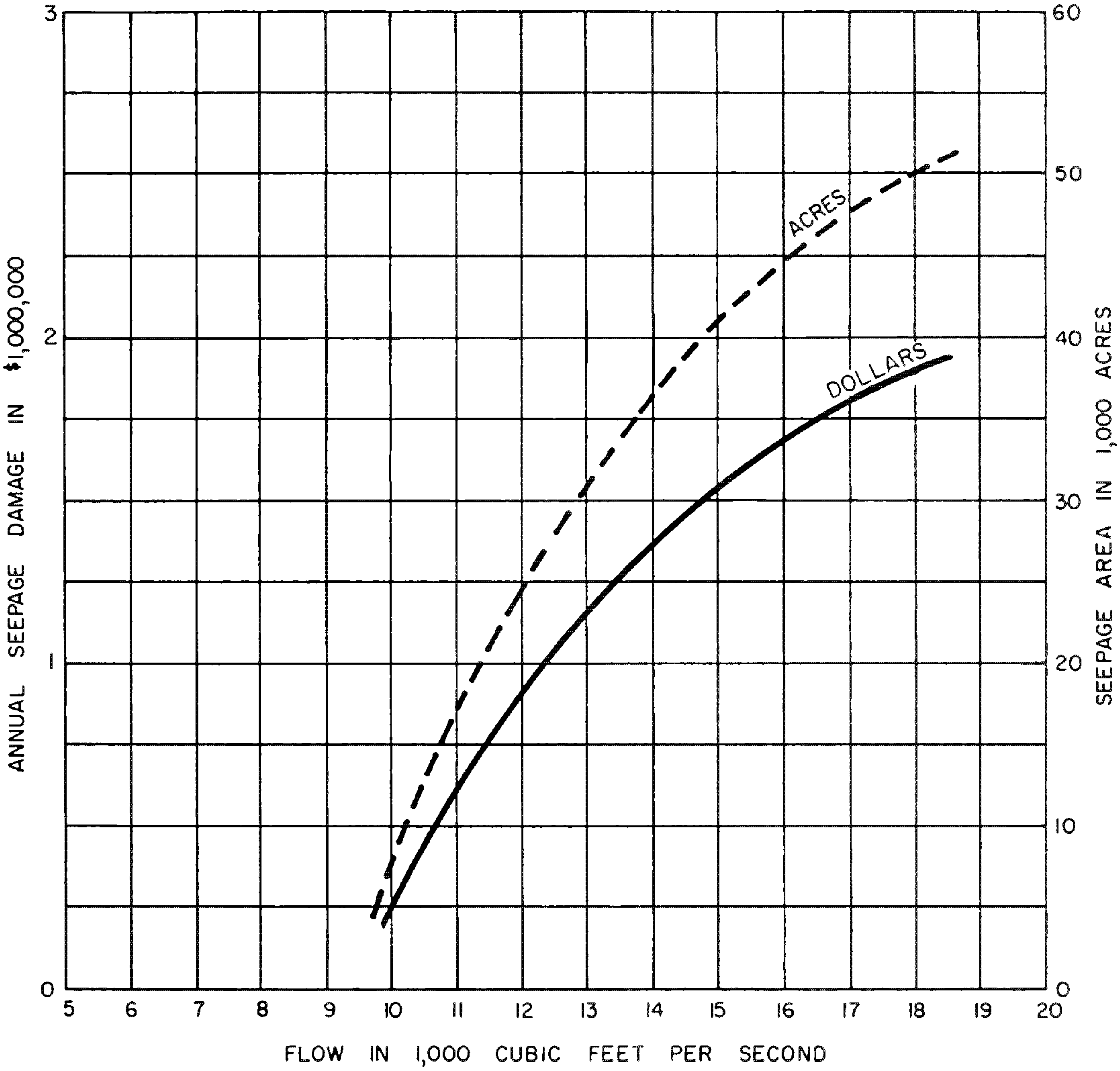
Four alternative methods of controlling summer seepage were investigated. These were: (1) a canal constructed in the Sutter Bypass to carry excess flows around the critical reach of the river between Colusa Weir and Fremont Weir; (2) a canal constructed in the existing Colusa Basin Drain to carry excess flows around the critical river reach; (3) a tile drainage system constructed in the seepage areas from Colusa Weir to Hood; and (4) the purchase of seepage easements in the seepage areas between Colusa Weir and Hood. A plan for controlling seepage resulting from river Flow Condition No. 2 was developed for each alternative. The riverflow conditions were assumed to exist for six months of the year for purposes of this analysis.

TABLE 10

PROJECTED DAMAGES ATTRIBUTABLE TO SUMMER SEEPAGE IN 1995, COLUSA WEIR TO HOOD

No Summer Seepage	With Summer Seepage									
							Urban Damage			
Return attributable to land per acre	Flow in cfs	Total seepage and flooded area in acres	Return attributable to land per acre	Diff. in return attributable to land per acre	Total crop damage	Cost of pumping plants and pumping	Miles of tile drain	Cost per mile 1/	Total	Total damages
Colusa Weir to Fremont Weir										
$50.30	10,000	8,081	$22.20	28.10	$ 227,100	$ 35,700	0	$ 0	$ 0	$ 262,800
50.30	14,000	36,960	16.50	33.80	1,249,200	228,200	0	0	0	1,477,400
50.30	18,000	50,285	12.60	37.70	1,895,700	284,000	0	0	0	2,179,700
Fremont Weir to American River										
$50.30	17,300	207	$12.80	37.50	$ 7,800	$ 0	0	$ 0	$ 0	$ 7,800
50.30	21,300	3,319	21.90	28.40	94,300	0	0	0	0	94,300
50.30	25,300	13,409	21.20	29.10	390,200	0	3	4,100	12,300	402,500
American River to Peripheral Canal										
$50.30	18,300	0	$50.30	0	$ 0	$ 0	0	$ 0	$ 0	$ 0
50.30	22,300	7,995	18.00	32.30	258,200	14,400	4	3,500	14,000	286,600
50.30	26,300	10,870	14.40	35.90	390,200	18,100	8	4,100	32,800	441,100

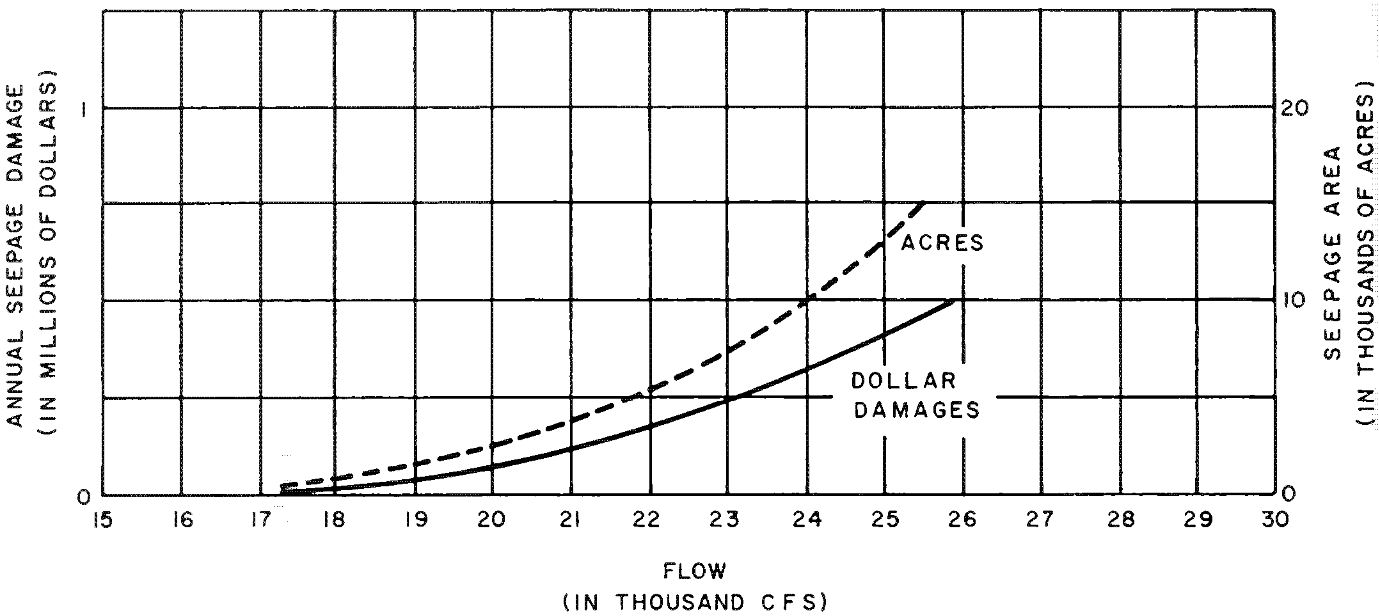
1/ Includes Operation and Maintenance.



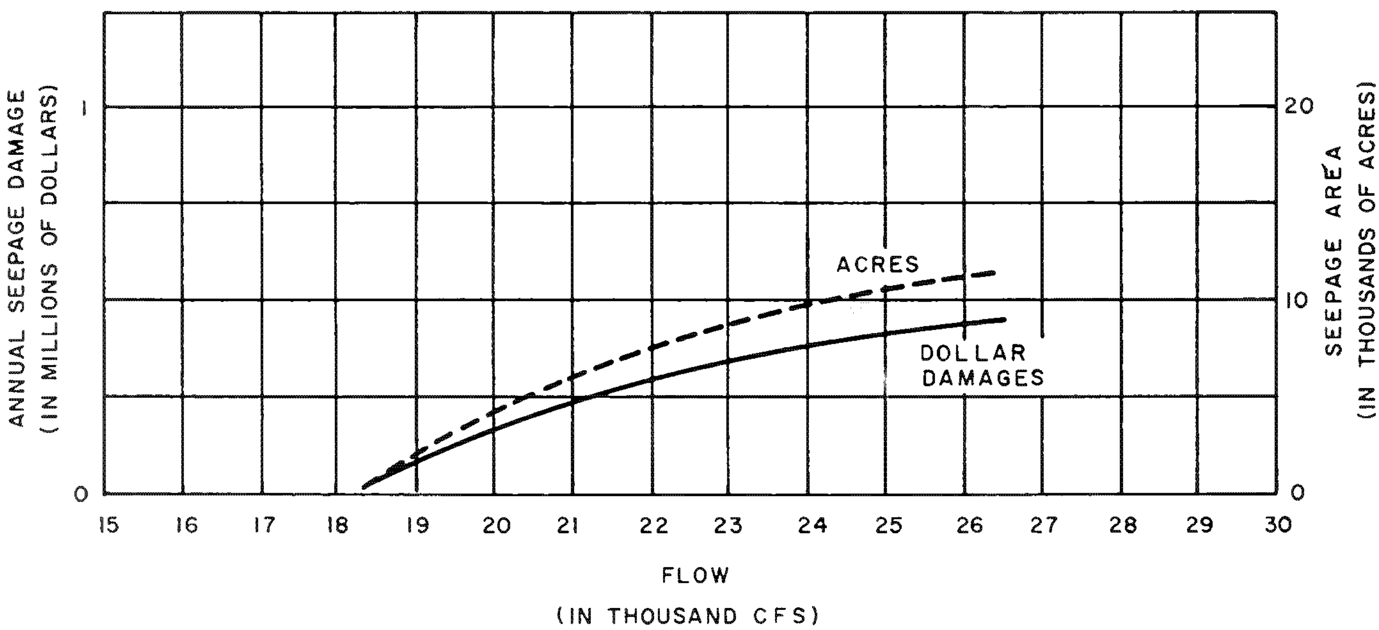
REACH – COLUSA WEIR TO FREMONT WEIR

ESTIMATED SUMMER SEEPAGE AREA AND DAMAGE

Figure 25



REACH - FREMONT WEIR TO AMERICAN RIVER



REACH - AMERICAN RIVER TO HOOD

ESTIMATED SUMMER SEEPAGE AREA AND DAMAGE

Figure 26

Sutter Bypass Canal. The canal in the Sutter Bypass was planned to carry only those flows in excess of the 9,000 cfs which is the flow that can be maintained in the critical reach of the river without causing seepage. The intake to the canal would be located adjacent to the south end of Colusa Weir. The canal would go easterly, crossing Butte Creek, thence down Butte Slough to the west borrow pit of the Sutter Bypass. The canal would follow an enlarged west borrow pit to Sacramento Slough and terminate at the Sacramento River near Verona.

In order to maintain a maximum of 9,000 cfs in the critical reach of the Sacramento River, a maximum flow of 5,000 cfs would have to be diverted into the canal. The canal was designed to carry a maximum diversion of 5,000 cfs from the Sacramento River plus the flows of Butte Creek and the west borrow pit of the Sutter Bypass.

The resulting large flows which would occur in the Sacramento River at Verona (21,300 cfs) would back water up along the Sacramento and Feather Rivers and along the canal in the Sutter Bypass. This backwater would submerge the present outlet works at Knights Landing Outfall Gates and would require the installation of a pumping plant at this location.

The backwater would cause summer seepage along 15 miles of the Sacramento River upstream from Fremont Weir and along 5 miles of the lower parts of the Feather River and Sutter Bypass. Tile drains and associated pumping plants would have to be installed in those reaches and in several locations along the Sacramento River between Verona and the beginning of the proposed Peripheral Canal near Hood.

A maximum of 5,000 cfs could be diverted from the Sacramento River through the Sutter Bypass Canal in the winter to somewhat relieve seepage between Colusa Weir and Fremont Weir. However, flows in the Sacramento River at Verona in excess of 21,300 cfs will cause backwater in excess of that projected under summer conditions. Thus, the canal would be of limited value in relieving river winter seepage resulting from riverflows above 21,300 cfs.

The estimated capital cost of the canal in the Sutter Bypass, the necessary tile drainage systems and associated pumping plants, and a pumping plant at Knights Landing Outfall Gates is $16,700,000. The estimated annual cost including operation and maintenance is $940,000. These costs are shown below.

SUMMARY OF COST OF
SUTTER BYPASS CANAL
(Based on 1965 Costs)

Item	Capital Cost	Annual Cost 4% Interest
Land acquisition	$ 426,000	$ 19,830
Canal	11,616,000	540,720
Bridges for highways, railroads, etc.	1,192,000	55,490
Tile drainage systems	2,084,900	97,050
Pumping plant @ Colusa Basin Drain Diversion Dam	1,428,000	66,470
Operation, maintenance and repairs	-----	94,200
Power costs	-----	65,400
TOTAL	$16,746,900	$939,160

Colusa Basin Drain Canal. Another method of conveying summer flows in excess of 9,000 cfs around the critical reach of the Sacramento River would be to utilize a portion of the Colusa Basin Drain. Under this alternative, a maximum of 5,000 cfs would be diverted from the Sacramento River into the proposed canal. The intake to the canal would be located 1-1/2 miles north of Colusa Weir. The canal would go southwest to Hopkins

Slough and then down an enlarged Hopkins Slough to the Colusa Basin Drain. The canal would follow an enlarged Colusa Basin Drain down to the Knights Landing Ridge Cut, thence to the Yolo Bypass. The canal would cross the Yolo Bypass and terminate at the Sacramento River about 1-1/4 miles north of Elkhorn Ferry.

A pumping plant would be required at the end of the canal to return the water to the Sacramento River. A fish screen would be needed at the diversion structure to prevent fish from going through the pumps.

The combination of riverflows and flows being returned to the river from the canal would cause water to back up the Sacramento River to Verona. Limited seepage would result from this backwater unless a tile drainage system was installed along the river from Verona to the canal at Elkhorn Ferry.

Flow from the canal plus the flow in the river would also be sufficient to cause seepage at some locations between Elkhorn Ferry and Hood. Therefore, tile drains and associated pumping plants would be required in the potential seepage areas along this reach of the river.

The canal, like the Sutter Bypass Canal, would be of limited value in controlling winter seepage.

The estimated cost of this canal, including a tile drainage system and associated pumping plants and fish screens and a pumping plant at Elkhorn Ferry, is $26,200,000. The estimated annual cost is $1,800,000 including operation and maintenance. The capital and annual costs of the individual features of Colusa Basin Drain Canal are:

SUMMARY OF COST OF
COLUSA BASIN DRAIN CANAL
(Based on 1965 Costs)

Item	Capital Cost	Annual Cost 4% Interest
Land acquisition	$ 730,500	$ 34,010
Canal	16,989,900	790,880
Bridges for highways, railroads, etc.	1,931,000	89,890
Fish screens	437,000	20,340
Pumping plant at end of canal and outlet structure	5,637,000	262,400
Tile drainage system	475,100	22,120
Operation, maintenance and repairs	-----	290,000
Power cost	-----	294,500
TOTAL	$26,200,500	$1,804,140

Tile Drainage System. A third alternative would be the installation of a tile drainage system along the river to keep the ground water table below the top 4 feet of soil, and hence, below the root zone of most crops.

A tile drainage system would generally be the most effective field drainage system for controlling high ground water along the critical river reach. The tile drains would be installed parallel to the river in locations which would be expected to have summer seepage along the river from Colusa Weir to Hood. The number of parallel tile drains needed would depend upon the amount of flow in the river. It is estimated that three parallel rows of tile would be required to control seepage resulting from Flow Condition No. 2. Pumping plants would be installed to pump drainage back into the river.

The higher summer riverflows would prevent drainage water from the Colusa Basin Drain and Butte Slough from flowing into the river by gravity. To prevent flooding along these two drains, pumping plants would be necessary at the Butte Slough Outfall Gates and at the Knights Landing Outfall Gates which controls the Colusa Basin Drain.

Another problem caused by the increased summer flows would be the increase in head that the existing drainage pumps along the river would have to work against to return drainage flows to the river. This increase in head would increase the cost of pumping.

The estimated costs of pumping drainage water, plus the cost of the pumping plants at the Knights Landing and Butte Slough Outfall Gates, were included as part of the cost of the tile drainage system.

There would be two additional benefits from the tile drainage system besides control of summer seepage; assistance in control of winter seepage and use of summer seepage to irrigate crops during the growing season. These benefits are not included in this analysis.

The degree of seepage control would depend upon the design of the drainage system. The system could be designed to control both winter and summer seepage. It could also be designed to control flows in excess of those shown under Flow Condition No. 2. It would therefore be much more flexible and could be considerably more effective in controlling seepage than either of the two alternative canal systems previously described.

Summer seepage could be used for irrigation purposes either through subirrigation or by surface application of seepage which could be collected from the drainage system and diverted into the irrigation system.

Because of the apparent relative advantage of this system over the canal systems, costs were estimated for drainage systems which would control seepage under each of the three previously described flow conditions.

There are several other types of field drainage systems including drainage ditches and gopher plowing which probably would be more economical in some areas than a tile drainage system. However, since the costs of these systems are generally less than a tile drainage system, cost estimates were based on a tile drainage system so as to be on the conservative side.

The estimated capital and annual costs of the drainage systems to control seepage under each of the three flow conditions are shown on Table 11.

Seepage Easement Rights. As another alternative, seepage easement rights could be purchased for the projected seepage areas between Colusa and Hood and along the lower Feather River and for the flooded areas in the lower Sutter Bypass. This procedure would be similar to the purchase of other flow easement rights. In this manner, lawsuits alleging seepage damage due to high ground water could be avoided.

There are certain disadvantages to the purchase of seepage easement rights. The most apparent is that seepage would not be physically controlled under this alternative, either during the summer or winter. Other disadvantages include possible clouded title to the land, a reduced tax base, reduction in tax revenue, reduction in bonding capacity of the area, and decrease in economic activity within the area. The estimated costs of seepage easement rights under assumed Flow Condition No. 2 are approximately $30,000,000. The estimated annual cost at 4 percent interest is $1,400,000. A summary of capital and annual costs of this alternative are shown at the top of page 122.

TABLE 11

SUMMARY OF COST OF TILE DRAINAGE SYSTEMS
(Based on 1965 Costs)

FLOW CONDITION No. 1 - 2 rows of tile drains

Item	Capital Cost	Annual Cost 4% Interest
Easement and crop loss	$ 85,300	$ 3,970
Tile drains	1,418,300	66,020
Pumps and sumps	232,500	10,820
Pumping plant at Butte Slough Outfall Gates	237,900	11,080
Operation, maintenance and repairs	-----	16,300
Power cost	-----	24,700
TOTAL	$ 1,974,000	$ 132,890

FLOW CONDITION No. 2 - 3 rows of tile drains

Item	Capital Cost	Annual Cost 4% Interest
Easement and crop loss	$ 1,455,400	$ 67,750
Tile drains	6,221,500	289,610
Pumps and sumps	1,027,500	47,830
Pumping plant at Butte Slough Outfall Gates	576,000	26,820
Pumping plant at Colusa Basin drain dam	1,527,000	71,080
Operation, maintenance and repairs	-----	94,700
Power cost	-----	130,500
TOTAL	$10,807,400	$ 728,290

FLOW CONDITION NO. 3 - 3 rows of tile drains

Item	Capital Cost	Annual Cost 4% Interest
Easement and crop loss	$ 1,953,100	$ 90,920
Tile drains	8,571,300	398,990
Pumps and sumps	1,726,000	80,350
Pumping plant at Butte Slough Outfall Gates	721,000	33,560
Pumping plant at Colusa Basin drain dam	1,829,000	85,140
Operation, maintenance and repair	-----	129,100
Power cost	-----	204,200
TOTAL	$14,800,400	$1,022,260

SUMMARY OF COST OF
SEEPAGE EASEMENT RIGHTS
(Based on 1965 Costs)

Reach	Area in acres	Capital cost	Annual cost 4% interest
Colusa Weir to Fremont Weir	37,000	$17,750,000	$ 826,260
Fremont Weir to American River	3,300	2,375,000	110,560
American River to Hood	8,000	9,600,000	446,880
TOTAL		$29,735,000	$1,383,700

Summary of Costs

The estimated costs of the alternative methods of mitigating summer seepage which could occur under Flow Condition No. 2 are:

SUMMARY OF COST OF ALTERNATIVES
FOR CONTROLLING SUMMER SEEPAGE
(Based on 1965 Costs)

Alternatives	Capital Cost	Total Annual Cost
Canal in the Sutter Bypass	$16,700,000	$ 940,000
Canal down Colusa Basin Drain	26,200,000	1,800,000
Tile Drainage System	10,800,000	730,000
Seepage Easement Rights	29,700,000	1,400,000
Damage Without Any Works		$1,828,300

It is apparent from the foregoing that the tile drainage system would have the lowest cost and highest benefit of any of the alternatives studied for controlling summer seepage resulting from the use of the Sacramento River as a conveyance facility for imported water. Under Flow Condition No. 2 (9,000 cfs importation) the benefit-to-cost ratio of this system would approximate 2.5 to 1.

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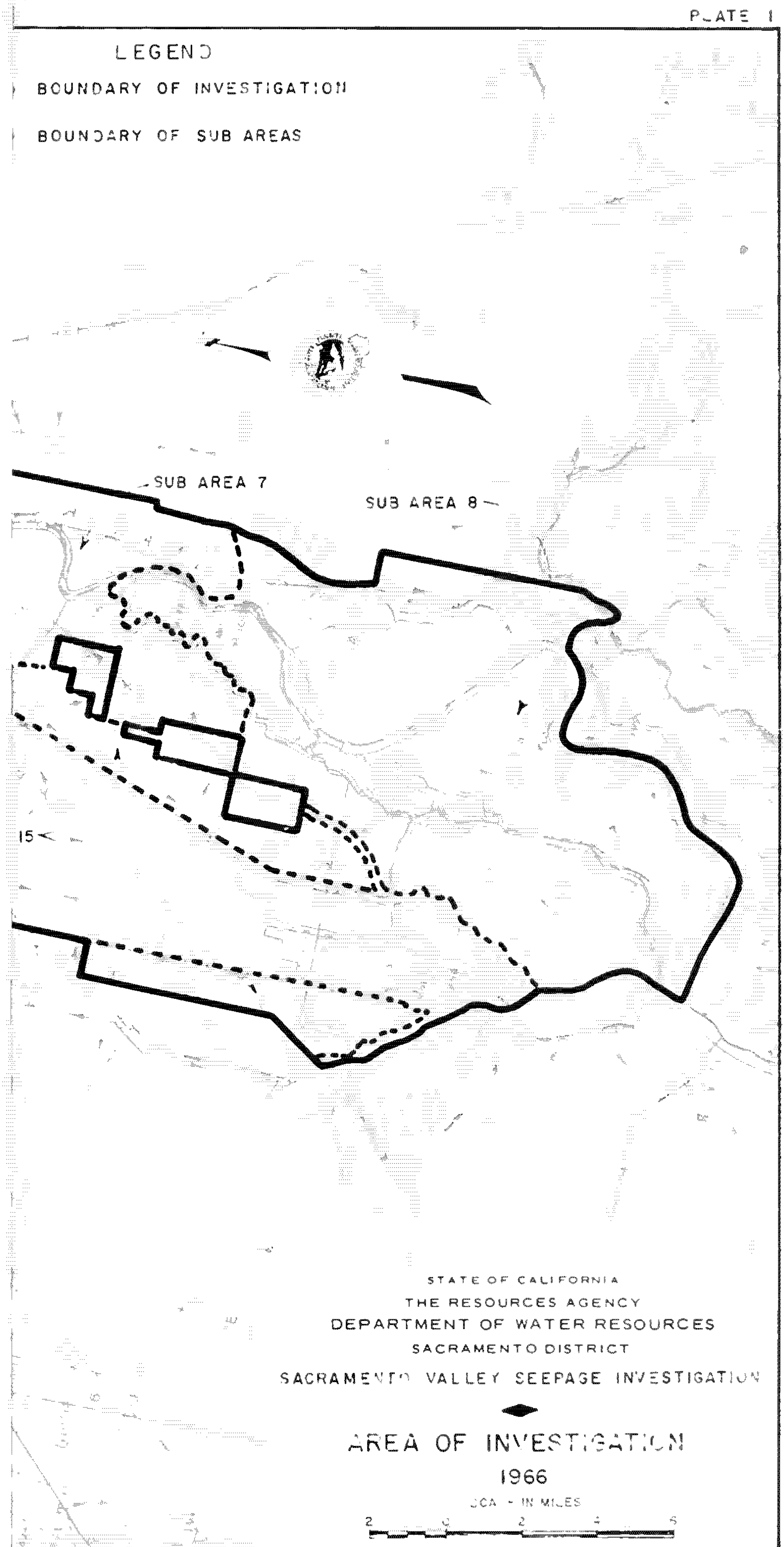

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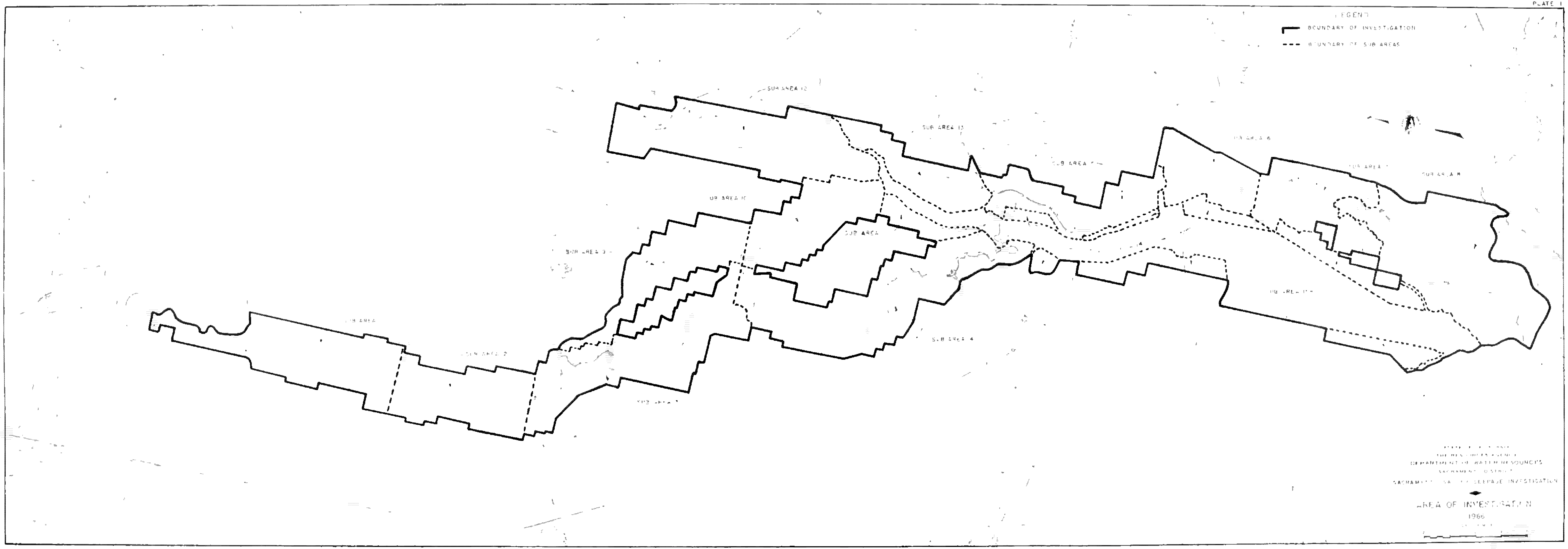
PLATE 1



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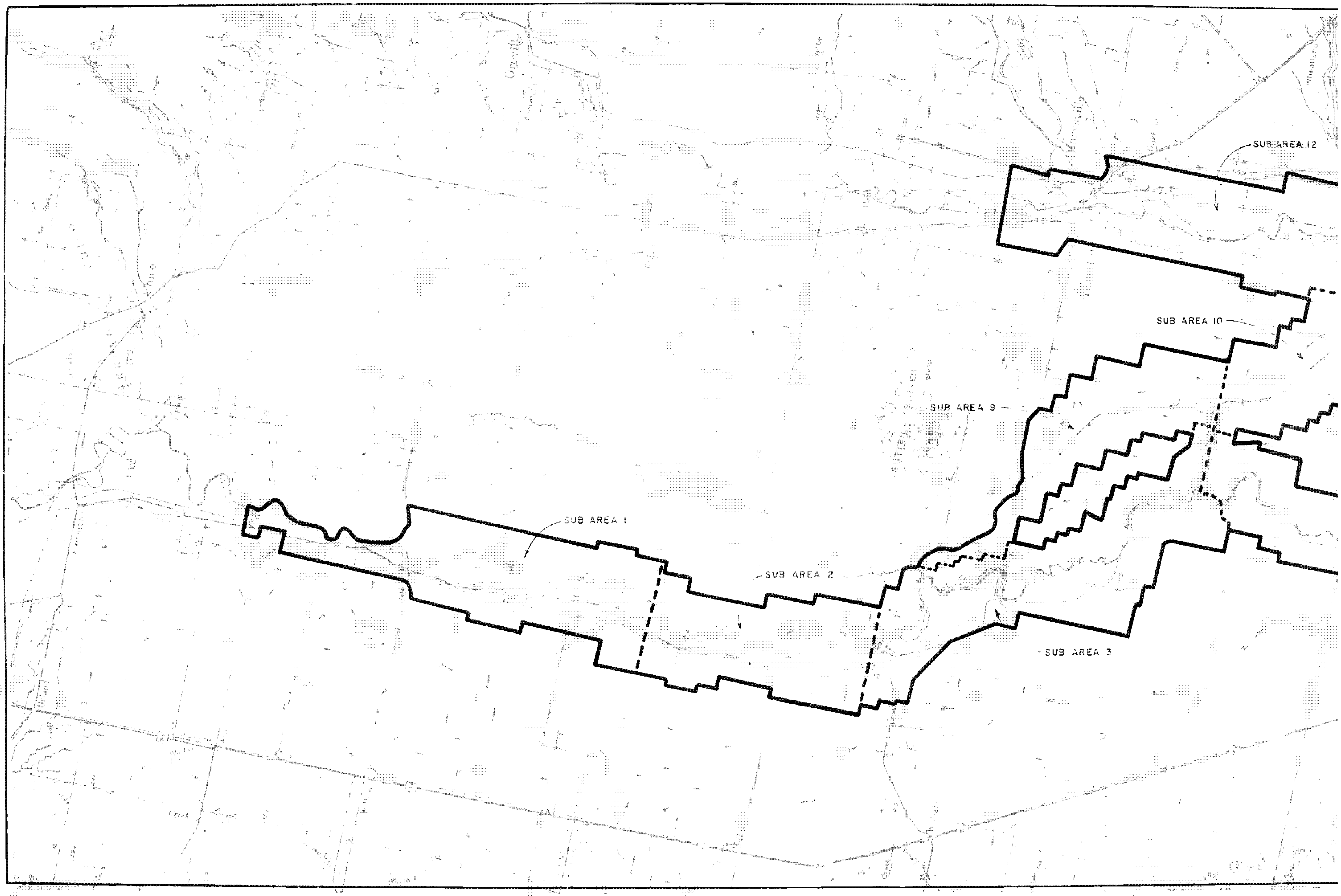
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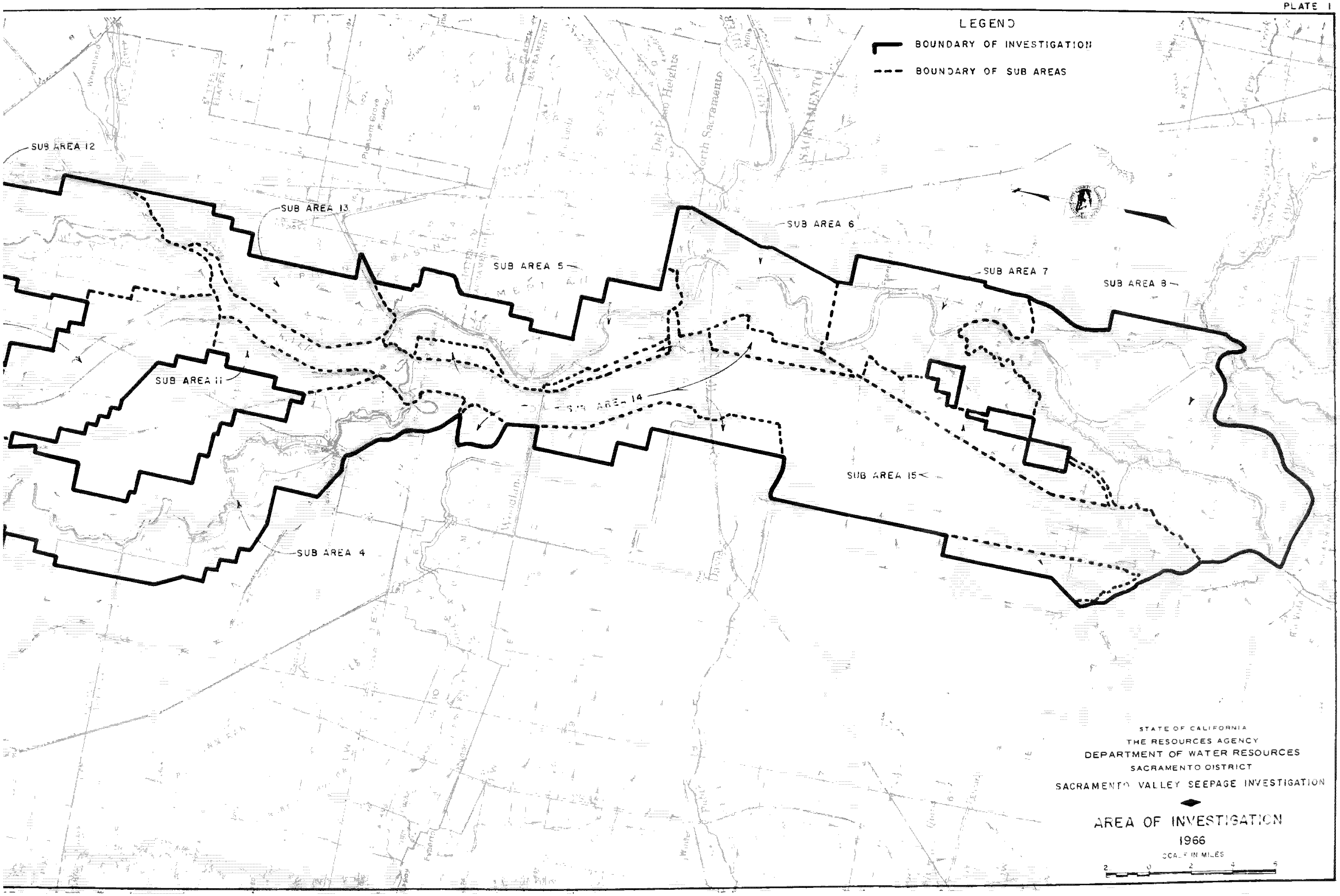
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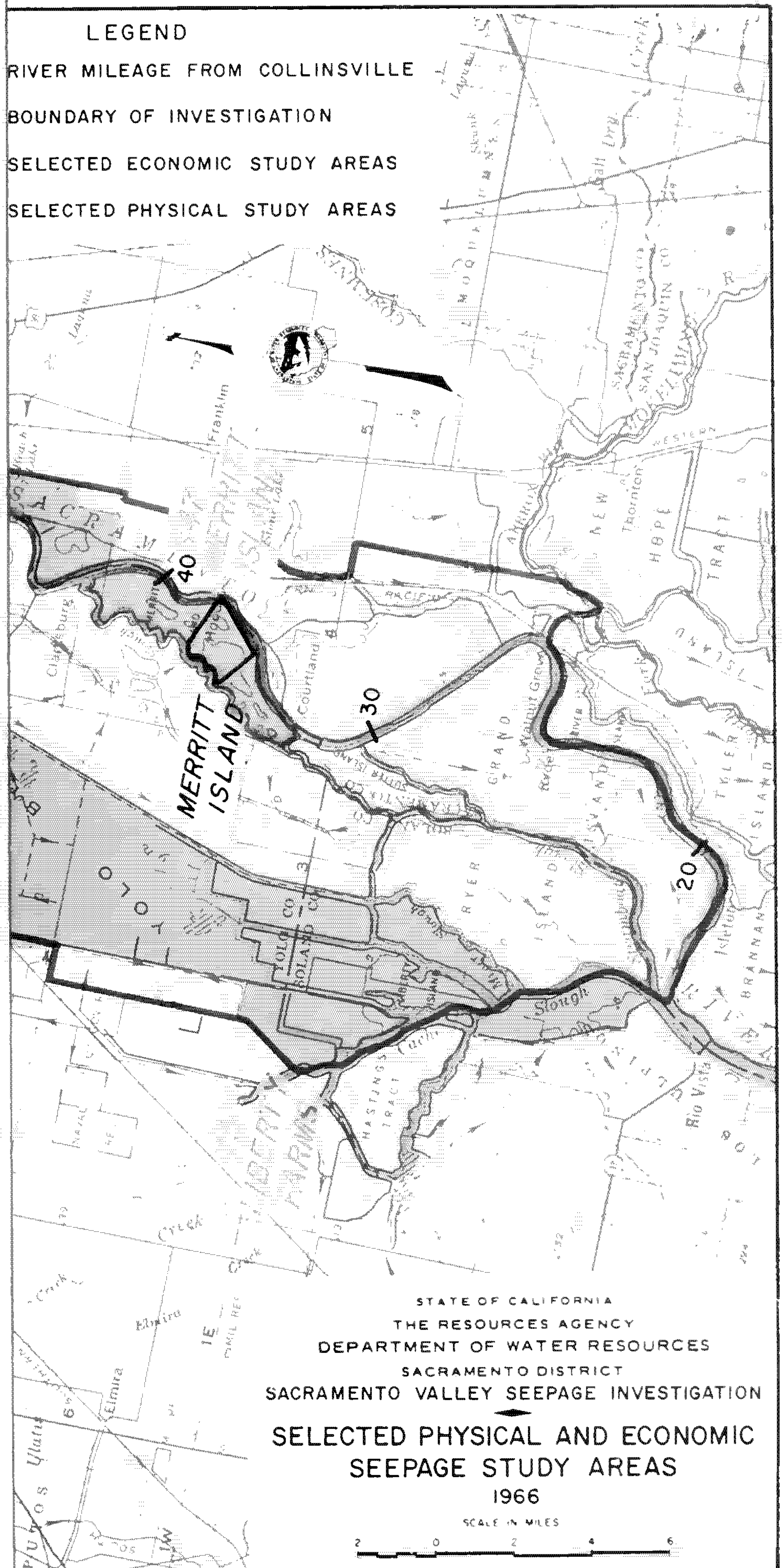
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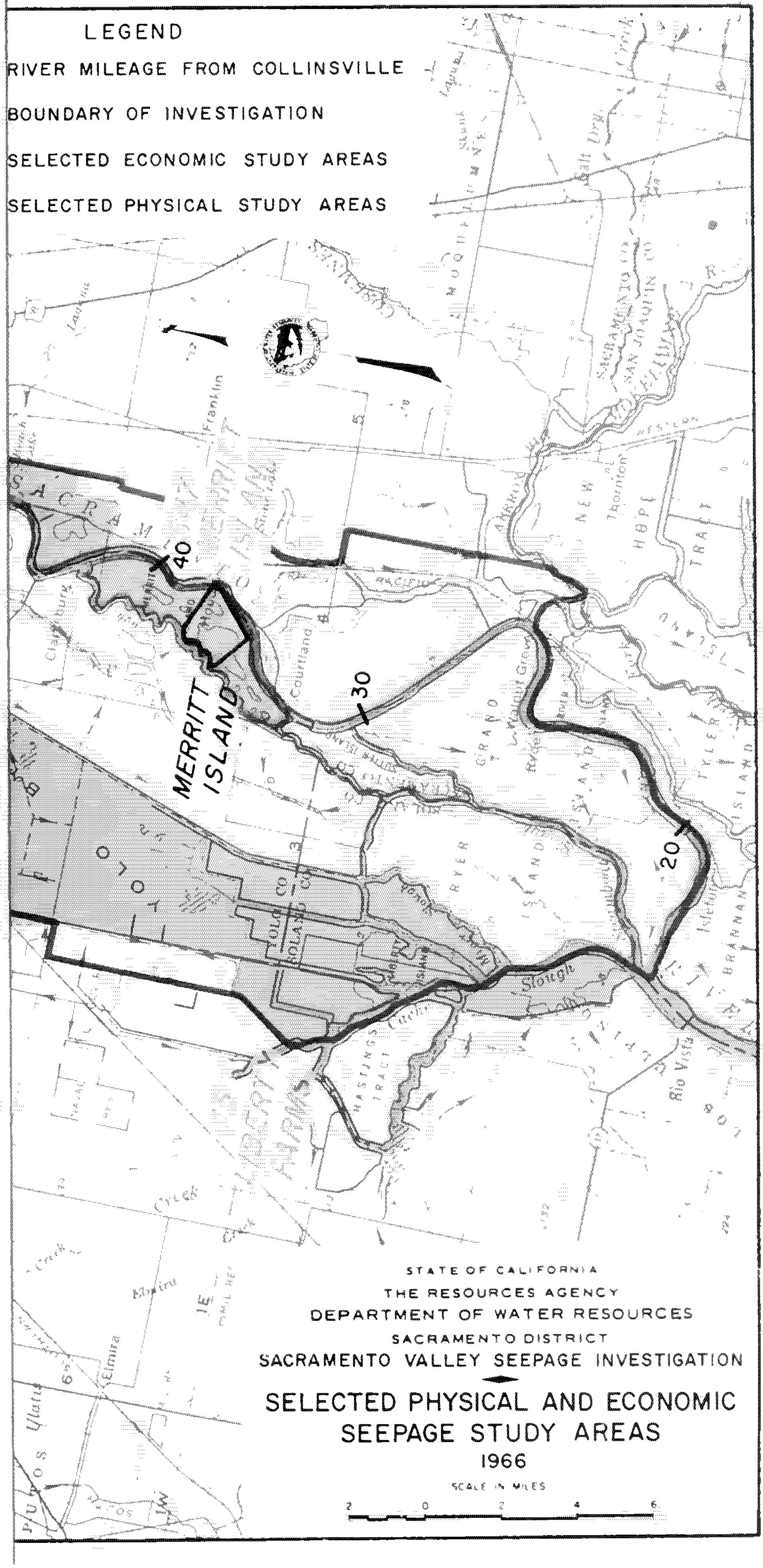
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ECONOMIC SEEPAGE STUDY

AREAS FOR CONCENTRATED STUDY

Geographical Location on Quad Maps		River Miles on Map		Code Area in Sample
From	To	From	To	
Sacramento River				
Ord Ferry	Butte Slough Outfall	[illegible]	165.[illegible]	[illegible]
Butte Slough Outfall	Tisdale Weir	[illegible]	146.[illegible]	[illegible]
Tisdale Weir	Fremont Weir	[illegible]	119.[illegible]	[illegible]
Fremont Weir	Sacramento Weir	[illegible]	85.[illegible]	[illegible]
Sacramento Weir	Clarksburg	[illegible]	[illegible]	[illegible]
Clarksburg	[illegible]	[illegible]	[illegible]	[illegible]
Sutter Bypass				
Butte Slough Outfall	Tisdale Weir		[illegible]	[illegible]
Tisdale Weir	[illegible]		[illegible]	[illegible]
Feather River				
North of Marysville	Bear River	12.0	[illegible]	[illegible]
Bear River	[illegible]	[illegible]	12.0	[illegible]
Yolo Bypass				
Fremont Weir	Sacramento Weir		[illegible]	[illegible]
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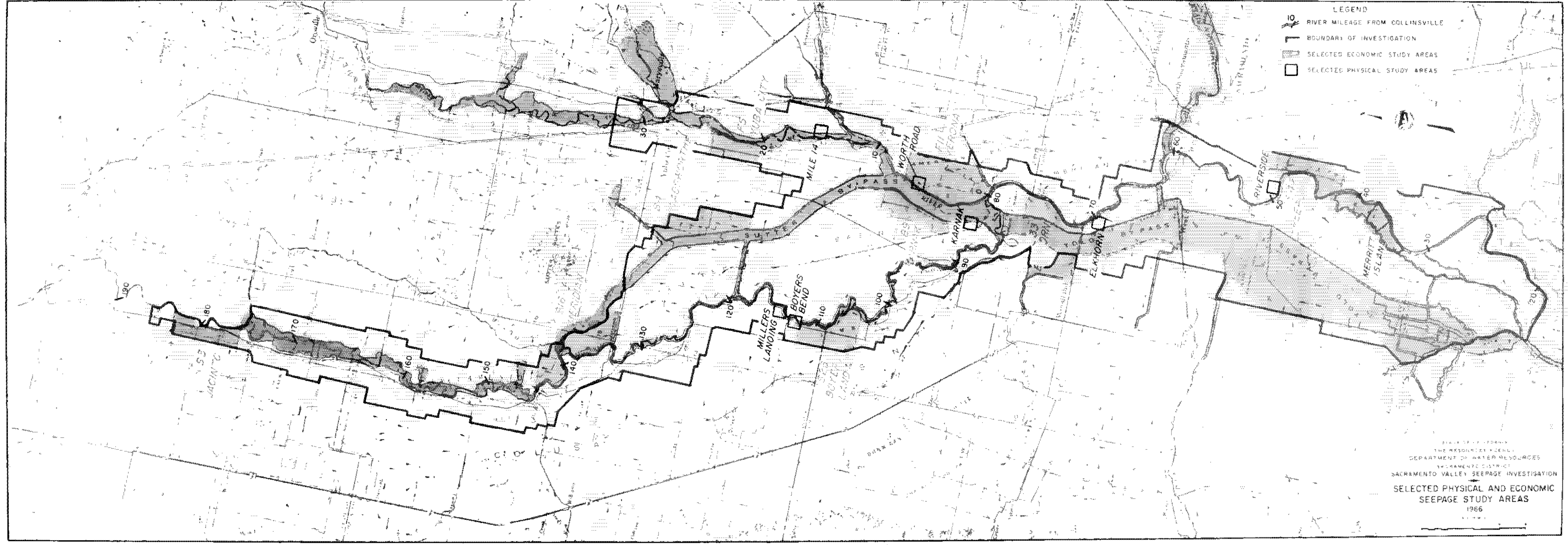

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SACRAMENTO VALLEY
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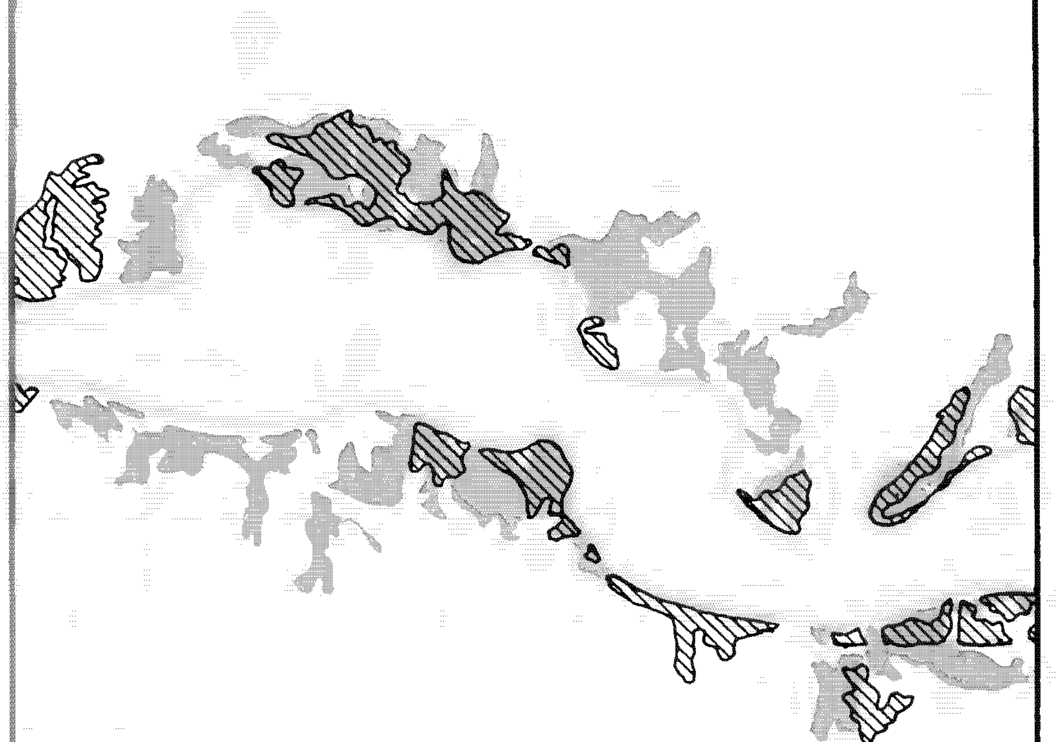

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PLATE 3

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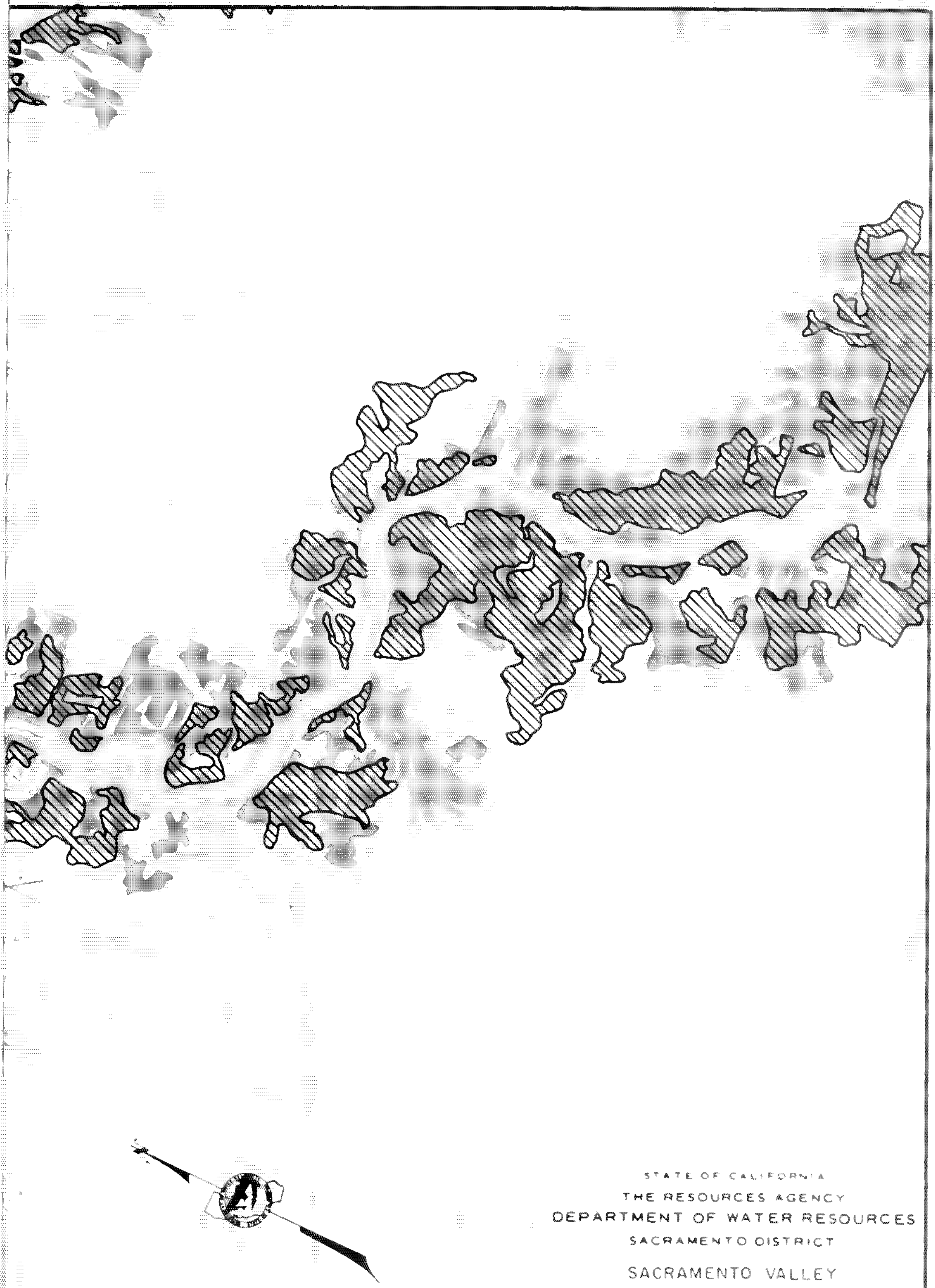

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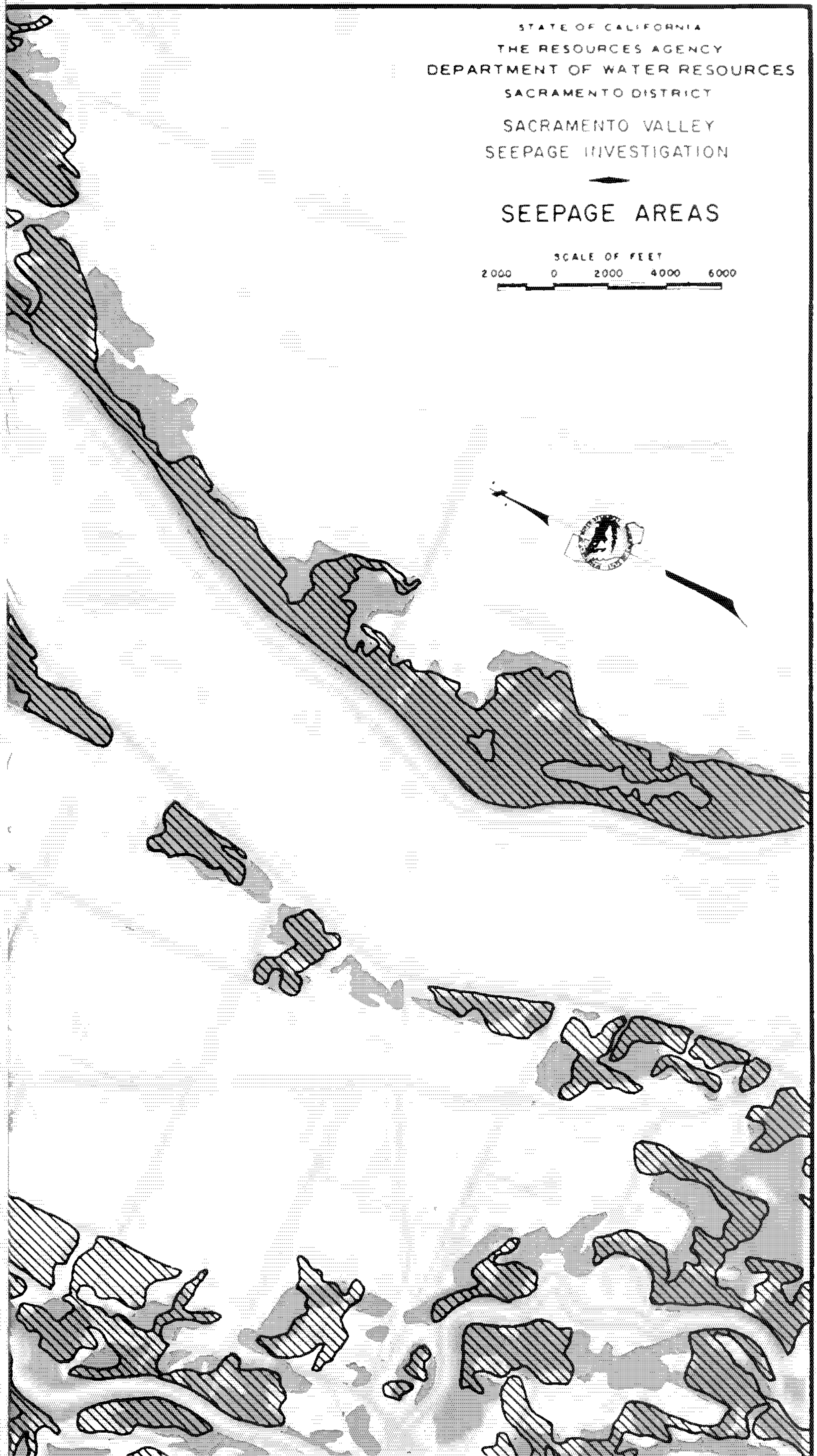
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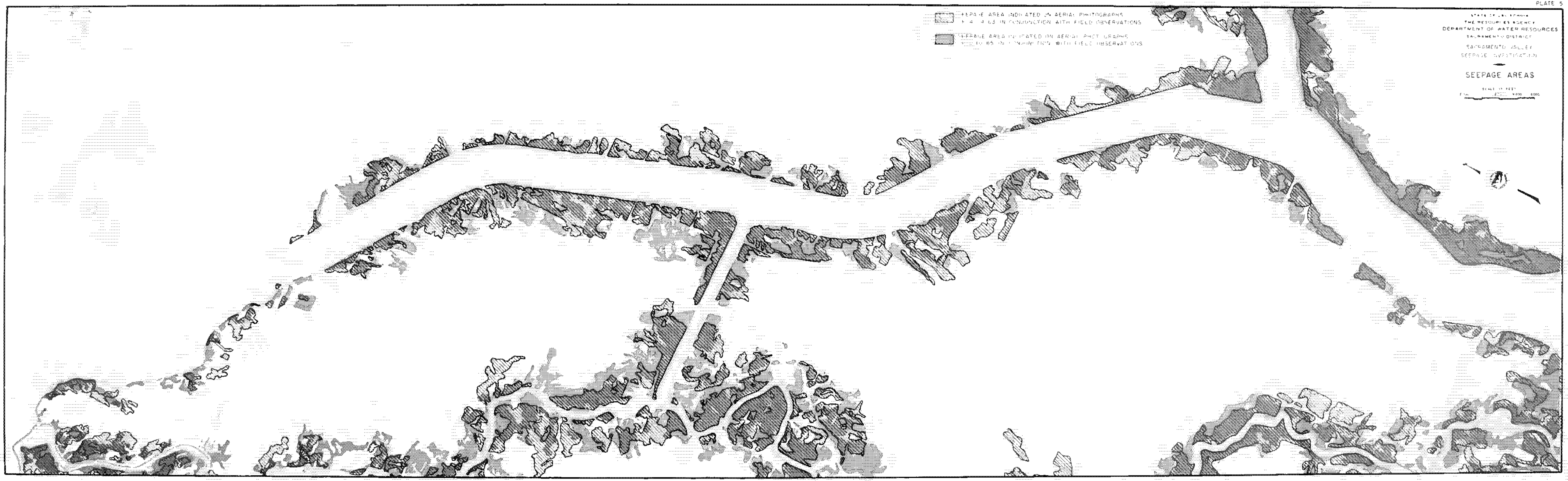

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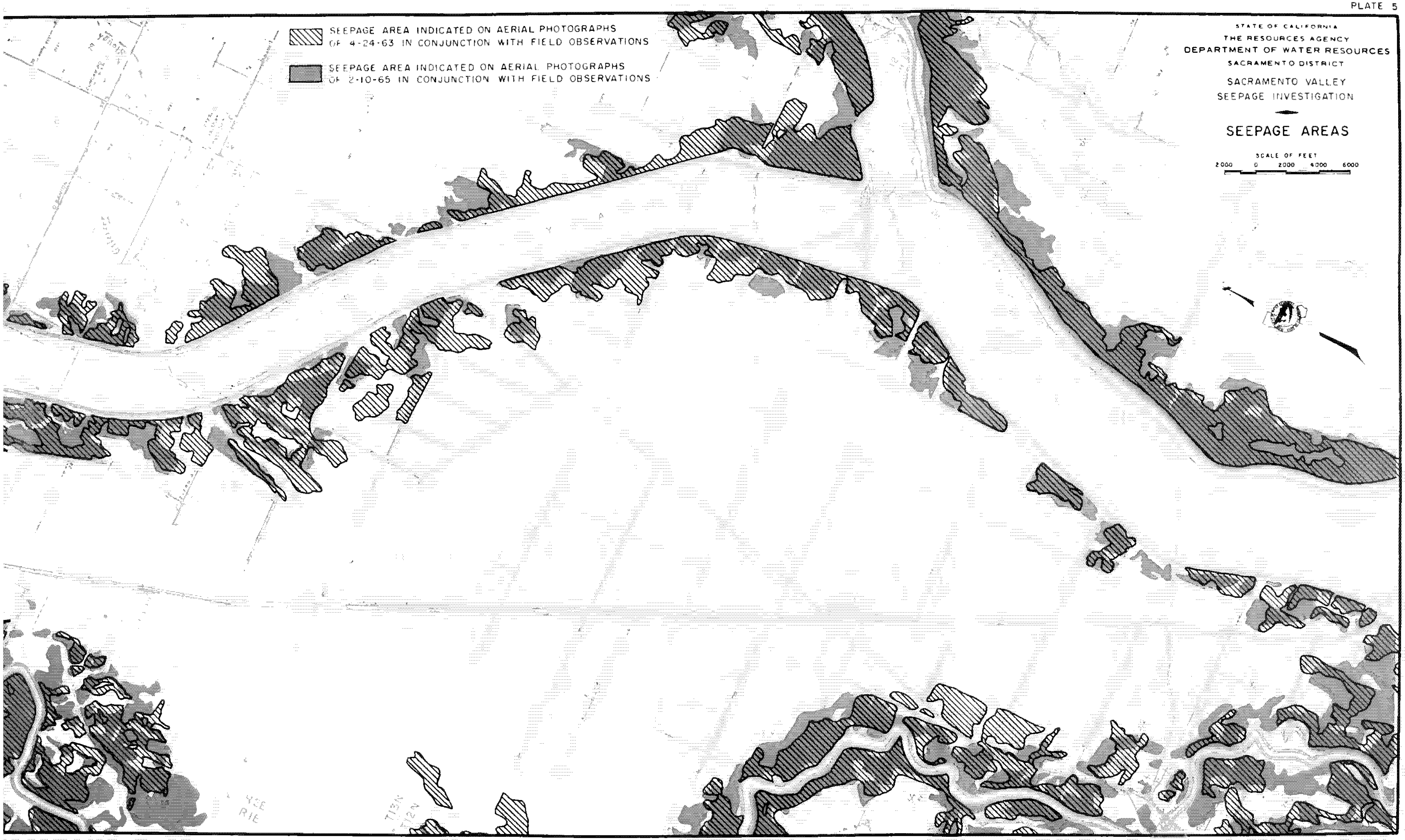
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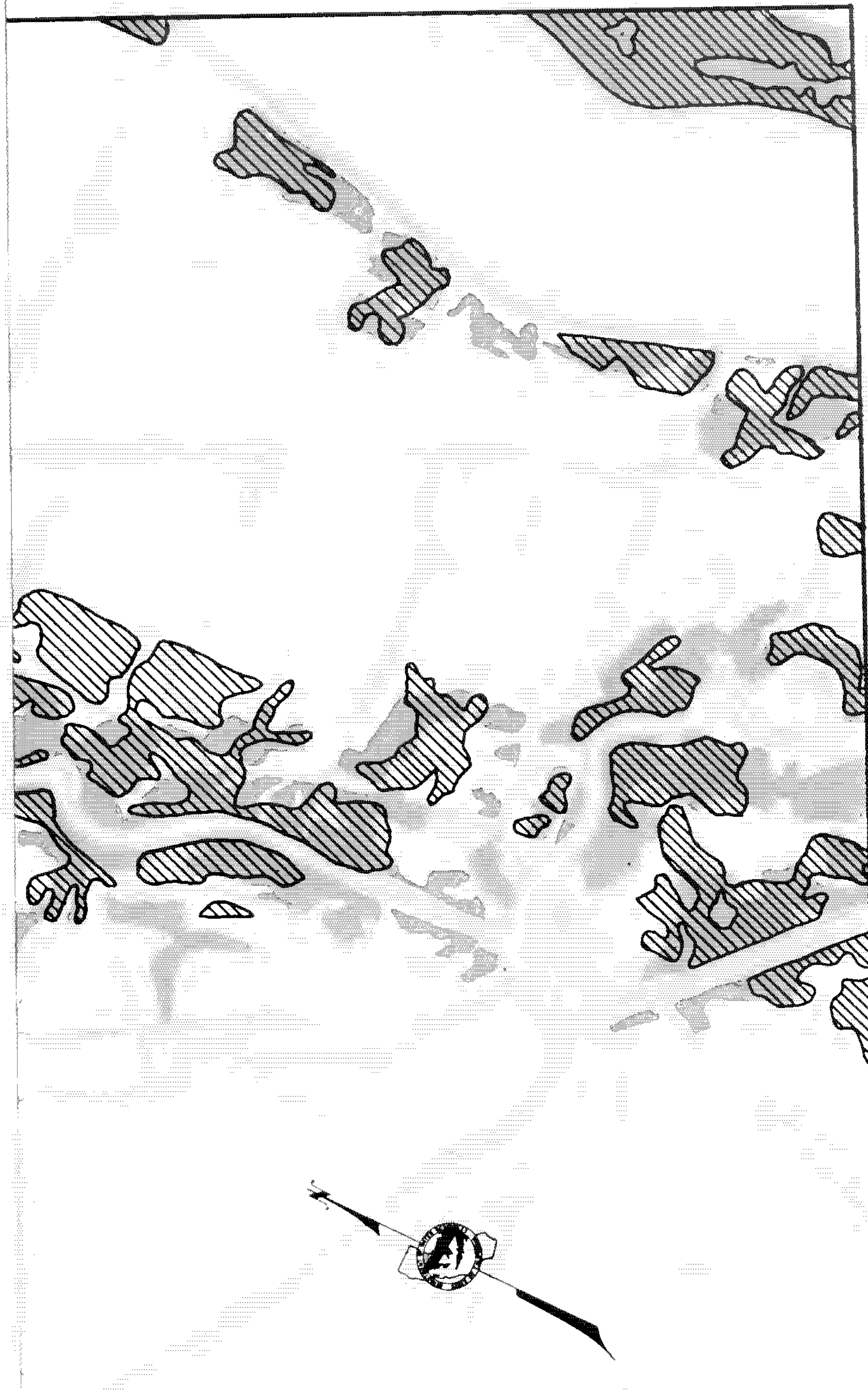

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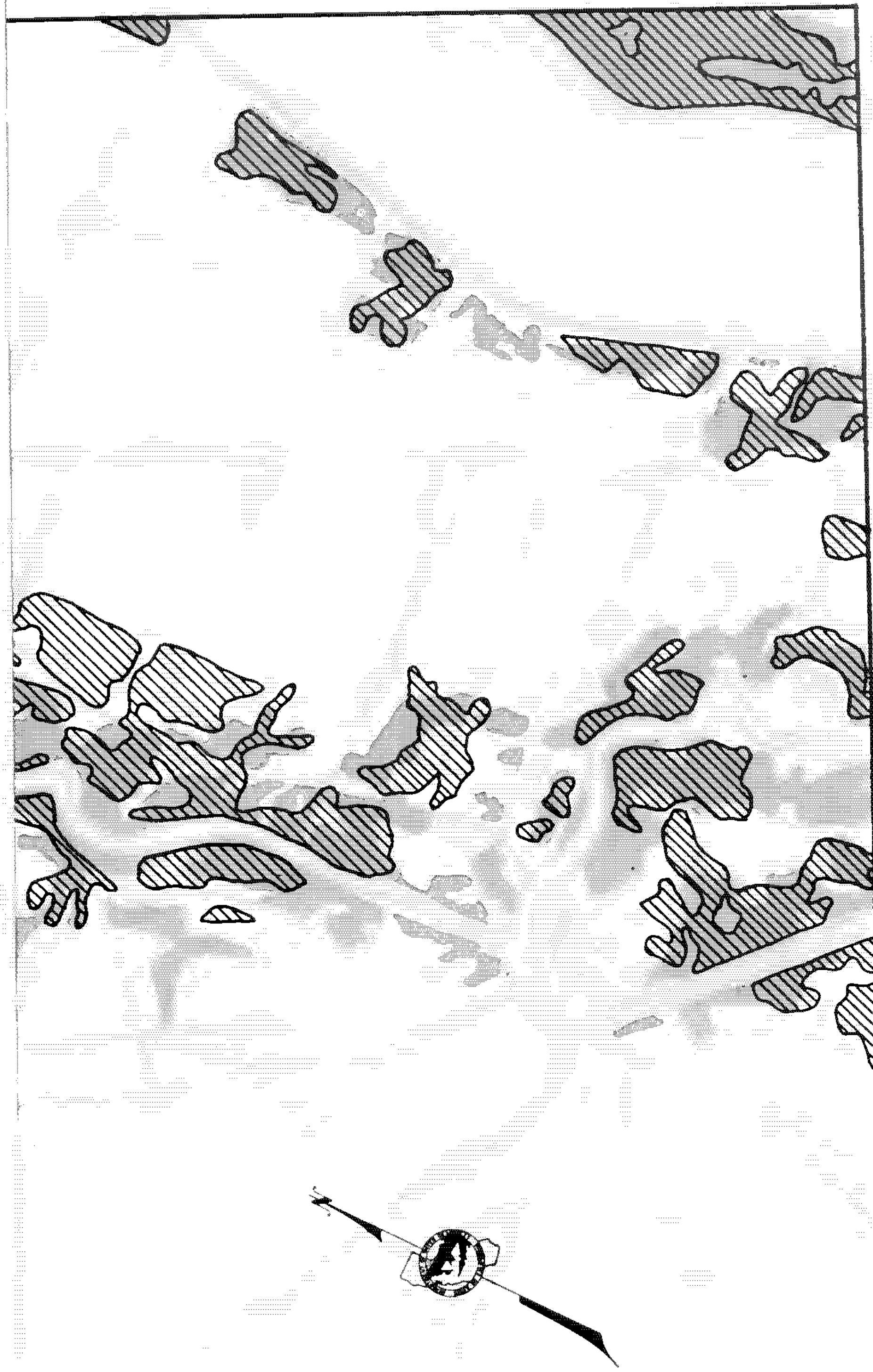

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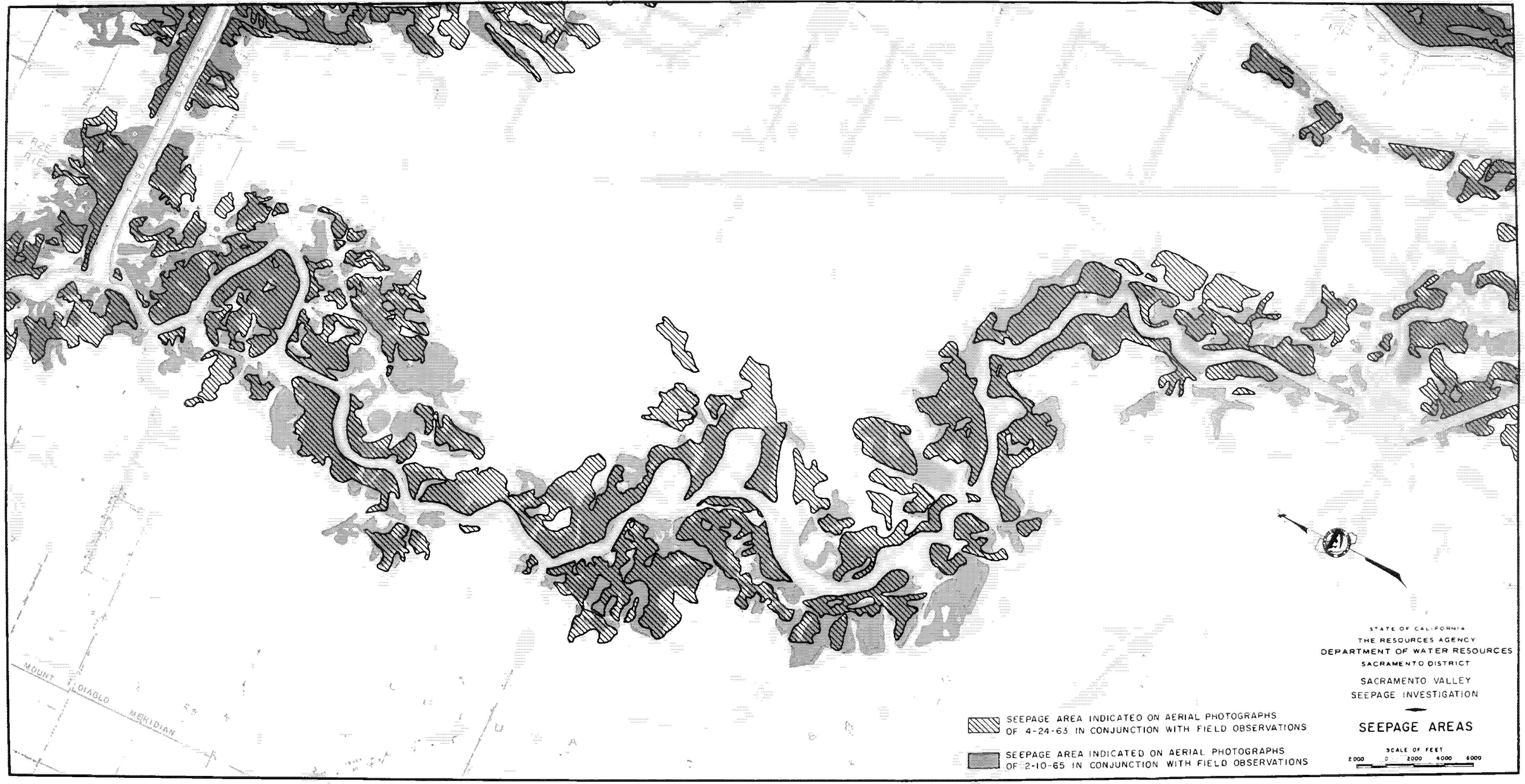
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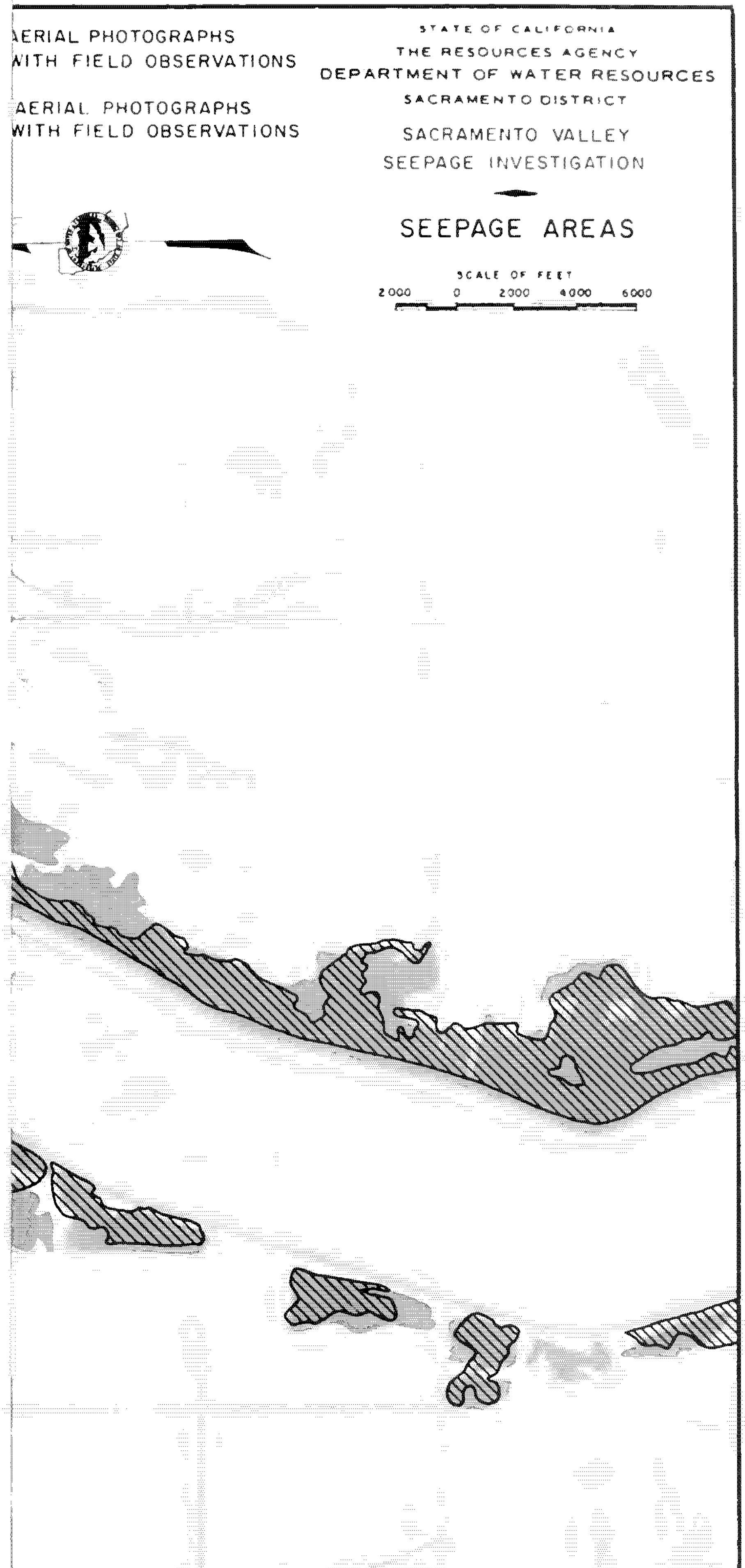
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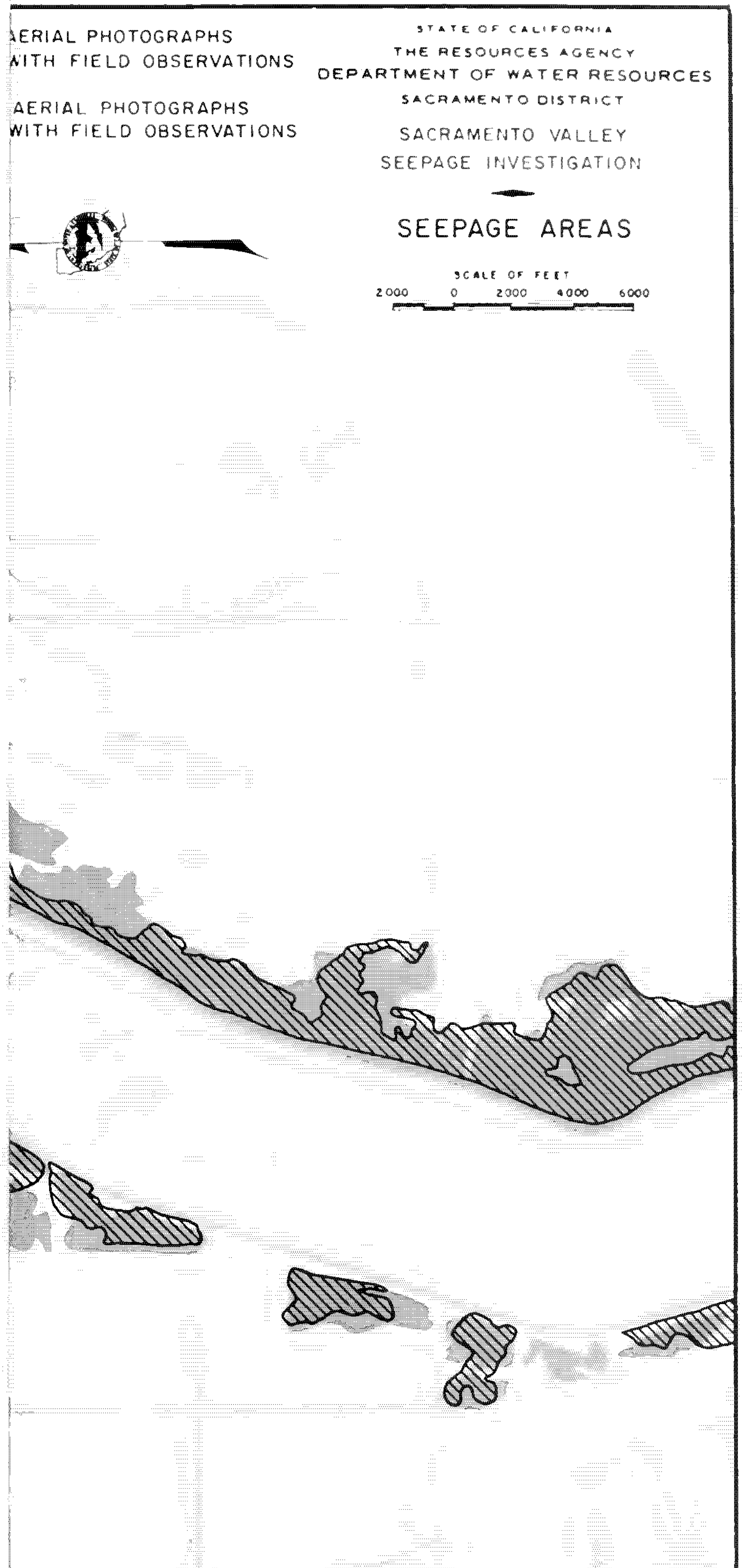
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WITH FIELD OBSERVATIONS
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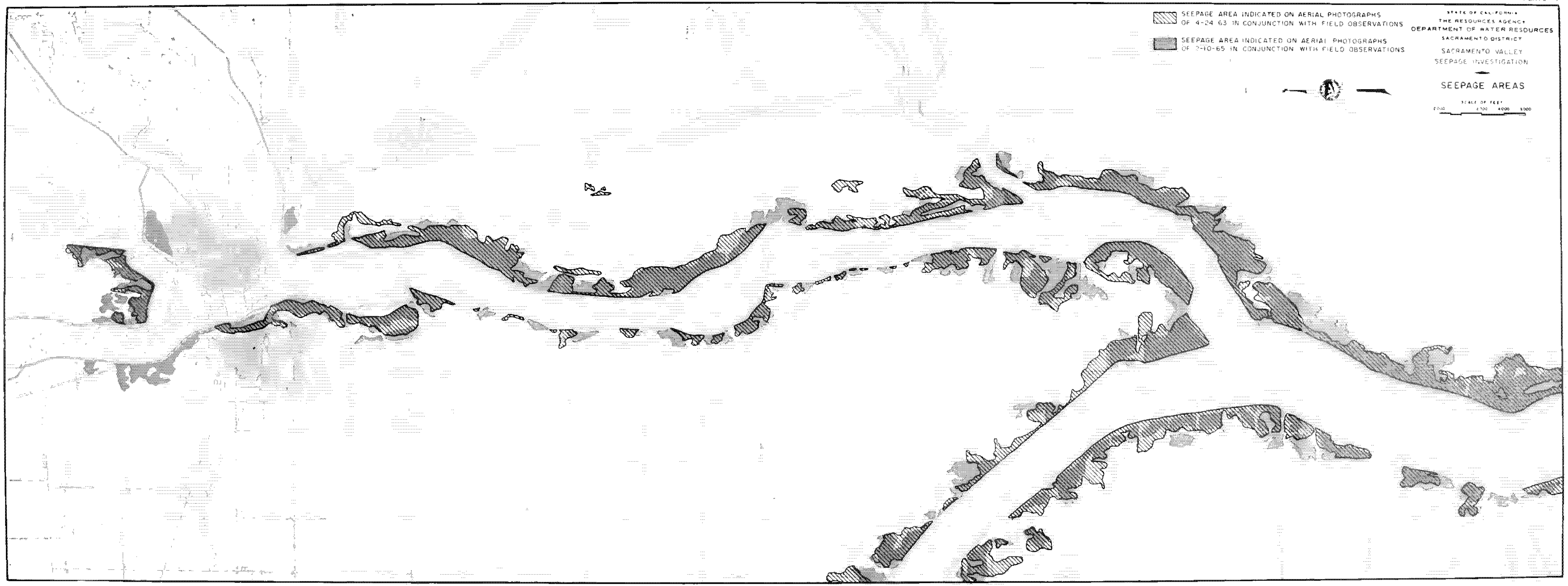
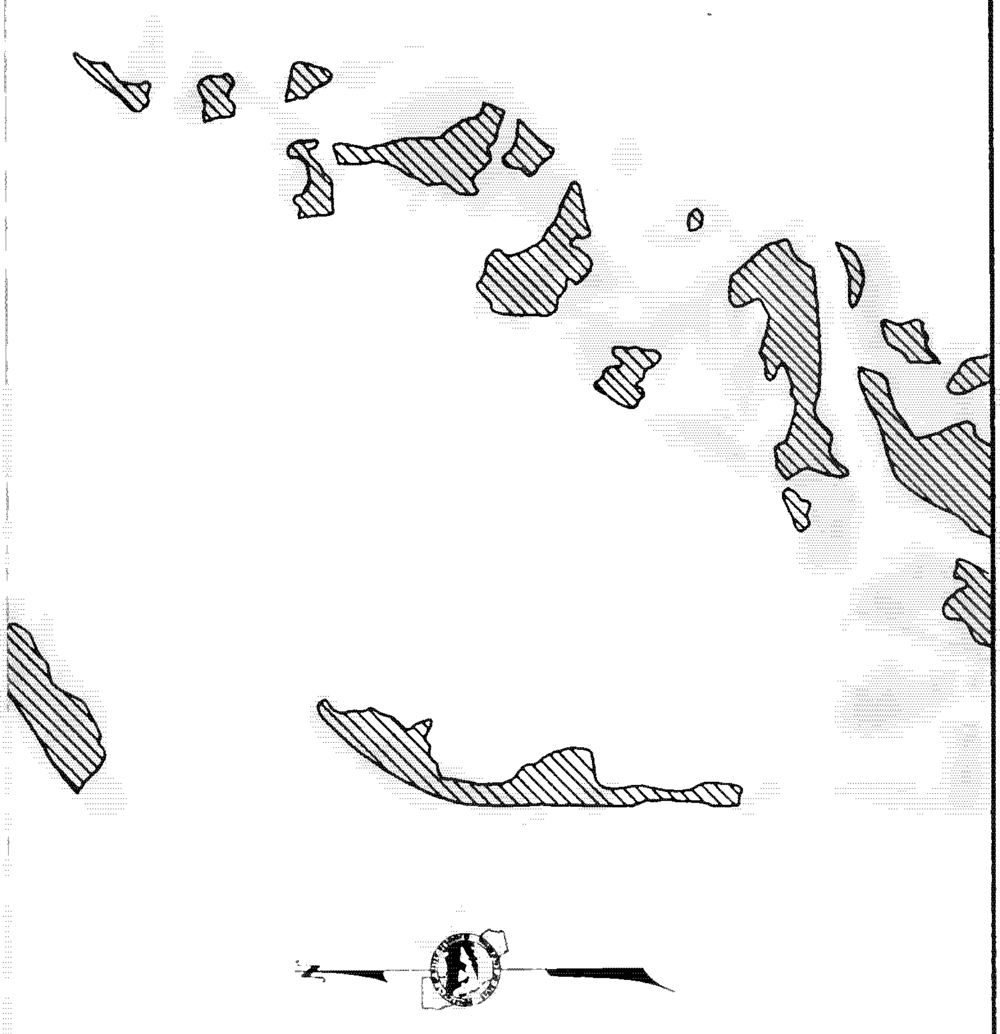
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
SEEPAGE AREAS
SCALE OF FEET
2000 0 2000 4000 6000

PLATE 7



DFCG-6



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000

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ED ON AERIAL PHOTOGRAPHS
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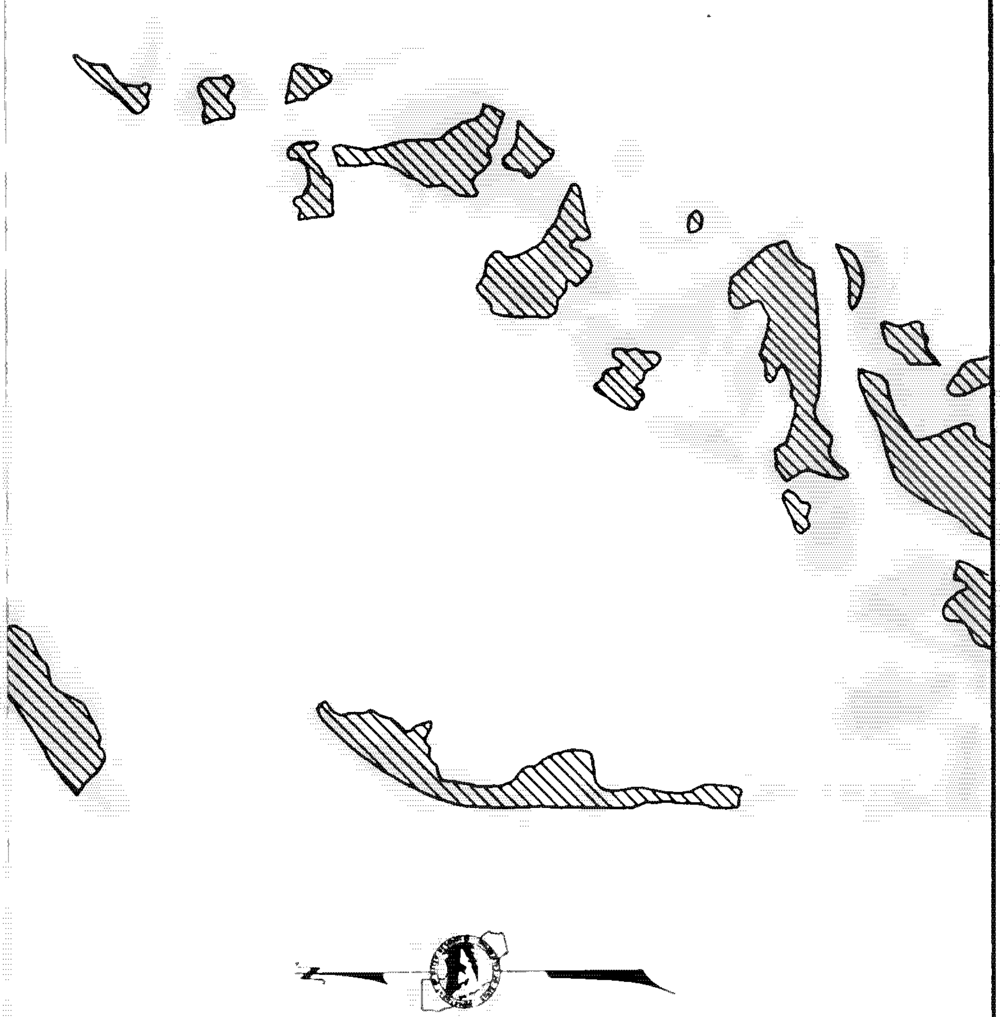

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STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000

PLATE 8

DFCG-6

ICATED ON AERIAL PHOTOGRAPHS
NJUNCTION WITH FIELD OBSERVATIONS

ICATED ON AERIAL PHOTOGRAPHS
NJUNCTION WITH FIELD OBSERVATIONS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000

ICATED ON AERIAL PHOTOGRAPHS
NJUNCTION WITH FIELD OBSERVATIONS

ICATED ON AERIAL PHOTOGRAPHS
NJUNCTION WITH FIELD OBSERVATIONS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

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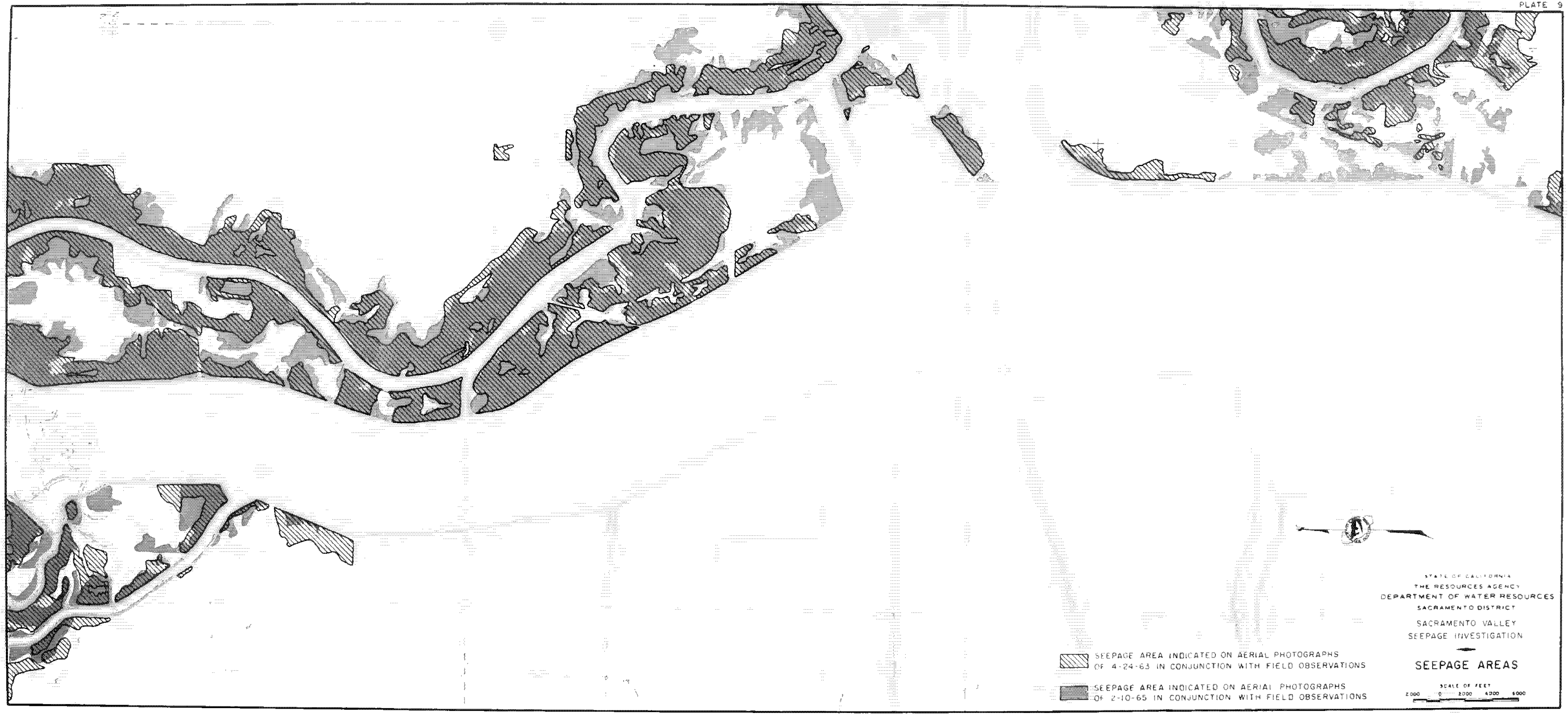
SEEPAGE INVESTIGATION

SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000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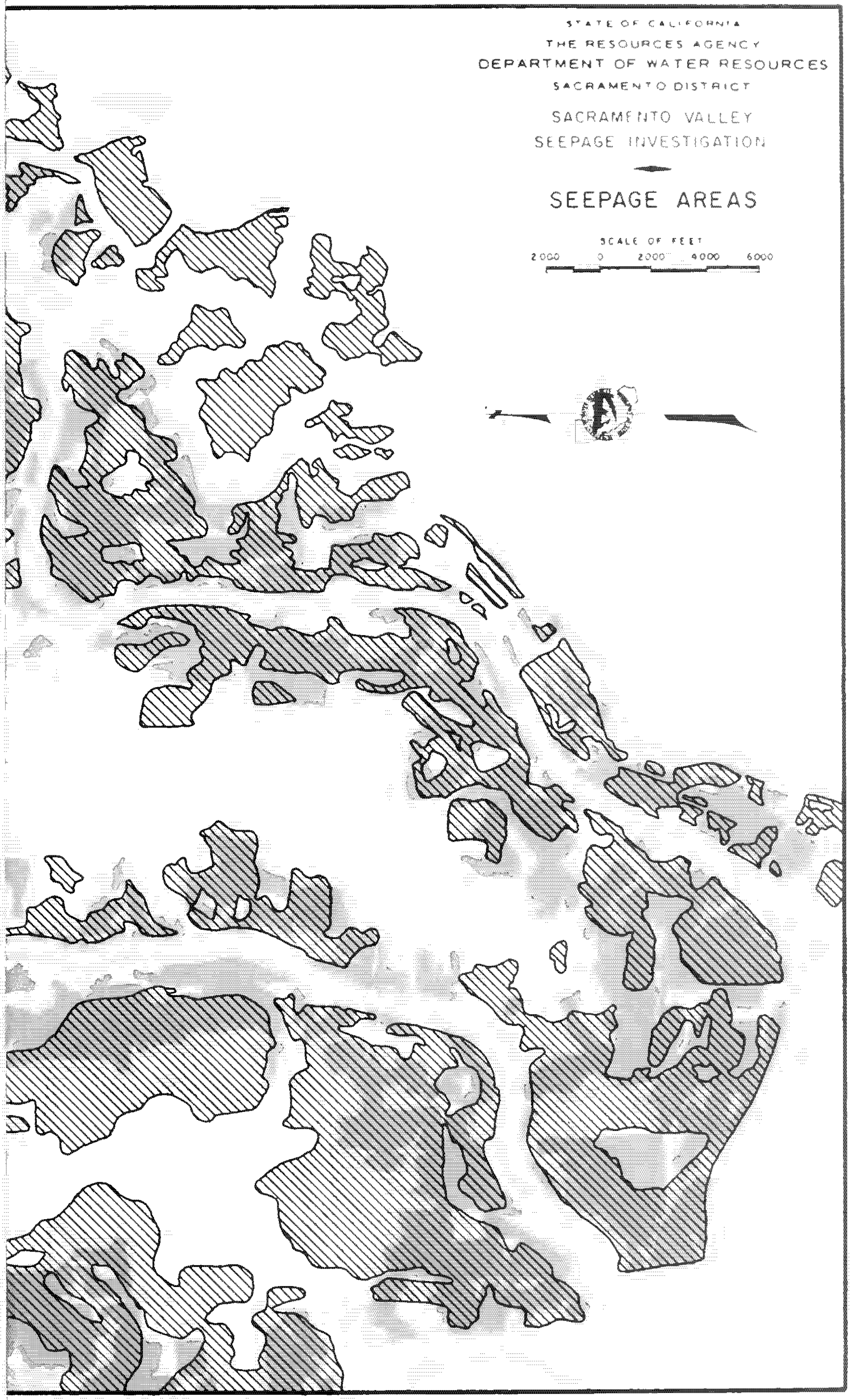
SEEPAGE AREA INDICATED ON AERIAL PHOTOGRAPHS OF 2-10-65 IN CONJUNCTION WITH FIELD OBSERVATIONS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
SEEPAGE AREAS
SCALE OF FEET
2000 0 2000 4000 6000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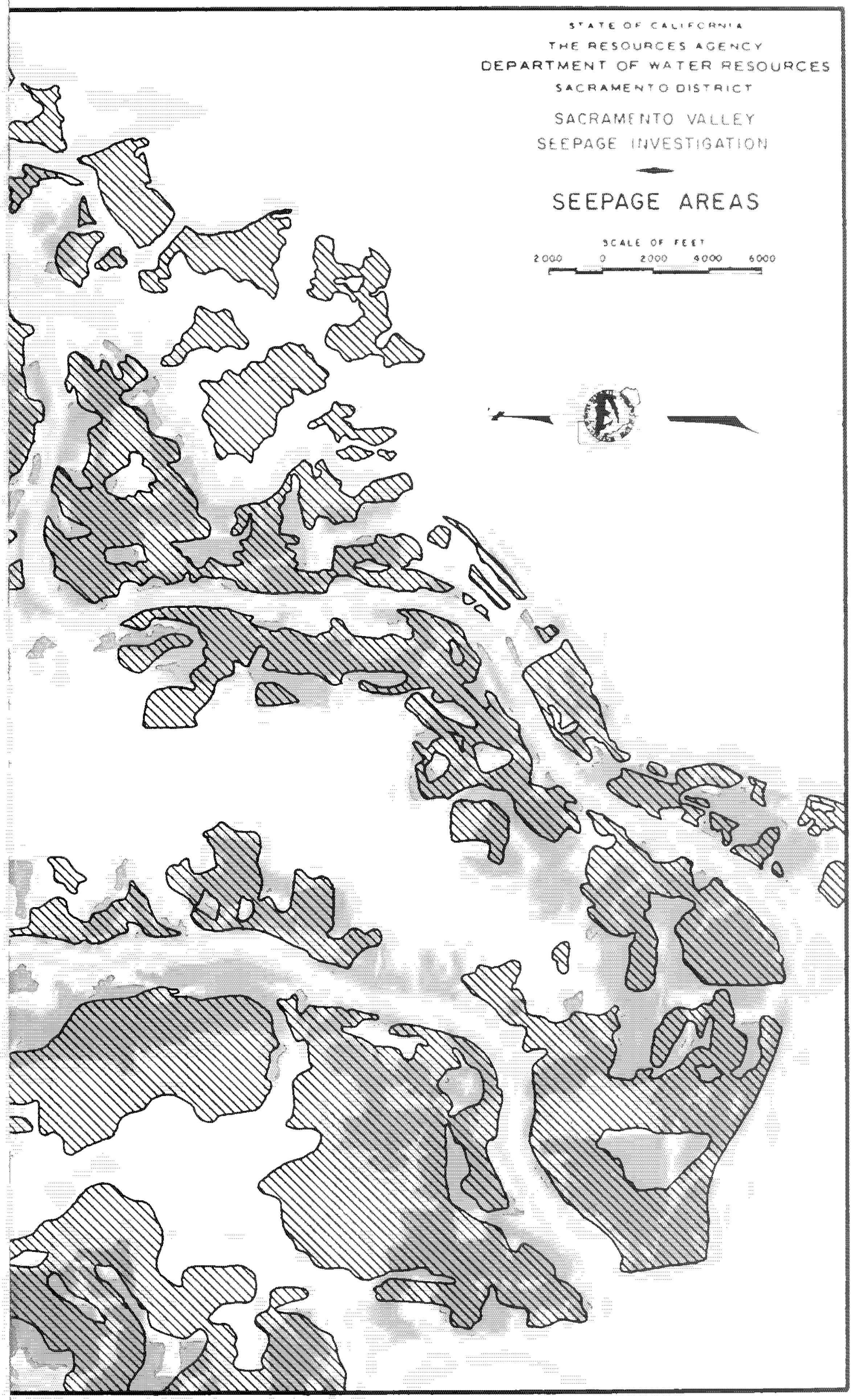
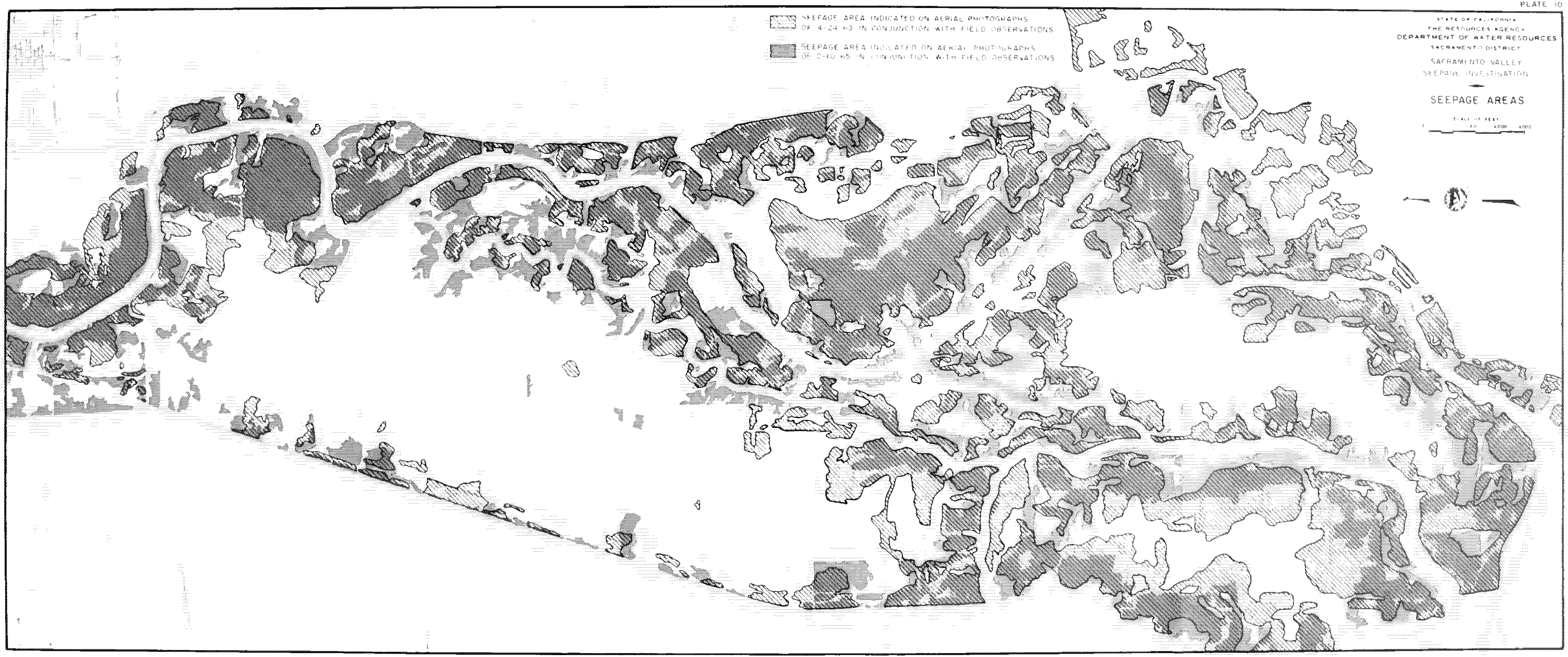
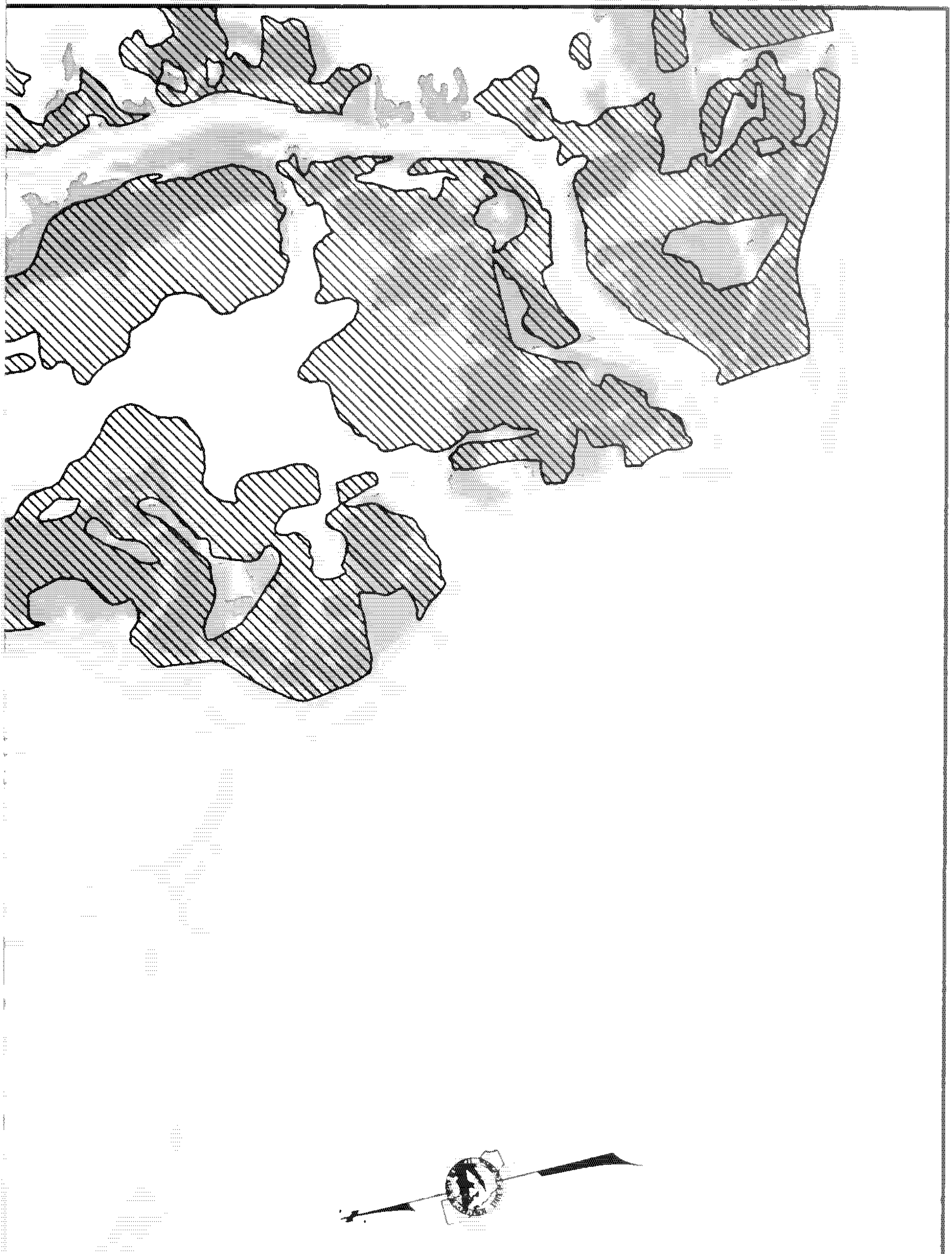
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
SEEPAGE AREAS
SCALE OF FEET
2000 0 2000 4000 6000


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
SEEPAGE AREAS
SCALE OF FEET
2000 0 2000 4000 6000


SEEPAGE AREA INDICATED ON AERIAL PHOTOGRAPHS OF 4-24-63 IN CONJUNCTION WITH FIELD OBSERVATIONS
SEEPAGE AREA INDICATED ON AERIAL PHOTOGRAPHS OF 2-10-65 IN CONJUNCTION WITH FIELD OBSERVATIONS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
SEEPAGE AREAS
SCALE OF FEET



ᴬREA INDICATED ON AERIAL PHOTOGRAPHS
3 IN CONJUNCTION WITH FIELD OBSERVATIONS

ᴬREA INDICATED ON AERIAL PHOTOGRAPHS
5 IN CONJUNCTION WITH FIELD OBSERVATIONS

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SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000

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SEEPAGE INVESTIGATION

SEEPAGE AREAS

SCALE OF FEET
2000 0 2000 4000 6000

AREA INDICATED ON AERIAL PHOTOGRAPHS
3 IN CONJUNCTION WITH FIELD OBSERVATIONS

AREA INDICATED ON AERIAL PHOTOGRAPHS
5 IN CONJUNCTION WITH FIELD OBSERVATIONS

PLATE 11

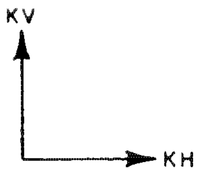
DFCG-6

LEGEND

A FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

C FLOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.



KV-VERTICAL PERMEABILITY IN FEET PER DAY.
KH-HORIZONTAL PERMEABILITY IN FEET PER DAY.

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES.
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES.
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- SILTY SANDS, SAND-SILT MIXTURES.
- CLAYEY SANDS, SAND-SILT MIXTURES.

- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
- PEAT AND OTHER HIGHLY ORGANIC SOILS.

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

MILLERS LANDING

LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B — STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

C — FLOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.

KV / KH

KV - VERTICAL PERMEABILITY IN FEET PER DAY.
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY.

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES.
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES.
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- SILTY SANDS, SAND-SILT MIXTURES.
- CLAYEY SANDS, SAND-SILT MIXTURES.
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
- PEAT AND OTHER HIGHLY ORGANIC SOILS.

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SEEPAGE INVESTIGATION

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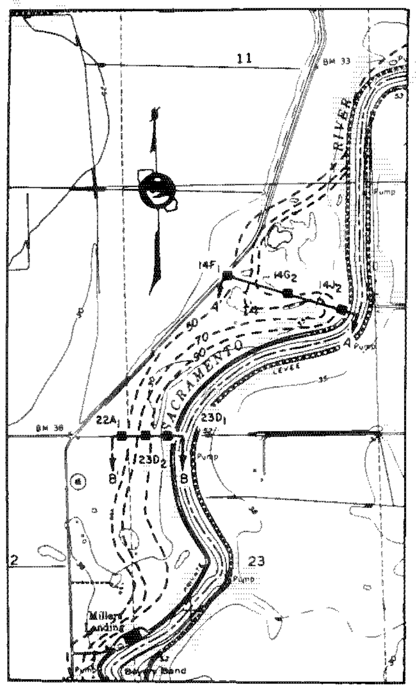
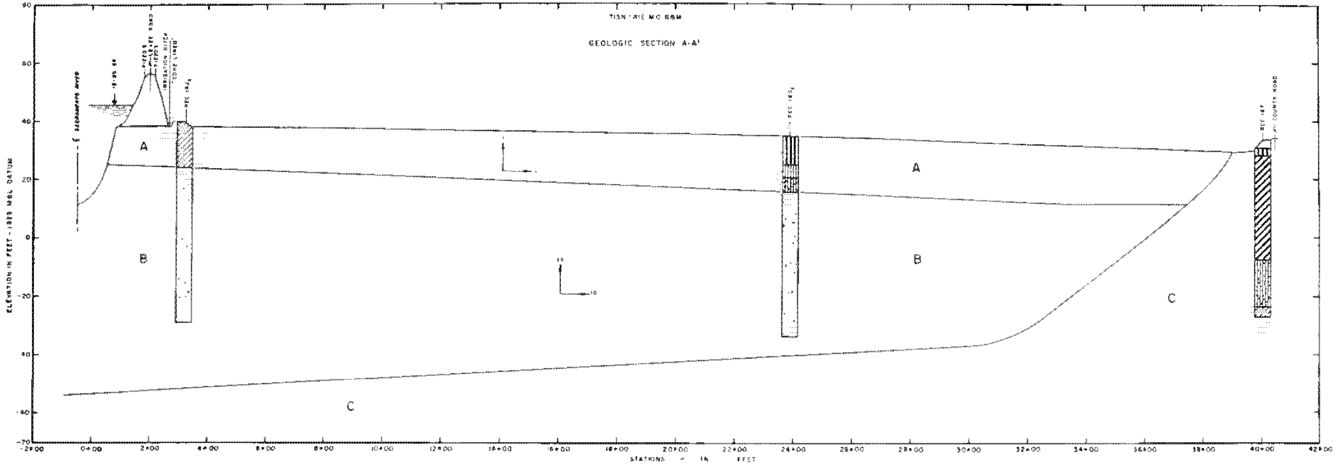
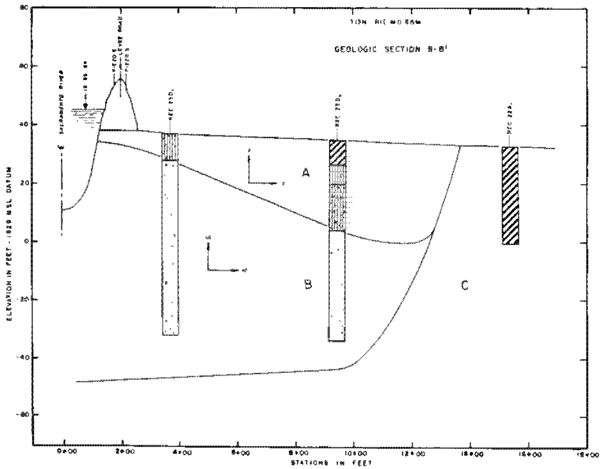
MILLERS LANDING



LOCATION MAP

SCALE OF FEET
1000 0 1000 2000 3000





LEGEND

- A — FLOOD PLAIN DEPOSIT: BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY
- B — STREAM DEPOSIT: GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY
- C — FLOOD BASIN DEPOSIT: GRAY, STIFF CLAY, LOW PERMEABILITY

KV - VERTICAL PERMEABILITY IN FEET PER DAY
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM FEET FOR UPPER 20 FEET OF SOIL

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SILTY SANDS, SAND-SILT MIXTURES
- CLAYEY SANDS, SAND-SILT MIXTURES
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
- PEAT AND OTHER HIGHLY ORGANIC SOILS

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

MILLERS LANDING

DFCG-6

LEGEND

PLAIN DEPOSIT
OWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO
GH PERMEABILITY.

M DEPOSIT
AY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

BASIN DEPOSIT
AY, STIFF CLAY, LOW PERMEABILITY.

/-VERTICAL PERMEABILITY IN FEET PER DAY.
1-HORIZONTAL PERMEABILITY IN FEET PER DAY.

NES OF EQUAL ELECTRICAL RESISTIVITY VALUES
OHM-FEET FOR UPPER 20 FEET OF SOIL.

.S OR ES, LITTLE		INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
ELS OR ES, LITTLE		INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
EL-SAND-		ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
AVEL- S.		INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
OR TLE OR NO		INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
S OR TLE OR NO		ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
ILT		PEAT AND OTHER HIGHLY ORGANIC SOILS.
SILT		

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MILE 14

LEGEND

PLAIN DEPOSIT
OWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO
GH PERMEABILITY.

M DEPOSIT
AY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

BASIN DEPOSIT
AY, STIFF CLAY, LOW PERMEABILITY.

/-VERTICAL PERMEABILITY IN FEET PER DAY
I-HORIZONTAL PERMEABILITY IN FEET PER DAY.

NES OF EQUAL ELECTRICAL RESISTIVITY VALUES
OHM-FEET FOR UPPER 20 FEET OF SOIL.

.S OR
ES, LITTLE

INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.

ELS OR
ES, LITTLE

INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.

EL-SAND-

ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.

AVEL-
S.

INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.

OR
TLE OR NO

INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.

S OR
TLE OR NO

ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.

SILT

PEAT AND OTHER HIGHLY ORGANIC SOILS.

SILT

75089

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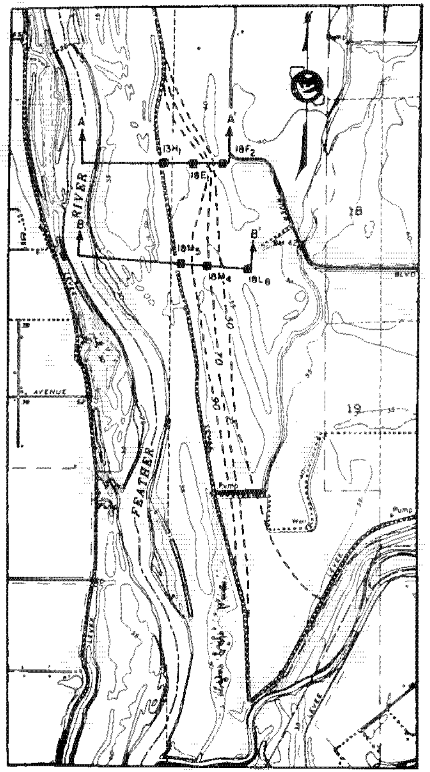
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

GEOLOGIC SECTION AT PHYSICAL TEST AREA

MILE 14

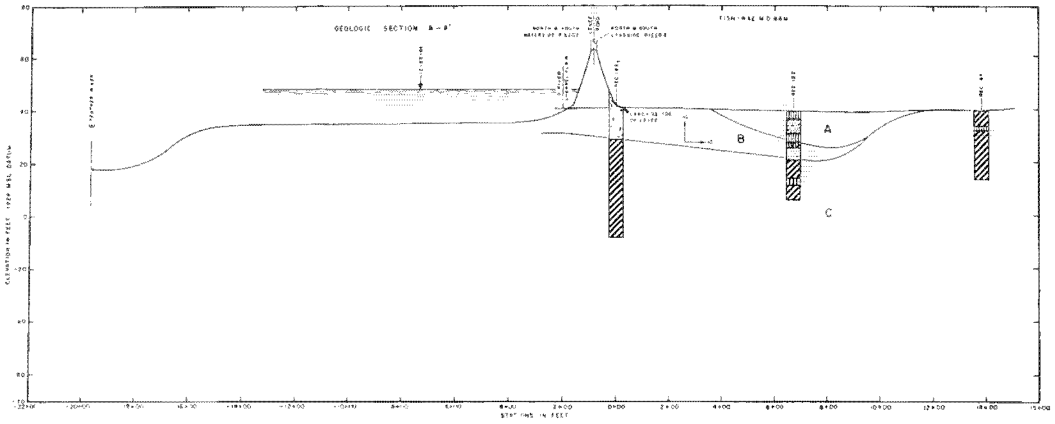
PLATE 15

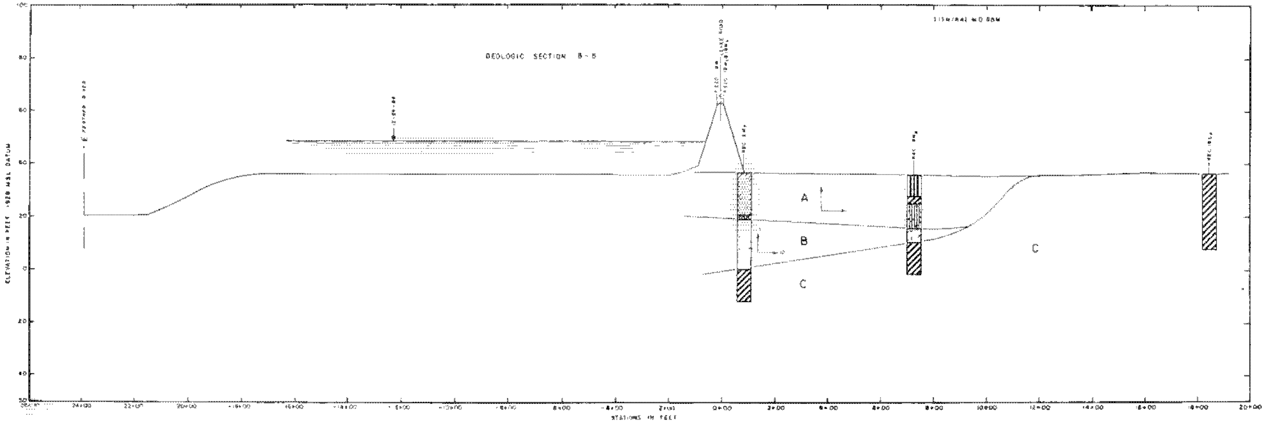


LOCATION MAP

SCALE OF FEET

1000 0 1000 2000 3000





LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY

B — STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

C — FLOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY

KV-VERTICAL PERMEABILITY IN FEET PER DAY
KH-HORIZONTAL PERMEABILITY IN FEET PER DAY

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SILTY SANDS, SAND-SILT MIXTURES
- CLAYEY SANDS, SAND-SILT MIXTURES
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
- PEAT AND OTHER HIGHLY ORGANIC SOILS

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

MILE 14

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LEGEND

LOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

TREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY.

LOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.

KV - VERTICAL PERMEABILITY IN FEET PER DAY.
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY.

H

LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

AVELS OR XTURES, LITTLE	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
GRAVELS OR (TURES, LITTLE	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
RAVEL - SAND -	ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
, GRAVEL- URES.	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
NDS OR , LITTLE OR NO	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
SANDS OR , LITTLE OR NO	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
ID - SILT	PEAT AND OTHER HIGHLY ORGANIC SOILS.
ND - SILT	

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

WORTH ROAD

LEGEND

LOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

TREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY.

LOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.

KV - VERTICAL PERMEABILITY IN FEET PER DAY.
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY.

H

LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

AVELS OR XTURES, LITTLE

RAVELS OR TURES, LITTLE

RAVEL - SAND -

, GRAVEL- URES.

NDS OR , LITTLE OR NO

SANDS OR , LITTLE OR NO

D - SILT

ND - SILT

INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.

INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.

ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.

INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.

INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.

ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.

PEAT AND OTHER HIGHLY ORGANIC SOILS.

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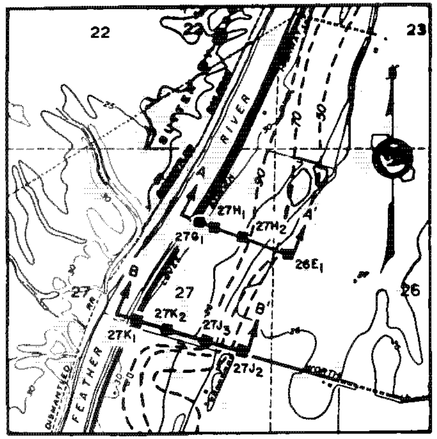
GEOLOGIC SECTION AT PHYSICAL TEST AREA

WORTH ROAD

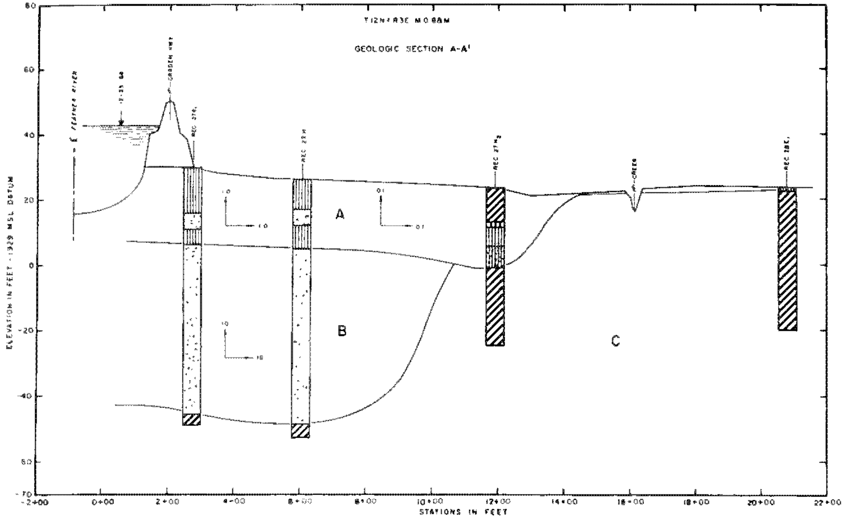
PLATE 14

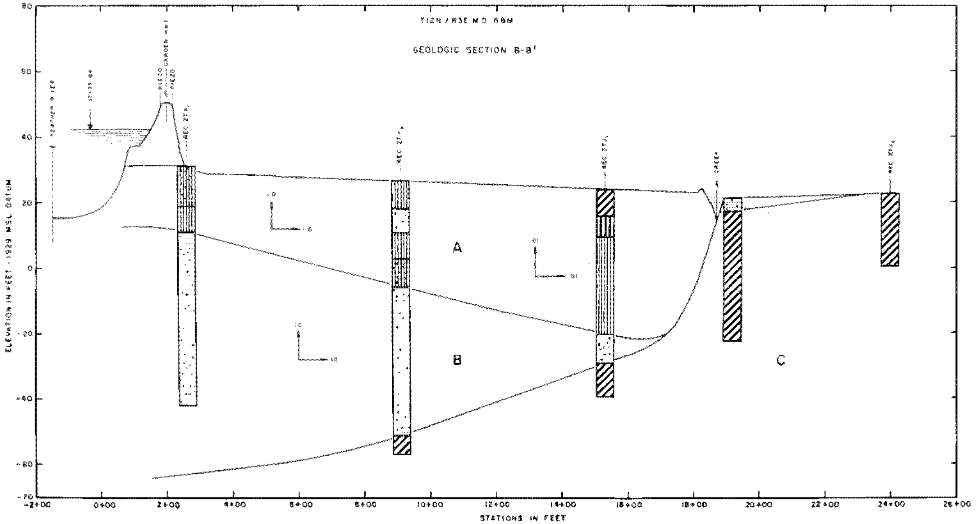


LOCATION MAP

SCALE OF FEET

1000 0 1000 2000 3000





LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY

B — STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

C — FLOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY

KV - VERTICAL PERMEABILITY IN FEET PER DAY
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES.
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES.
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SILTY SANDS, SAND-SILT MIXTURES
- CLAYEY SANDS, SAND-SILT MIXTURES.
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
- PEAT AND OTHER HIGHLY ORGANIC SOILS

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WORTH ROAD

DFCG-6

LEGEND

IN DEPOSIT
,SOFT CLAY OR SILT TO SILTY SAND, LOW TO
ERMEABILITY.

POSIT
OOSE, GRAVELLY SAND, HIGH PERMEABILITY.

IN DEPOSIT
STIFF CLAY, LOW PERMEABILITY.

RTICAL PERMEABILITY IN FEET PER DAY.
RIZONTAL PERMEABILITY IN FEET PER DAY.

OF EQUAL ELECTRICAL RESISTIVITY VALUES
-FEET FOR UPPER 20 FEET OF SOIL.

ITTLE	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
OR ITTLE	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
SAND -	ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
-	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
OR NO	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
OR NO	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
	PEAT AND OTHER HIGHLY ORGANIC SOILS.

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

KARNAK

LEGEND

IN DEPOSIT
,SOFT CLAY OR SILT TO SILTY SAND, LOW TO
ERMEABILITY.

EPOSIT
OOSE, GRAVELLY SAND, HIGH PERMEABILITY.

IN DEPOSIT
STIFF CLAY, LOW PERMEABILITY.

RTICAL PERMEABILITY IN FEET PER DAY.
RIZONTAL PERMEABILITY IN FEET PER DAY.

OF EQUAL ELECTRICAL RESISTIVITY VALUES
-FEET FOR UPPER 20 FEET OF SOIL.

R
ITTLE — INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.

OR
ITTLE — INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.

SAND- — ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.

- — INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.

OR NO — INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.

OR NO — ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.

PEAT AND OTHER HIGHLY ORGANIC SOILS.

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DEPARTMENT OF WATER RESOURCES
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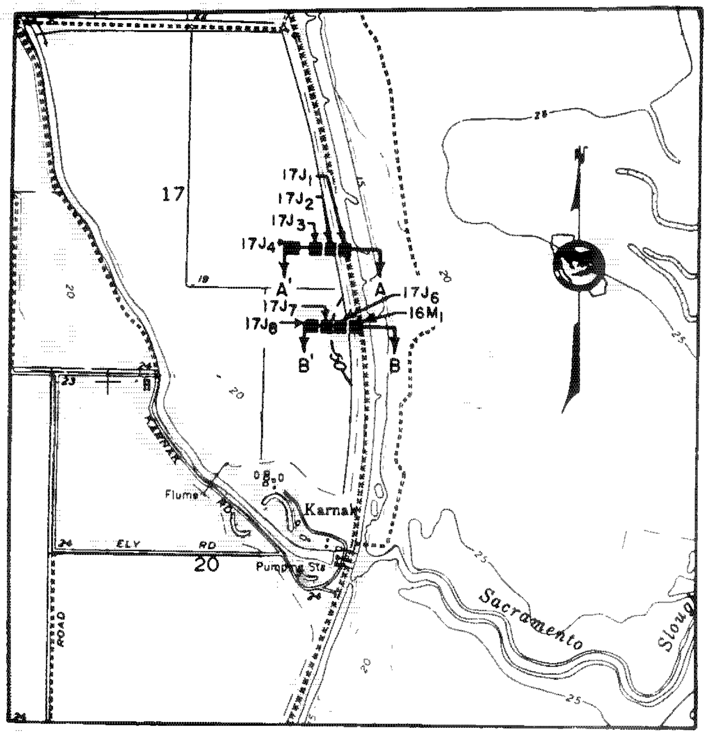
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

GEOLOGIC SECTION AT PHYSICAL TEST AREA

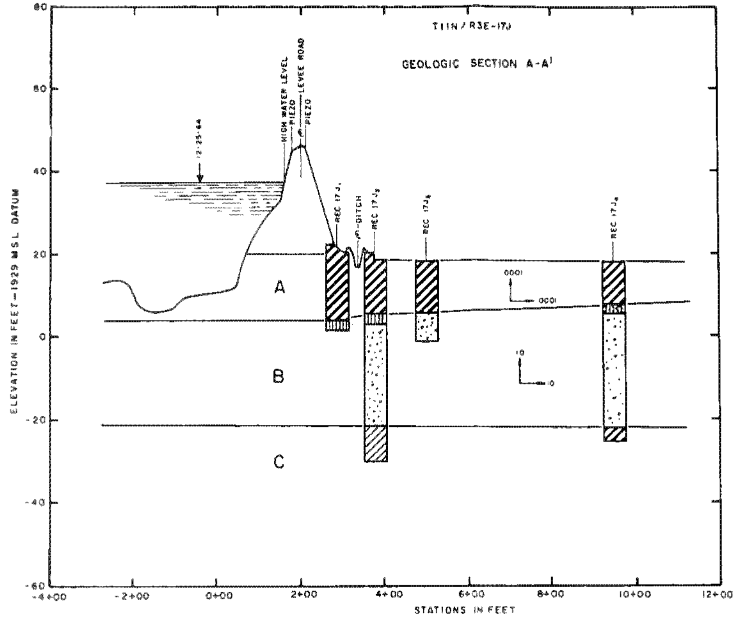
KARNAK

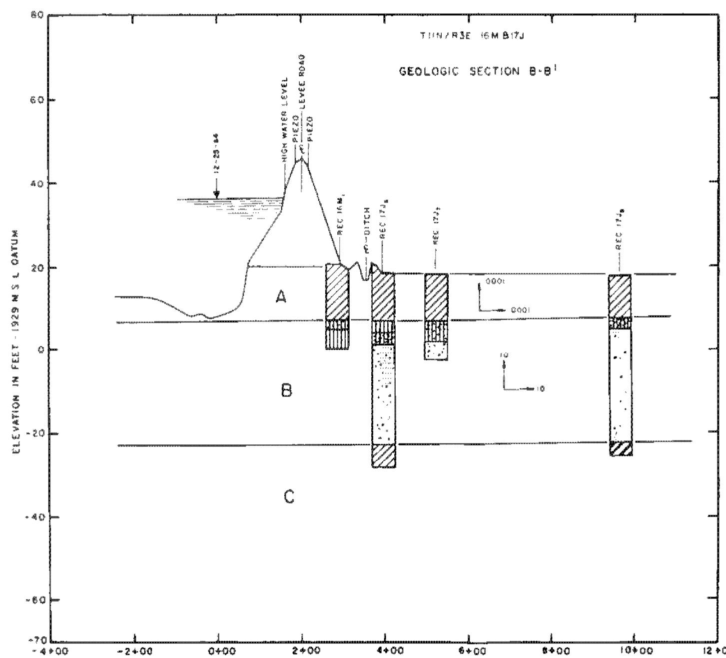


LOCATION MAP

SCALE OF FEET

1000 0 1000 2000 3000





LEGEND

A — FLOOD PLAIN DEPOSIT: BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B — STREAM DEPOSIT: GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY.

C — FLOOD BASIN DEPOSIT: GRAY, STIFF CLAY, LOW PERMEABILITY.

KV-VERTICAL PERMEABILITY IN FEET PER DAY.
KH-HORIZONTAL PERMEABILITY IN FEET PER DAY.

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- PEAT AND OTHER HIGHLY ORGANIC SOILS.

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GEOLOGIC SECTION AT PHYSICAL TEST AREA

KARNAK

LEGEND

LOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

TREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

LOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.

KV-VERTICAL PERMEABILITY IN FEET PER DAY.
KH-HORIZONTAL PERMEABILITY IN FEET PER DAY.

KH

LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

RAVELS OR
IXTURES, LITTLE

GRAVELS OR
XTURES, LITTLE

GRAVEL-SAND-

S, GRAVEL-
TURES.

ANDS OR
S, LITTLE OR NO

SANDS OR
S, LITTLE OR NO

ND-SILT

SAND-SILT

INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.

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GEOLOGIC SECTION
AT PHYSICAL TEST AREA

ELKHORN

LEGEND

LOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

TREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

LOOD BASIN DEPOSIT
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GRAVEL-SAND-

S, GRAVEL-
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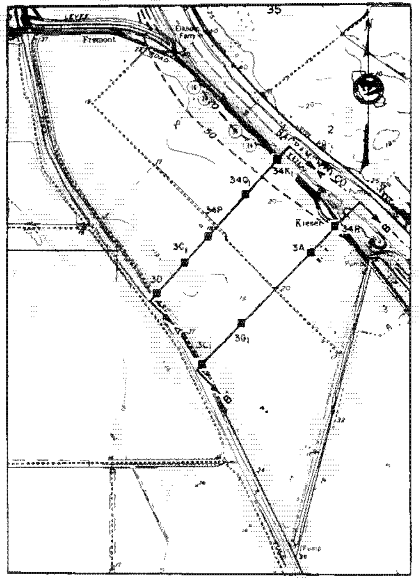
SEEPAGE INVESTIGATION

GEOLOGIC SECTION AT PHYSICAL TEST AREA

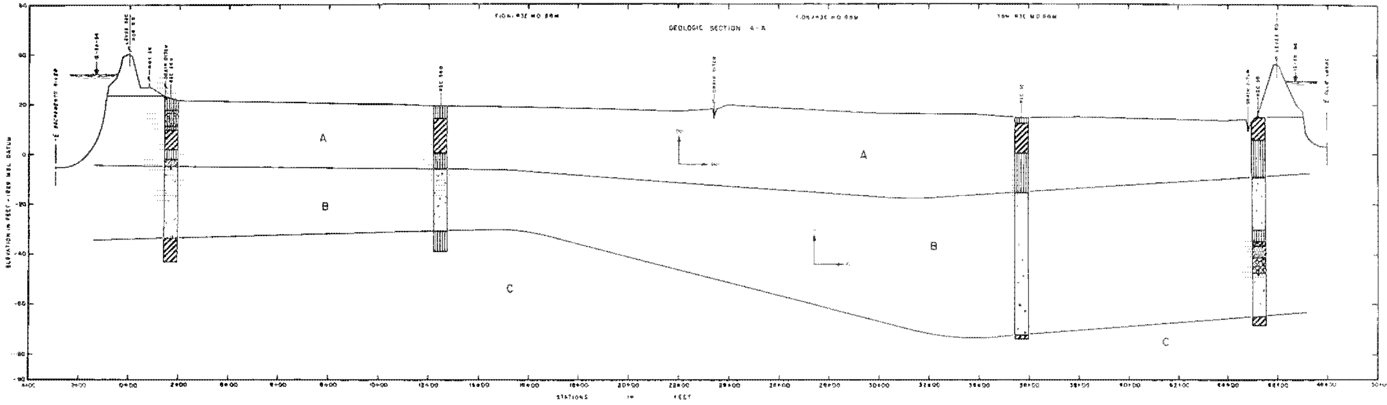
ELKHORN

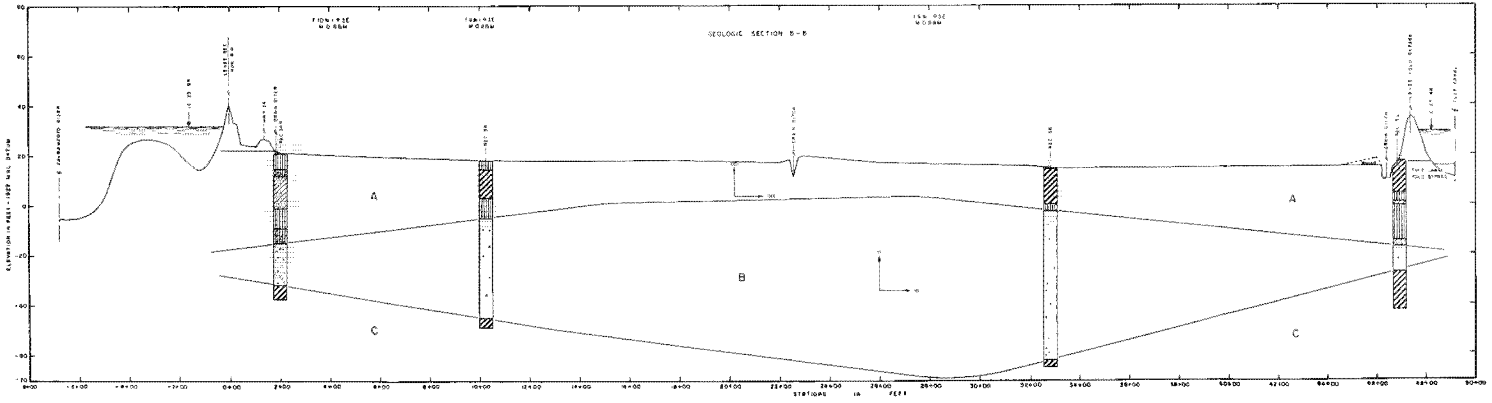
PLATE 16



LOCATION MAP

SCALE OF FEET
1000 0 1000 2000 3000





LEGEND

A FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY

B STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

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GRAY, STIFF CLAY, LOW PERMEABILITY

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LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM FEET FOR UPPER 20 FEET OF SOIL

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SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

GEOLOGIC SECTION AT PHYSICAL TEST AREA

ELKHORN

DFCG-6

LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B — STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

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KV - VERTICAL PERMEABILITY IN FEET PER DAY
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY.

⟶ KH

50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM - FEET FOR UPPER 20 FEET OF SOIL.

ADED GRAVELS OR SAND MIXTURES, LITTLE NES.

GRADED GRAVELS OR SAND MIXTURES, LITTLE NES.

AVELS, GRAVEL - SAND - TURES.

GRAVELS, GRAVEL- LAY MIXTURES.

ADED SANDS OR Y SANDS, LITTLE OR NO

GRADED SANDS OR Y SANDS, LITTLE OR NO

NDS, SAND - SILT S.

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SACRAMENTO VALLEY
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GEOLOGIC SECTION AT PHYSICAL TEST AREA

RIVERSIDE

LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B — STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

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GRAY, STIFF CLAY, LOW PERMEABILITY.

KV - VERTICAL PERMEABILITY IN FEET PER DAY
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→ KH

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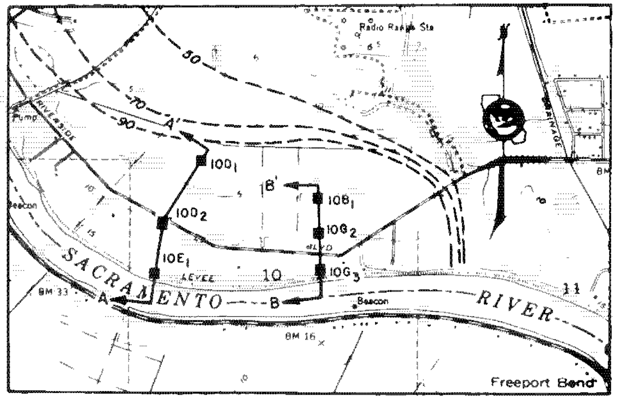
SEEPAGE INVESTIGATION

GEOLOGIC SECTION AT PHYSICAL TEST AREA

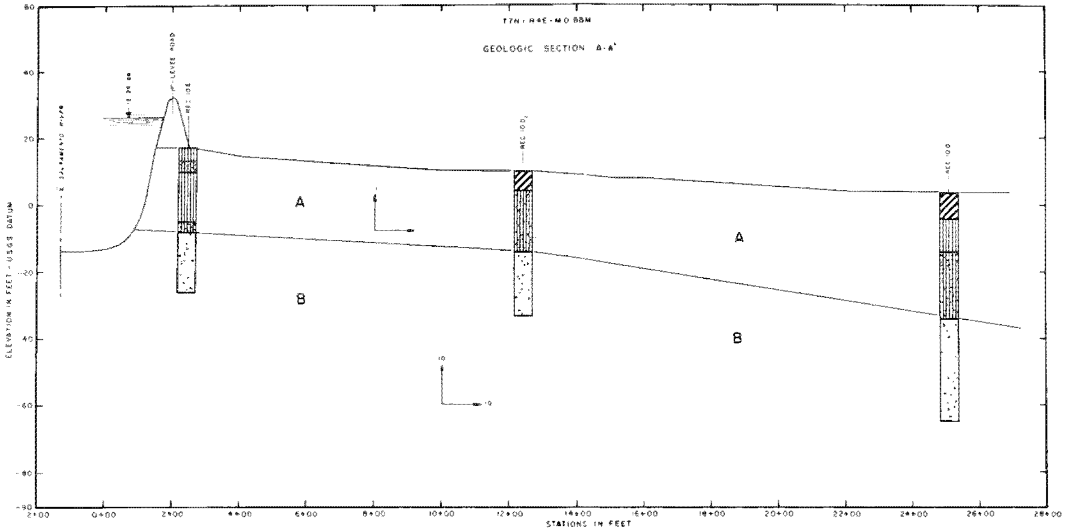
RIVERSIDE

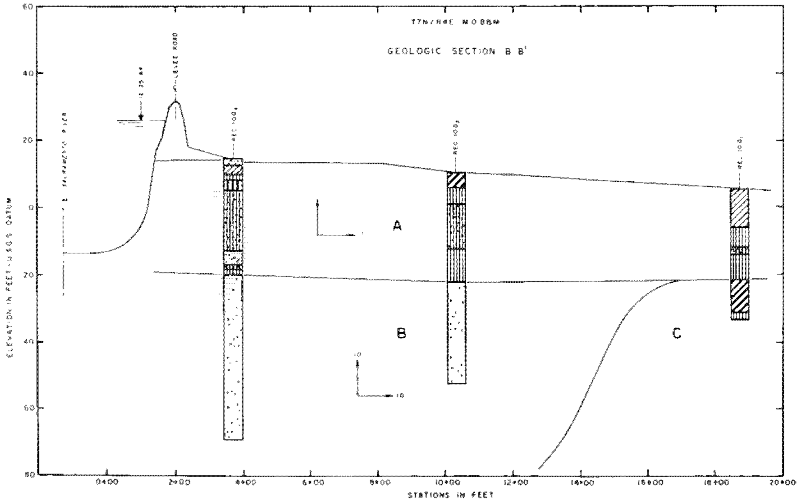


LOCATION MAP

SCALE OF FEET

1000 0 1000 2000 3000





LEGEND

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STATE OF CALIFORNIA
THE RESOURCES AGENCY
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SACRAMENTO DISTRICT
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GEOLOGIC SECTION AT PHYSICAL TEST AREA

RIVERSIDE

LEGEND

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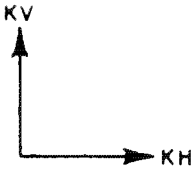

KV - VERTICAL PERMEABILITY IN FEET PER DAY.
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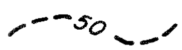

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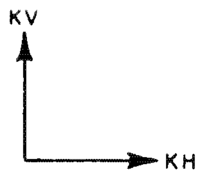
MERRITT ISLAND

LEGEND

A FLOOD PLAIN DEPOSIT
BROWN, SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY.

B STREAM DEPOSIT
GRAY, LOOSE, GRAVELLY SAND, HIGH PERMEABILITY

C FLOOD BASIN DEPOSIT
GRAY, STIFF CLAY, LOW PERMEABILITY.



KV-VERTICAL PERMEABILITY IN FEET PER DAY.
KH-HORIZONTAL PERMEABILITY IN FEET PER DAY.

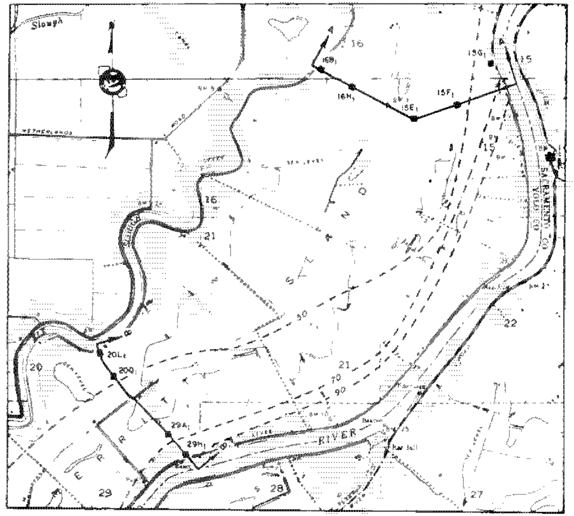
50 — LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM-FEET FOR UPPER 20 FEET OF SOIL.

- WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES.
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES.
- WELL-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- POORLY-GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES.
- SILTY SANDS, SAND-SILT MIXTURES.
- CLAYEY SANDS, SAND-SILT MIXTURES.
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY.
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.
- PEAT AND OTHER HIGHLY ORGANIC SOILS.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

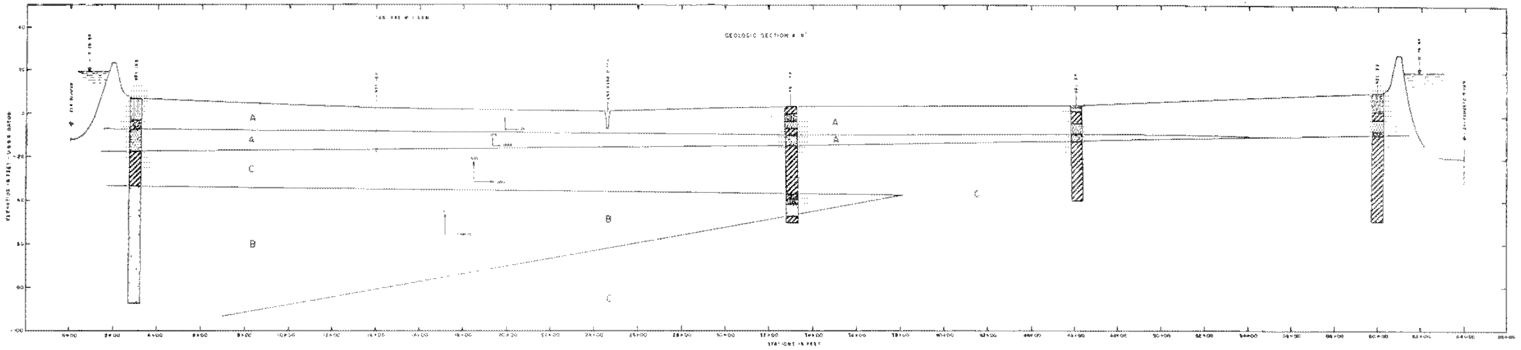
GEOLOGIC SECTION AT PHYSICAL TEST AREA

MERRITT ISLAND



LOCATION MAP

SCALE OF FEET
1000 0 1000 2000 3000



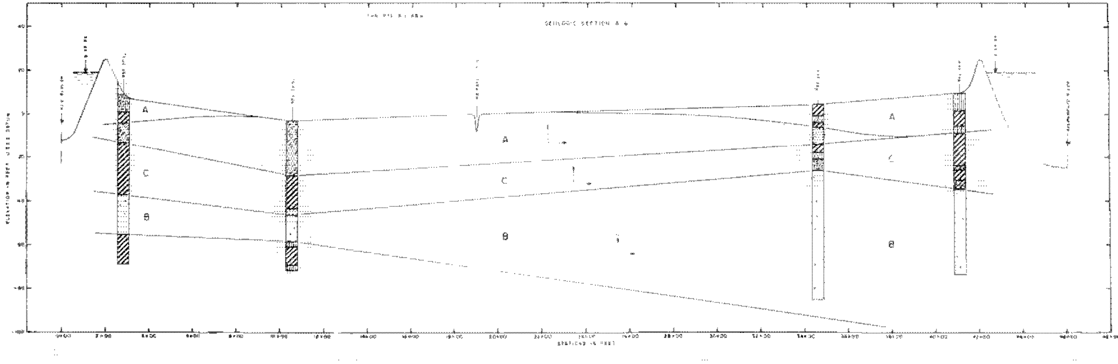


PLATE 16

LEGEND

A — FLOOD PLAIN DEPOSIT
BROWN SOFT CLAY OR SILT TO SILTY SAND, LOW TO HIGH PERMEABILITY

B — STREAM DEPOSIT
GRAY LOOSE, GRAVELLY SAND HIGH PERMEABILITY

C — FLOOD BASIN DEPOSIT
GRAY STIFF CLAY, LOW PERMEABILITY

KV - VERTICAL PERMEABILITY IN FEET PER DAY
KH - HORIZONTAL PERMEABILITY IN FEET PER DAY

LINES OF EQUAL ELECTRICAL RESISTIVITY VALUES IN OHM FEET FOR UPPER 20 FEET OF SOIL

- WELL GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- POORLY GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
- WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SILTY SANDS, SAND-SILT MIXTURES
- CLAYEY SANDS, SAND-SILT MIXTURES
- INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
- ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY
- INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
- INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
- ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
- PEAT AND OTHER HIGHLY ORGANIC SOILS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

GEOLOGIC SECTION
AT PHYSICAL TEST AREA

MERRITT ISLAND

DFCG-6

LEGEND

OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

TO 70 OHM – FEET,
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

75089

RICAL RESISTIVITY DATA ARE BASED
INNER ELECTRODE ARRANGEMENT WITH
SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA JACINTO

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

75089

RICAL RESISTIVITY DATA ARE BASED
ENNER ELECTRODE ARRANGEMENT WITH
SPACINGS OF 20 FEET

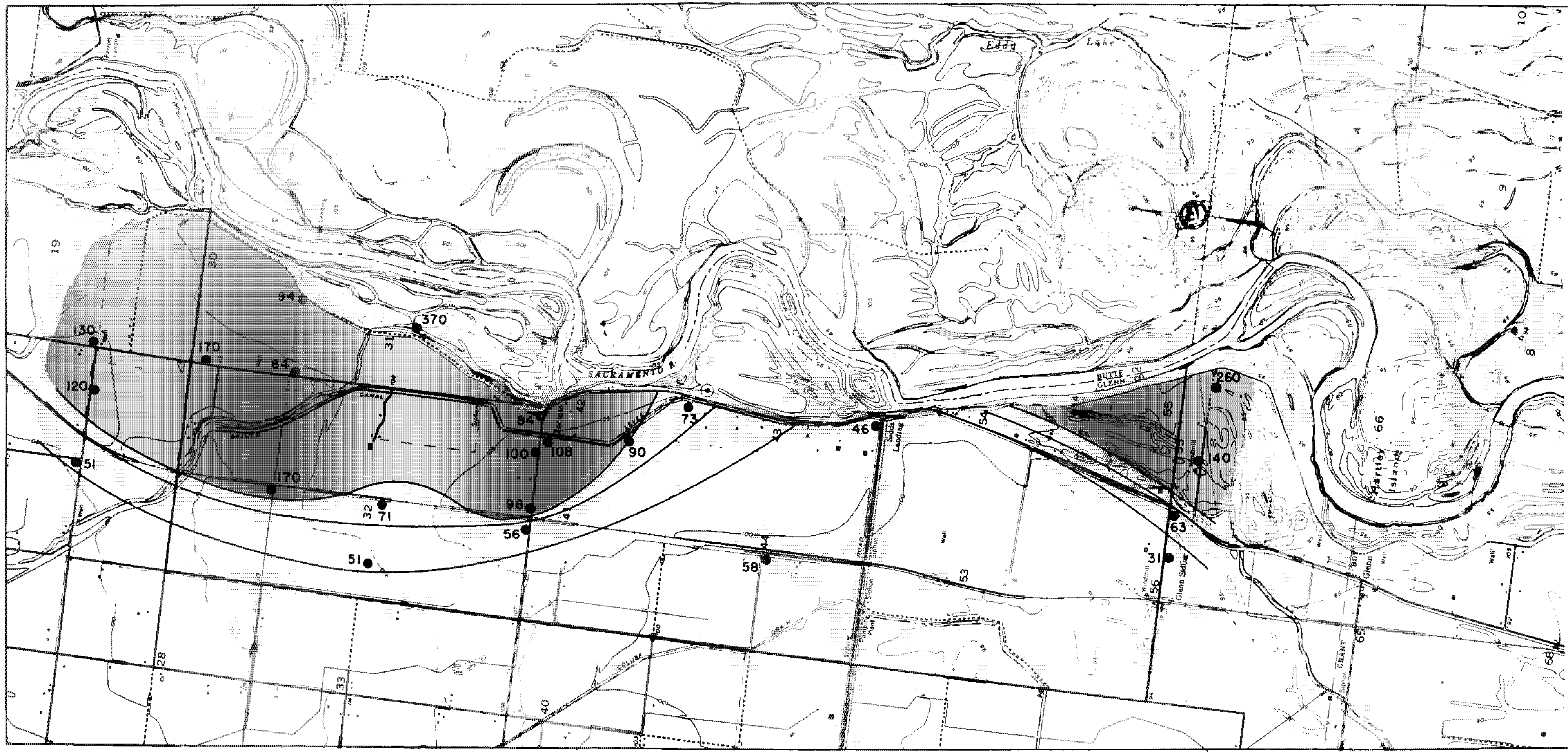
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
JACINTO

SCALE OF FEET
1000 0 1000 2000 3000

PLATE 19



LEGEND

90 OHM - FEET AND ABOVE
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET,
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
JACINTO

SCALE OF FEET
1000 0 1000 2000 3000

DFCG-6

LEGEND

90 OHM - FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW;
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA MERIDAN

SCALE OF FEET

1000 0 1000 2000 3000

LEGEND

- 90 OHM - FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
- 70 TO 90 OHM - FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
- 50 TO 70 OHM - FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
- 50 OHM - FEET AND BELOW; VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

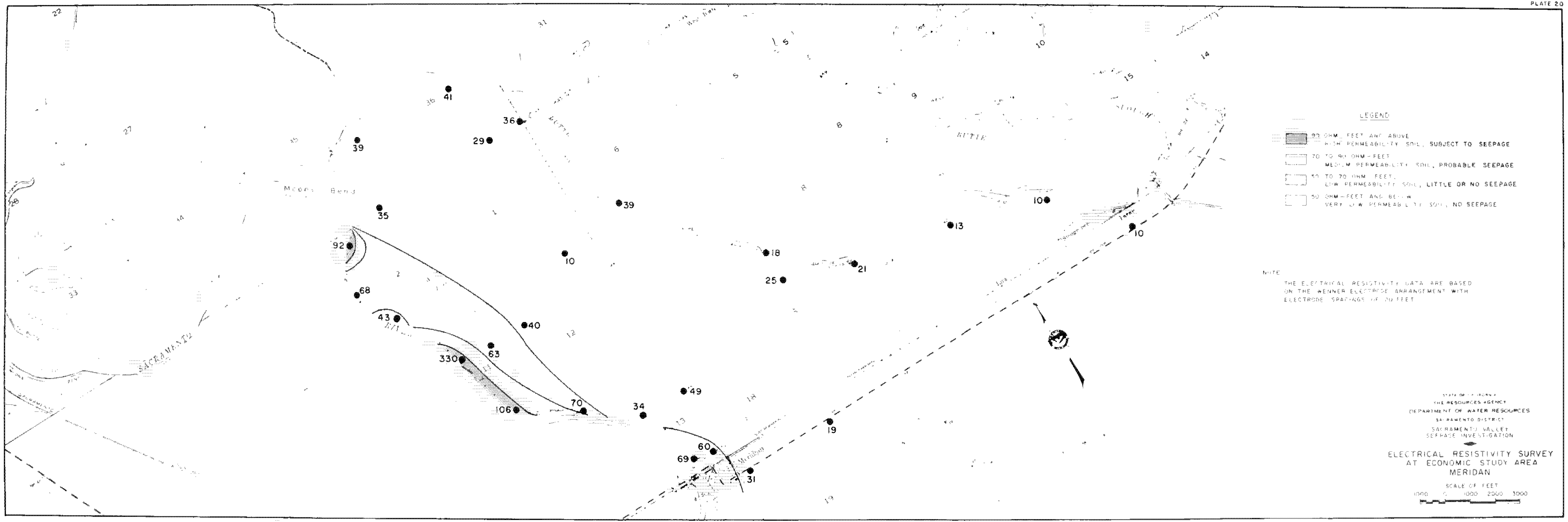
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA MERIDAN

SCALE OF FEET

1000 0 1000 2000 3000

PLATE 20



DFCG-6

LEGEND

(dark shading)	90 OHM – FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
(fine vertical lines)	70 TO 90 OHM – FEET; MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
(cross-hatching)	50 TO 70 OHM – FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
(wide vertical lines)	50 OHM – FEET AND BELOW; VERY LOW PERMEABILITY SOIL, NO SEEPAGE

75089

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THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA WADSWORTH

SCALE OF FEET

1000 0 1000 2000 3000

LEGEND

90 OHM – FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET; MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW; VERY LOW PERMEABILITY SOIL, NO SEEPAGE

)TE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA

WADSWORTH

SCALE OF FEET

1000 0 1000 2000 3000


PLATE 21
LEGEND
90 OHM - FEET AND ABOVE
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
50 TO 70 OHM - FEET
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
50 OHM - FEET AND BELOW
VERY LOW PERMEABILITY SOIL, NO SEEPAGE
NOTE
THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET
SUTTER BY-PASS
SUTTER BASIN
SUTTER NATIONAL WILDLIFE REFUGE
60
58
81
66
59
66
40
35
88
25
38
50
54
69
63
50
55
53
56
77
83
DEPARTMENT OF WATER RESOURCES
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
WADSWORTH
SCALE OF FEET
1000 0 1000 2000 3000

DFCG-6

LEGEND

90 OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
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SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA YUBA CITY

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM – FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW, VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA YUBA CITY

SCALE OF FEET

1000 0 1000 2000 3000

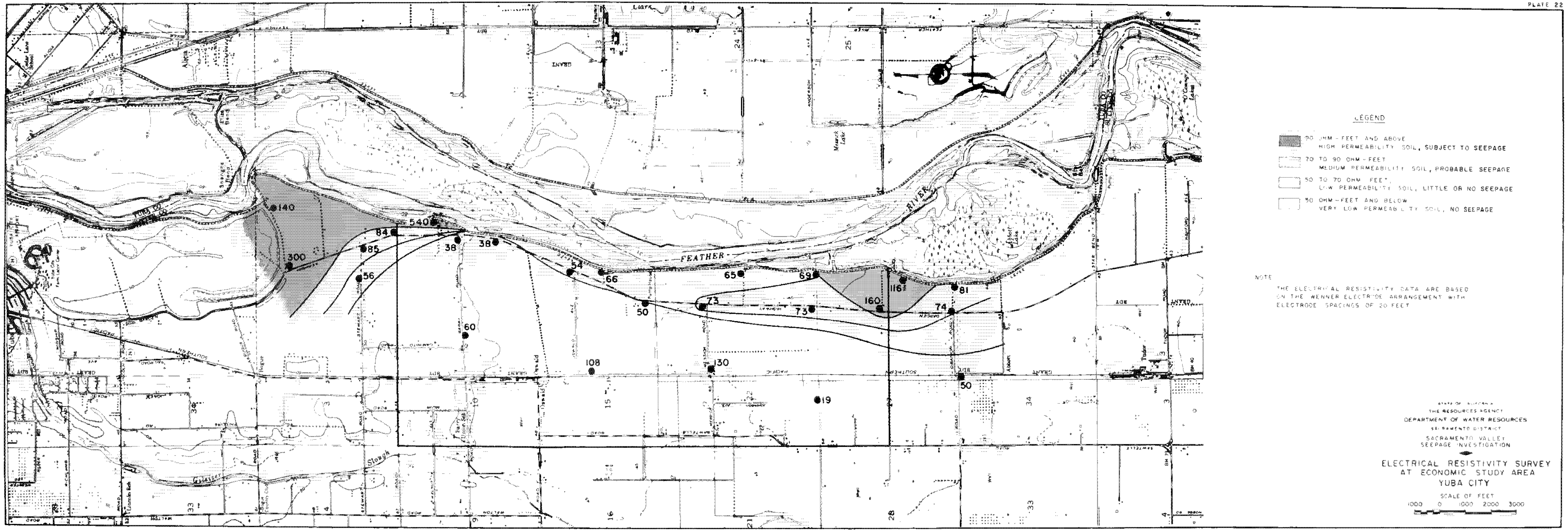


PLATE 22
FEATHER RIVER
LEGEND
90 OHM - FEET AND ABOVE
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
70 TO 90 OHM - FEET
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
50 TO 70 OHM FEET,
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
50 OHM - FEET AND BELOW
VERY LOW PERMEABILITY SOIL, NO SEEPAGE
NOTE
THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
YUBA CITY
SCALE OF FEET
1000 0 1000 2000 3000

DFCG-6

LEGEND

90 OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

ECTRICAL RESISTIVITY DATA ARE BASED
WENNER ELECTRODE ARRANGEMENT WITH
ODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA BOYERS LANDING

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM - FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

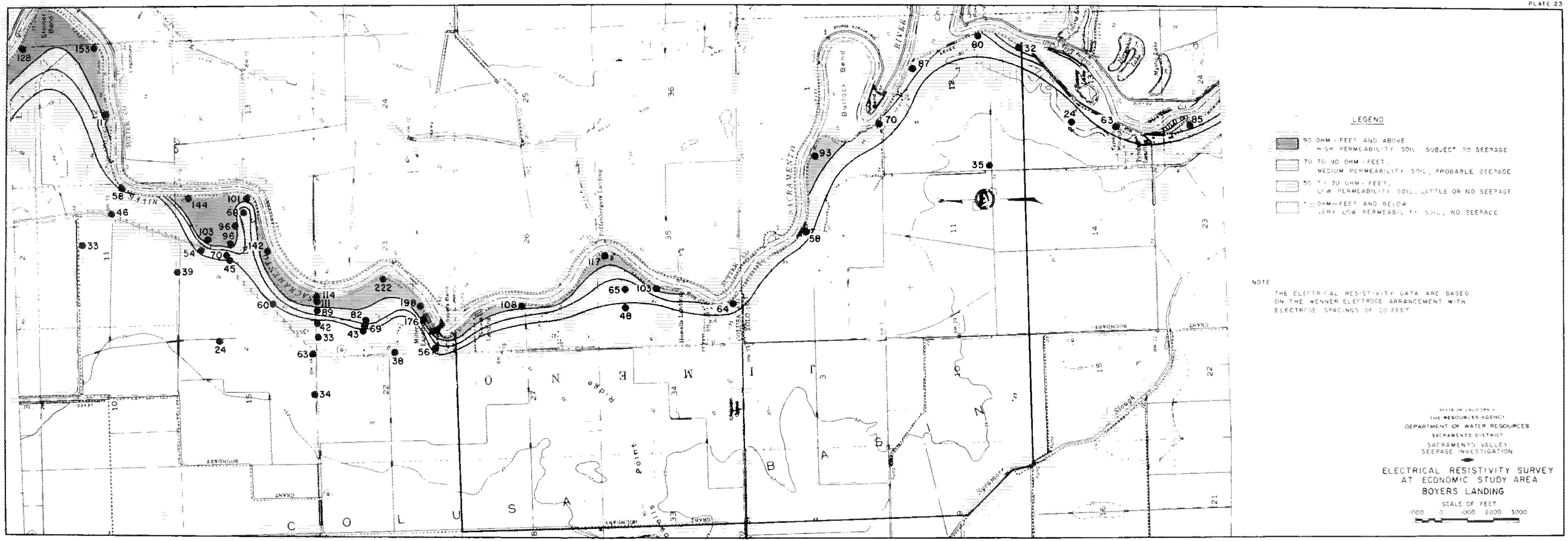
ECTRICAL RESISTIVITY DATA ARE BASED
WENNER ELECTRODE ARRANGEMENT WITH
ODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
BOYERS LANDING

SCALE OF FEET
1000 0 1000 2000 3000


SACRAMENTO RIVER
Bullock Bend
SUTTER CO
COLUSA
YOLO
Point Ridge
COLUSA
SYCAMORE SLOUGH
LEGEND
90 OHM - FEET AND ABOVE
HIGH PERMEABILITY SOIL SUBJECT TO SEEPAGE
70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
50 TO 70 OHM - FEET,
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
50 OHM - FEET AND BELOW
VERY LOW PERMEABILITY SOIL, NO SEEPAGE
NOTE
THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
BOYERS LANDING
SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM - FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET;
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW;
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

OTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA KARNAK

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM - FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW; VERY LOW PERMEABILITY SOIL, NO SEEPAGE

75089

OTE

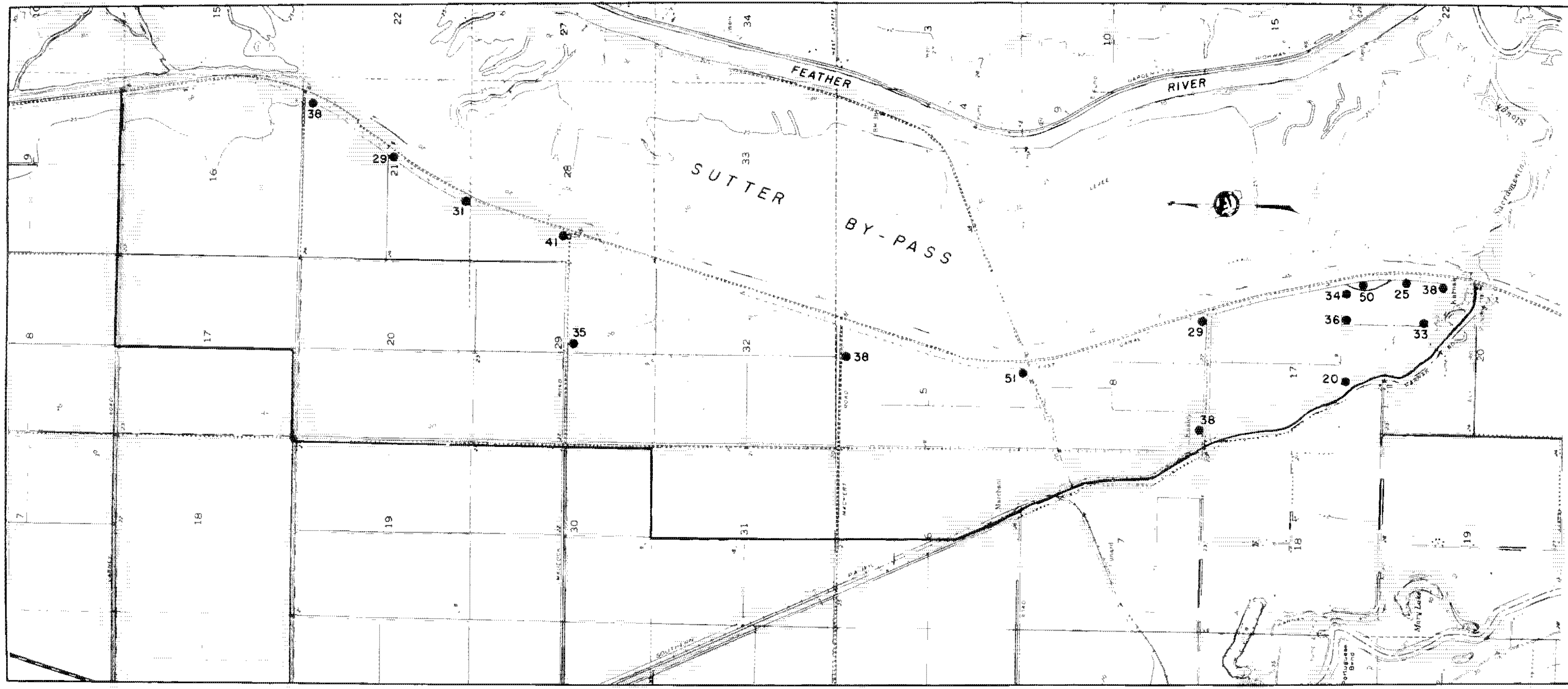
THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
KARNAK

SCALE OF FEET
1000 0 1000 2000 3000



LEGEND

90 OHM-FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM-FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM-FEET, LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM-FEET AND BELOW, VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
KARNAK

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM FEET AND ABOVE, HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM-FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM-FEET; LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM-FEET AND BELOW, VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA VERONA

SCALE OF FEET

1000 0 1000 2000 3000

LEGEND

90 OHM FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM-FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM-FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM-FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA VERONA

SCALE OF FEET

1000 0 1000 2000 3000

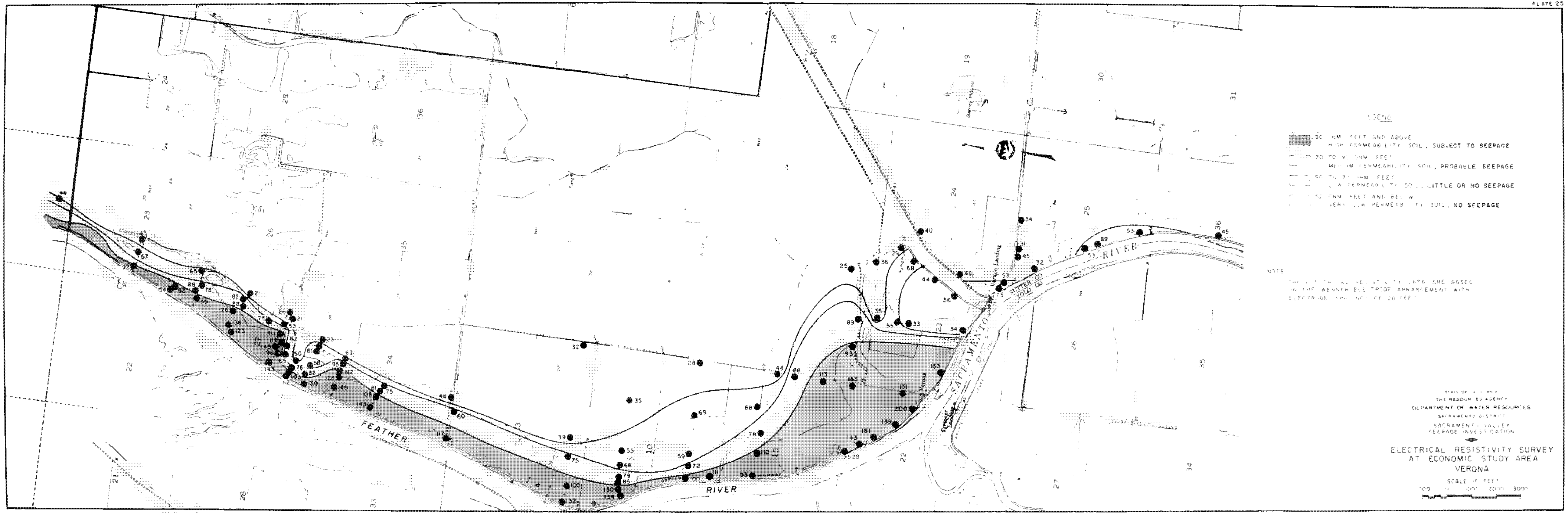


PLATE 25
SUBJECT TO SEEPAGE
PROBABLE SEEPAGE
LITTLE OR NO SEEPAGE
NO SEEPAGE
DEPARTMENT OF WATER RESOURCES
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
VERONA
FEATHER
RIVER
SACRAMENTO
RIVER
SUTTER CO
YOLO CO

DFCG-6

LEGEND

90 OHM - FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

ECTRICAL RESISTIVITY DATA ARE BASED
WENNER ELECTRODE ARRANGEMENT WITH
ODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA ELKHORN

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM - FEET AND ABOVE
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM - FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM - FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

ECTRICAL RESISTIVITY DATA ARE BASED
WENNER ELECTRODE ARRANGEMENT WITH
ODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA ELKHORN

SCALE OF FEET
1000 0 1000 2000 3000

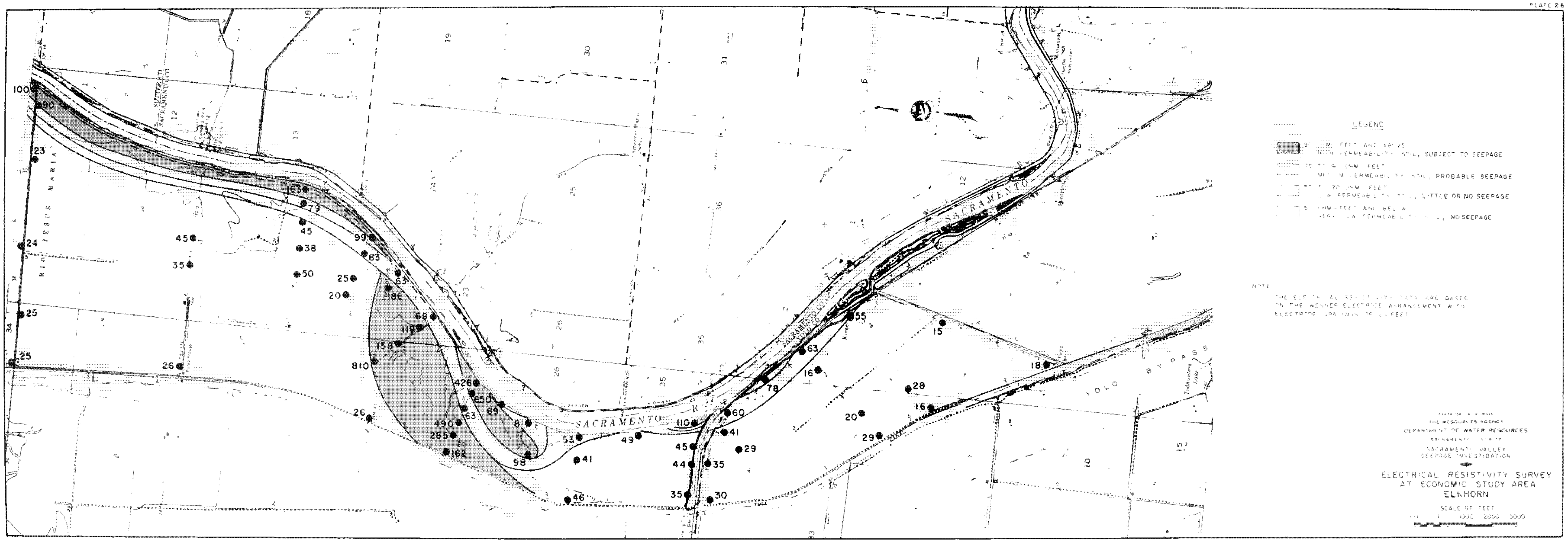


PLATE 26
LEGEND
SUBJECT TO SEEPAGE
PROBABLE SEEPAGE
LITTLE OR NO SEEPAGE
NO SEEPAGE
SACRAMENTO
SACRAMENTO
YOLO BY PASS
DEPARTMENT OF WATER RESOURCES
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
ELKHORN
SCALE OF FEET
2000 3000

DFCG-6

LEGEND

OHM - FEET AND ABOVE ,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

TO 90 OHM - FEET;
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

OHM - FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

RICAL RESISTIVITY DATA ARE BASED
ENNER ELECTRODE ARRANGEMENT WITH
SPACINGS OF 20 FEET

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DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
FREEPORT

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

OHM - FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

TO 90 OHM - FEET;
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

TO 70 OHM - FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

OHM - FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

RICAL RESISTIVITY DATA ARE BASED
ENNER ELECTRODE ARRANGEMENT WITH
SPACINGS OF 20 FEET

STATE OF CALIFORNIA
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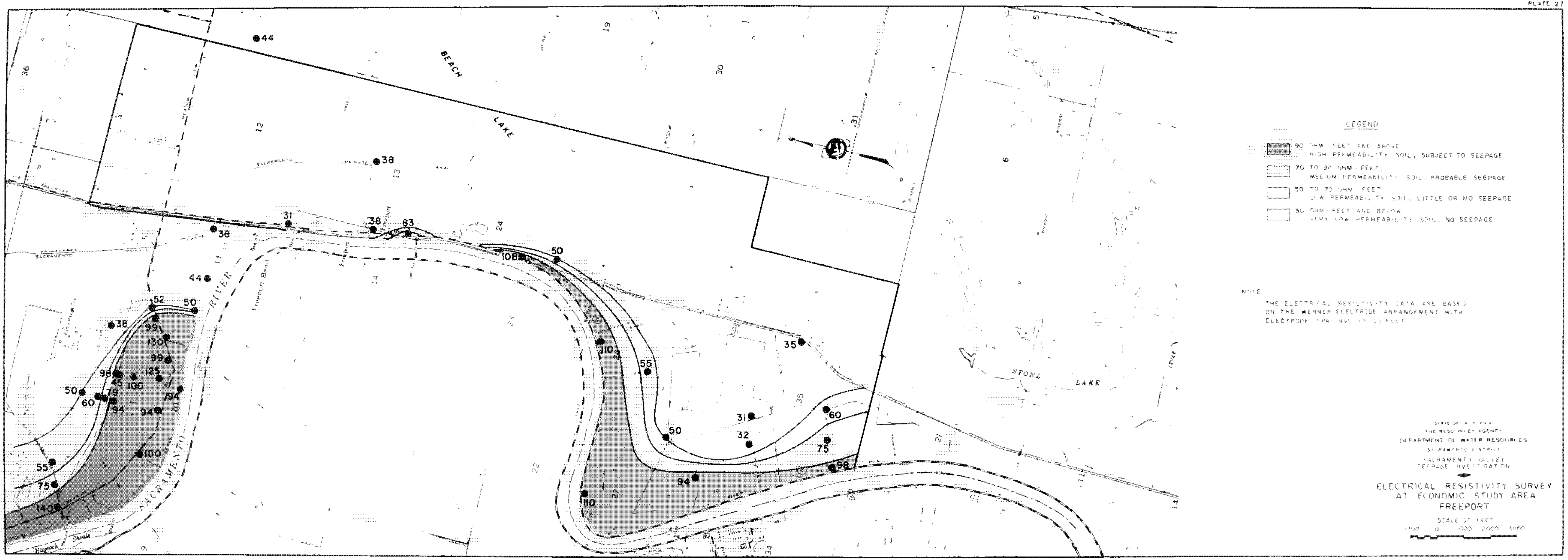
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
FREEPORT

SCALE OF FEET
1000 0 1000 2000 3000

PLATE 27



DFCG-6

LEGEND

90 OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

)TE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

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DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA MERRITT ISLAND

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

90 OHM – FEET AND ABOVE,
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

)TE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
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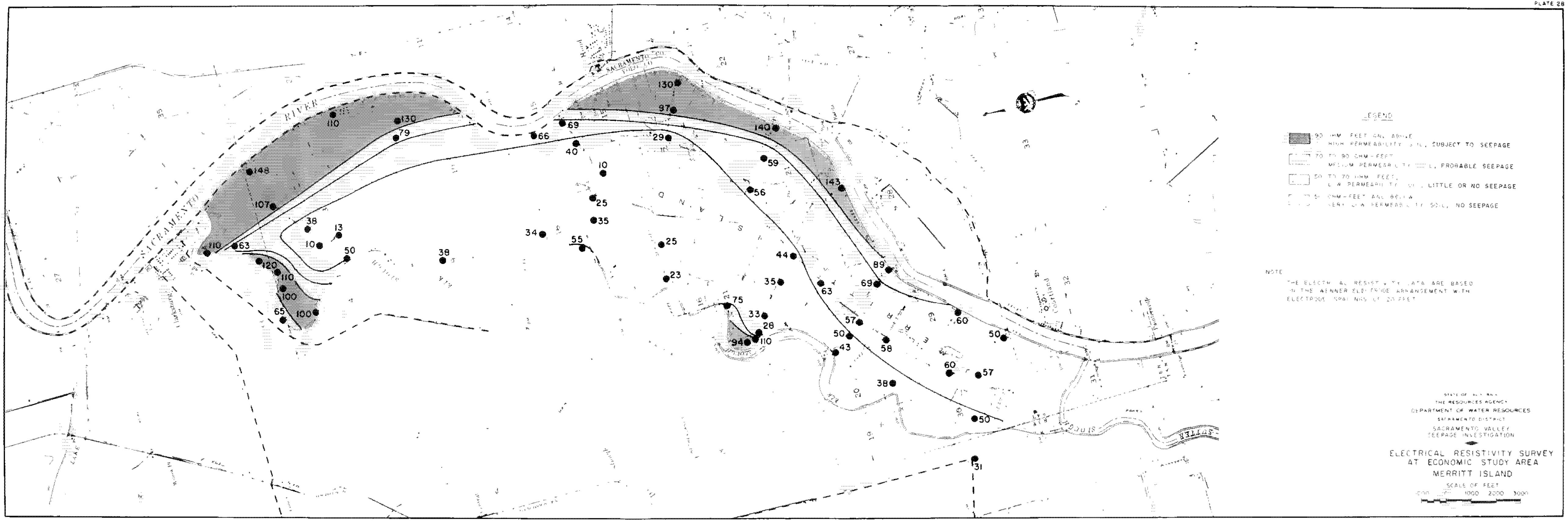
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
MERRITT ISLAND

SCALE OF FEET
1000 0 1000 2000 3000


SACRAMENTO RIVER
RIVER
SACRAMENTO CO.
YOLO CO.
LEGEND
SUBJECT TO SEEPAGE
PROBABLE SEEPAGE
LITTLE OR NO SEEPAGE
NO SEEPAGE
NOTE
DEPARTMENT OF WATER RESOURCES
SACRAMENTO VALLEY
ELECTRICAL RESISTIVITY SURVEY
AT ECONOMIC STUDY AREA
MERRITT ISLAND
SCALE OF FEET
1000 2000 3000

DFCG-6

LEGEND

90 OHM – FEET AND ABOVE
HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE

70 TO 90 OHM – FEET,
MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE

50 TO 70 OHM – FEET;
LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE

50 OHM – FEET AND BELOW,
VERY LOW PERMEABILITY SOIL, NO SEEPAGE

OTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

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SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA LIBERTY FARMS

SCALE OF FEET
1000 0 1000 2000 3000

LEGEND

- 90 OHM - FEET AND ABOVE
  HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
- 70 TO 90 OHM - FEET,
  MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
- 50 TO 70 OHM - FEET;
  LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
- 50 OHM - FEET AND BELOW,
  VERY LOW PERMEABILITY SOIL, NO SEEPAGE

OTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

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DEPARTMENT OF WATER RESOURCES
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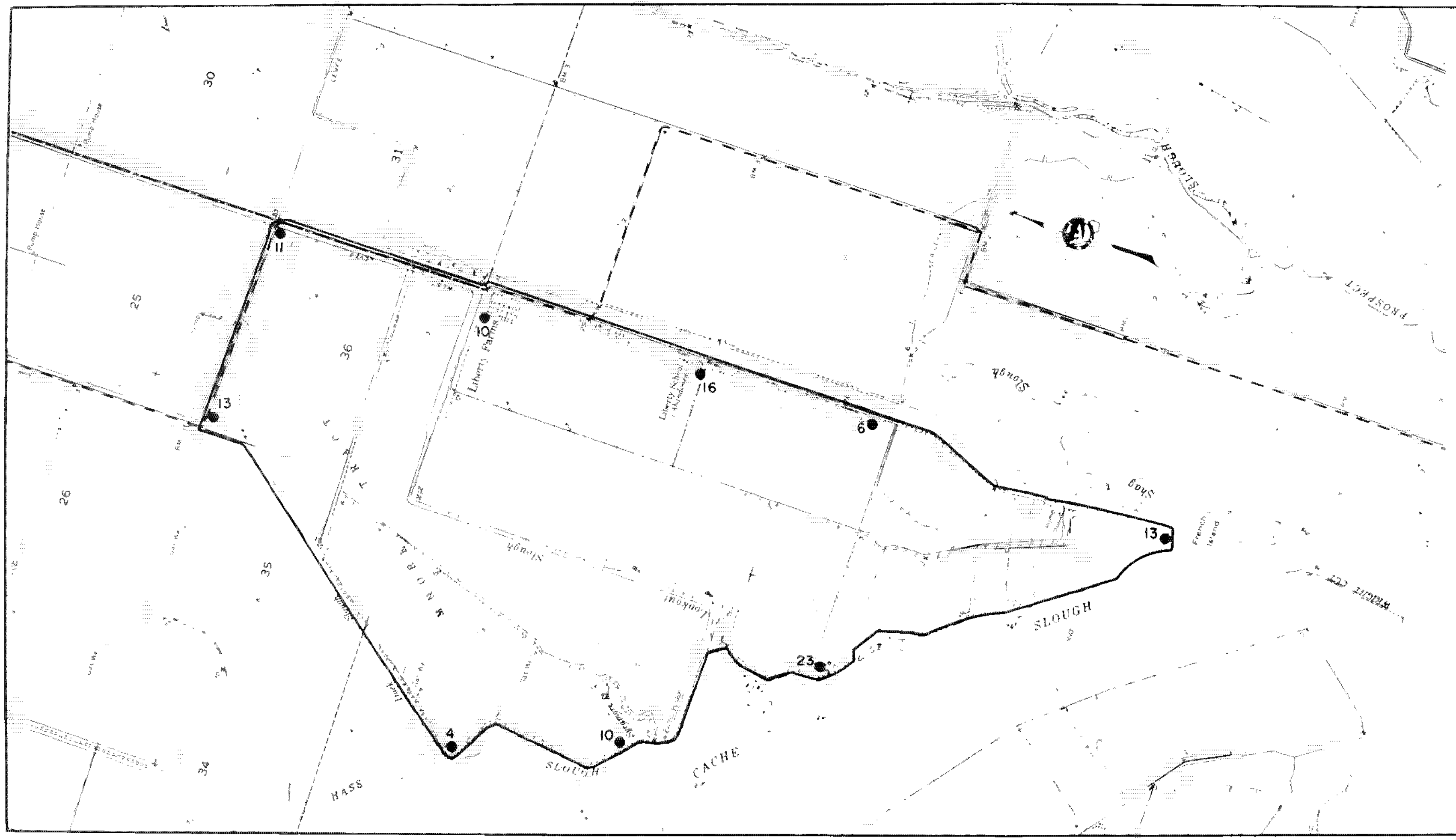
SEEPAGE INVESTIGATION

ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA LIBERTY FARMS

SCALE OF FEET
1000 0 1000 2000 3000



LEGEND

(shaded)	90 OHM - FEET AND ABOVE HIGH PERMEABILITY SOIL, SUBJECT TO SEEPAGE
(box)	70 TO 90 OHM - FEET, MEDIUM PERMEABILITY SOIL, PROBABLE SEEPAGE
(box)	50 TO 70 OHM - FEET, LOW PERMEABILITY SOIL, LITTLE OR NO SEEPAGE
(box)	50 OHM - FEET AND BELOW, VERY LOW PERMEABILITY SOIL, NO SEEPAGE

NOTE

THE ELECTRICAL RESISTIVITY DATA ARE BASED ON THE WENNER ELECTRODE ARRANGEMENT WITH ELECTRODE SPACINGS OF 20 FEET

STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
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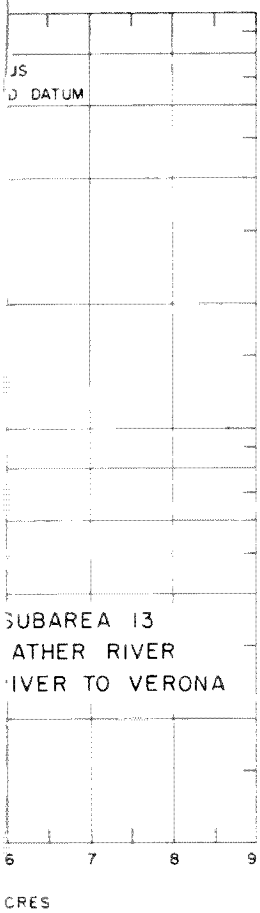
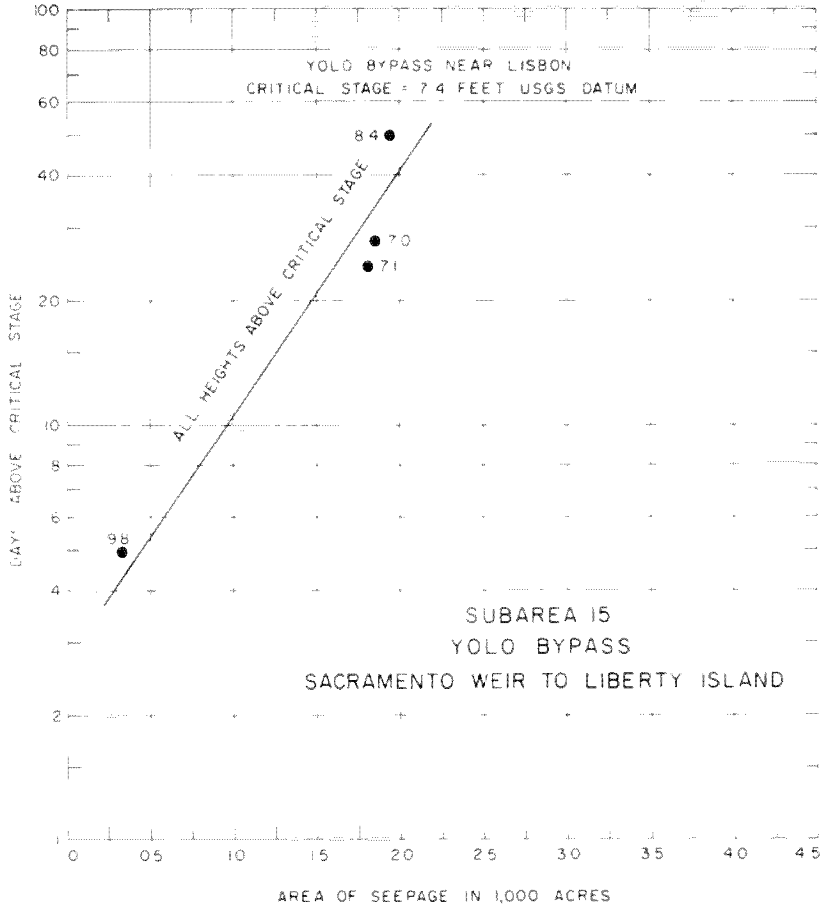
SEEPAGE INVESTIGATION

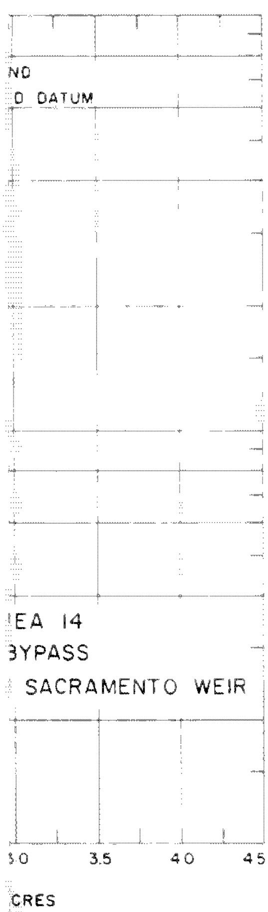
ELECTRICAL RESISTIVITY SURVEY AT ECONOMIC STUDY AREA LIBERTY FARMS

SCALE OF FEET
1000 0 1000 2000 3000

DFCG-6







NOTE

(1) These correlation curves represent the seepage area which would result from each individual seepage occurrence.

(2) If the river drops below critical stage for 5 consecutive days or less, the period, including the 5 days, is considered to be a single occurrence of seepage.

(3) The average height above critical stage is determined for each seepage occurrence by summating the daily gage heights above and below critical stage, divided by the number of days in the seepage occurrence.

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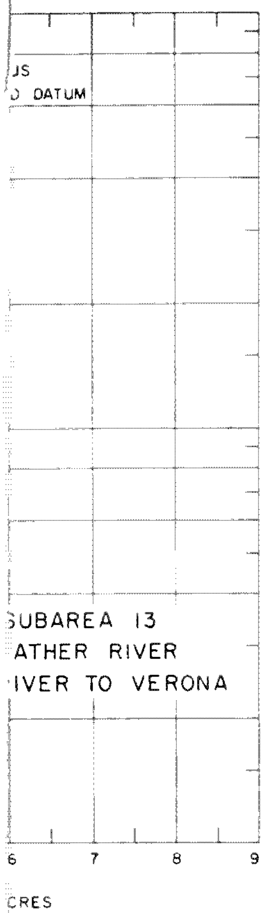
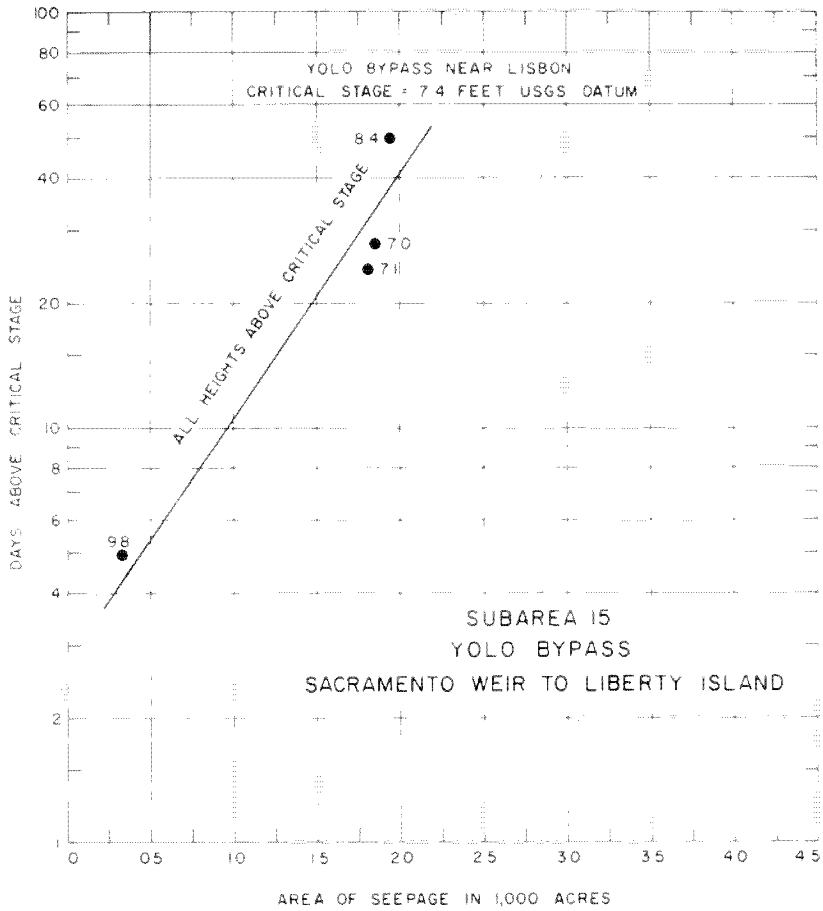
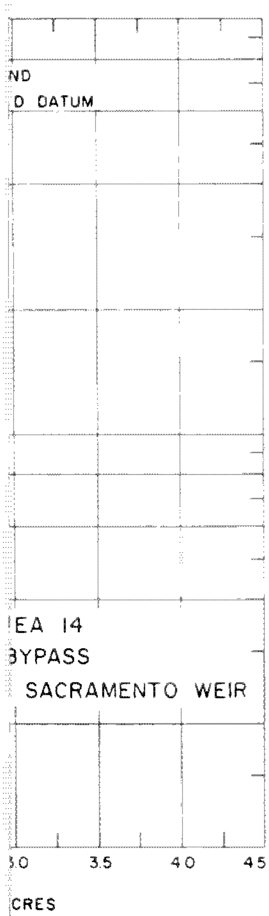
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY SEEPAGE INVESTIGATION

SEEPAGE EVALUATION CURVES
1966







NOTE:

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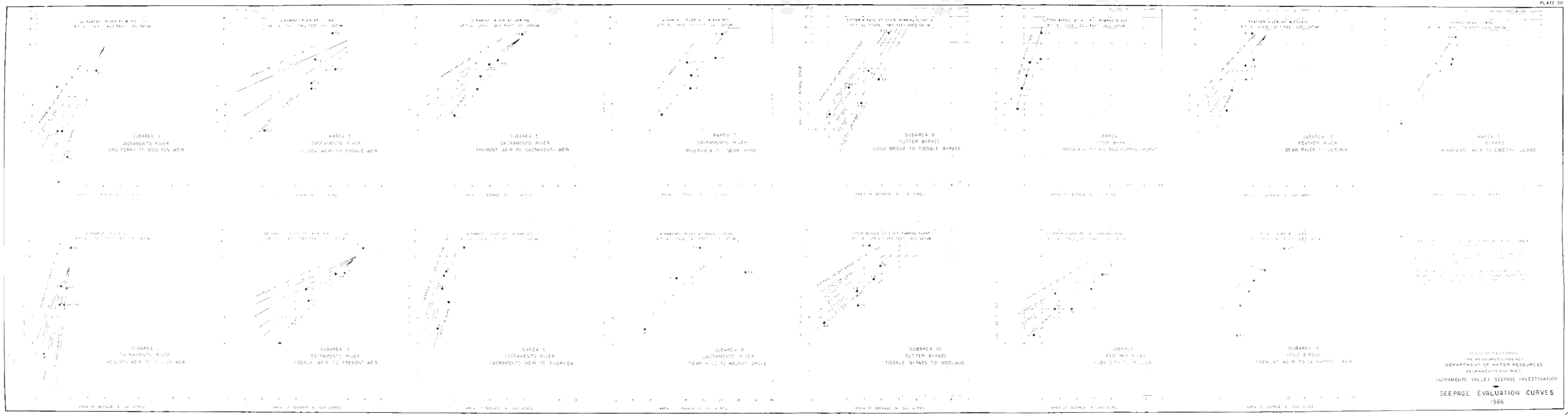
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY SEEPAGE INVESTIGATION

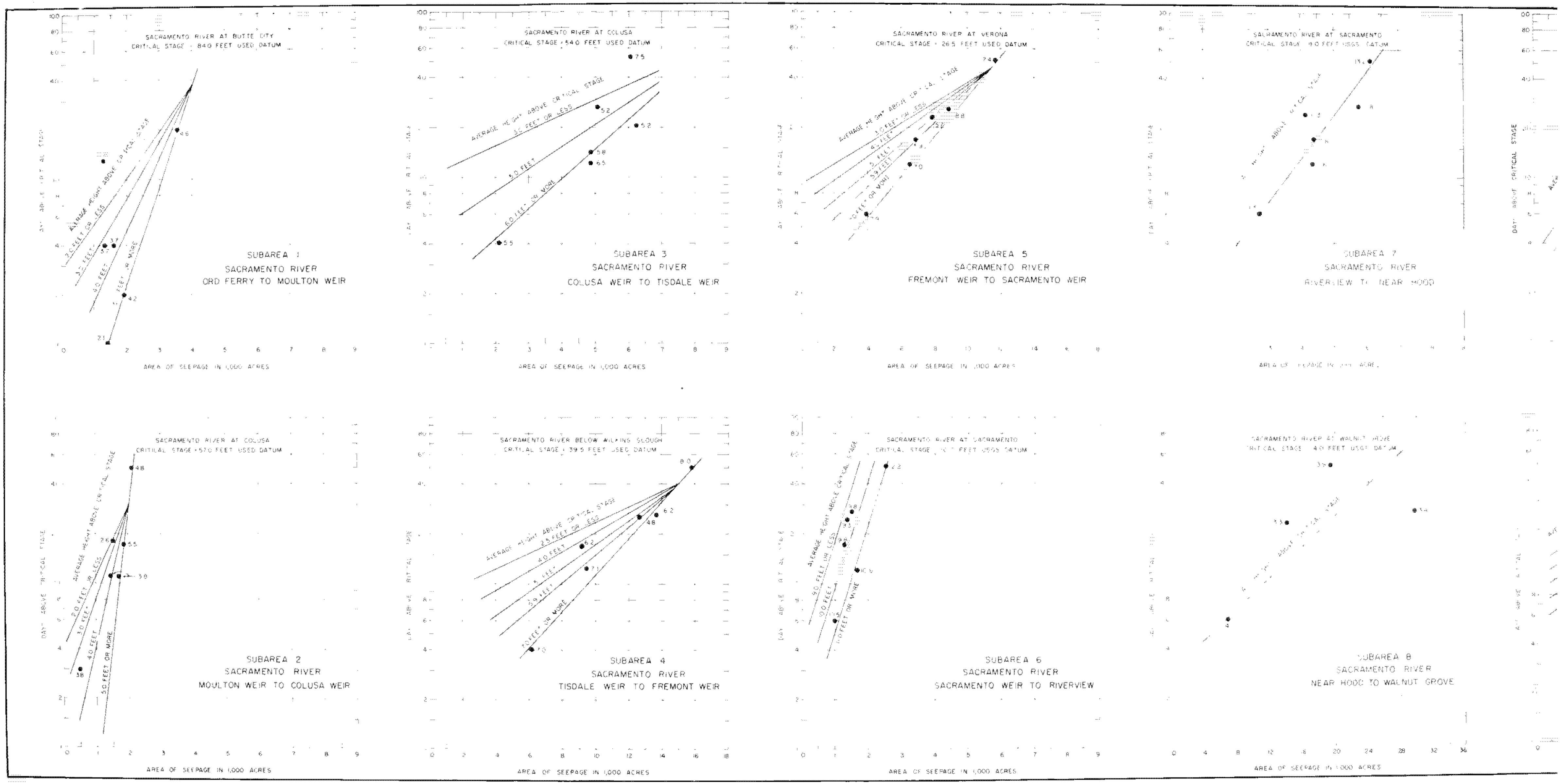
SEEPAGE EVALUATION CURVES

1966

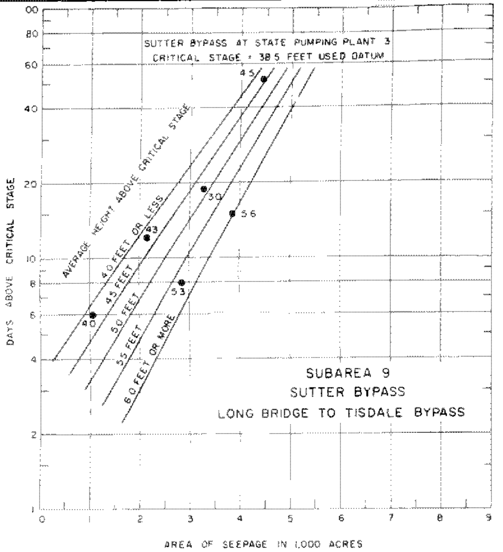
PLATE 30

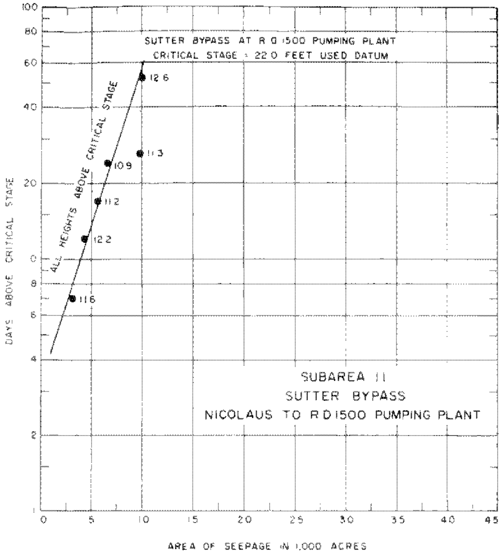


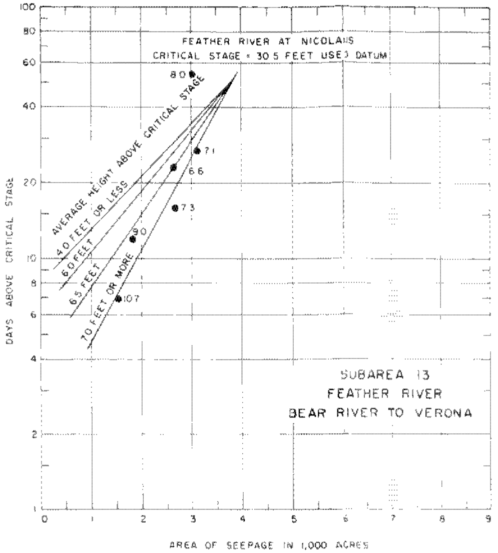
DFCG-6

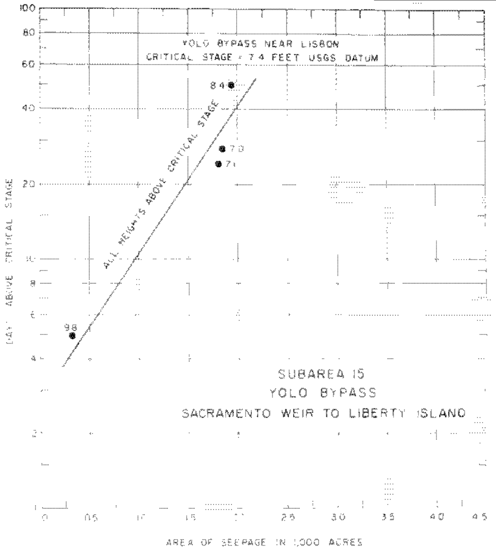

SACRAMENTO RIVER AT BUTTE CITY
SUBAREA 1
SACRAMENTO RIVER
ORD FERRY TO MOULTON WEIR
AREA OF SEEPAGE IN 1,000 ACRES
SACRAMENTO RIVER AT COLUSA
CRITICAL STAGE - 54.0 FEET USED DATUM
AVERAGE HEIGHT ABOVE CRITICAL STAGE
5.0 FEET
SUBAREA 3
SACRAMENTO RIVER
COLUSA WEIR TO TISDALE WEIR
AREA OF SEEPAGE IN 1,000 ACRES
SACRAMENTO RIVER AT VERONA
CRITICAL STAGE - 26.5 FEET USED DATUM
SUBAREA 5
SACRAMENTO RIVER
FREMONT WEIR TO SACRAMENTO WEIR
SACRAMENTO RIVER AT SACRAMENTO
SUBAREA 7
SACRAMENTO RIVER
SACRAMENTO RIVER AT COLUSA
SUBAREA 2
SACRAMENTO RIVER
MOULTON WEIR TO COLUSA WEIR
AREA OF SEEPAGE IN 1,000 ACRES
SACRAMENTO RIVER BELOW WILKINS SLOUGH
SUBAREA 4
SACRAMENTO RIVER
TISDALE WEIR TO FREMONT WEIR
AREA OF SEEPAGE IN 1,000 ACRES
SUBAREA 6
SACRAMENTO RIVER
SACRAMENTO WEIR TO RIVERVIEW
AREA OF SEEPAGE IN 1,000 ACRES
SUBAREA 8
SACRAMENTO RIVER
NEAR HOOD TO WALNUT GROVE
AREA OF SEEPAGE IN 1,000 ACRES

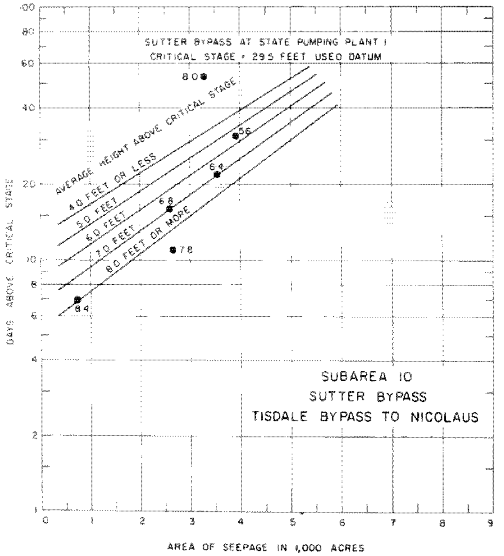
DFCG-6

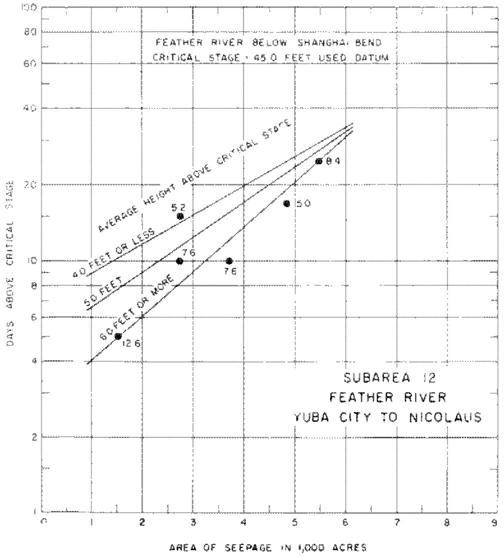


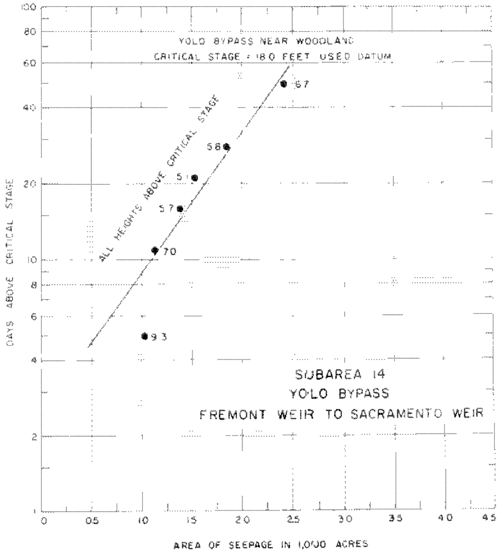












NOTE

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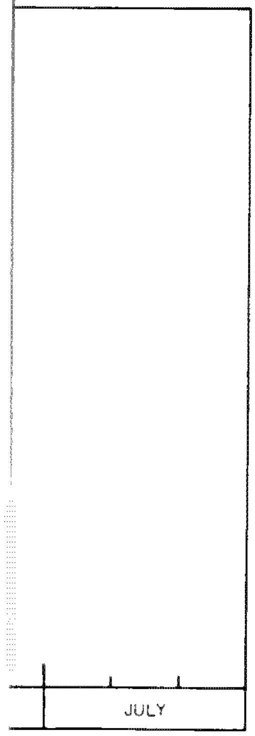
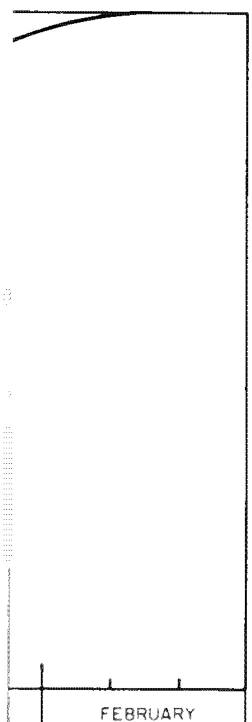
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

SEEPAGE EVALUATION CURVES

1966





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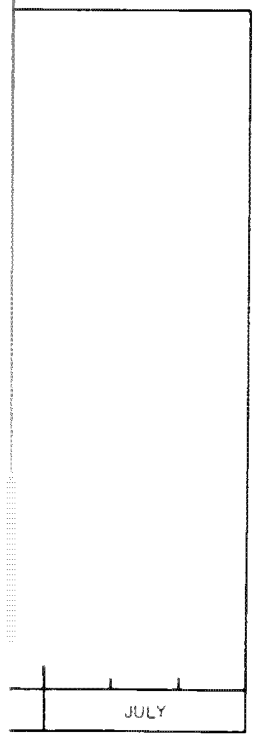
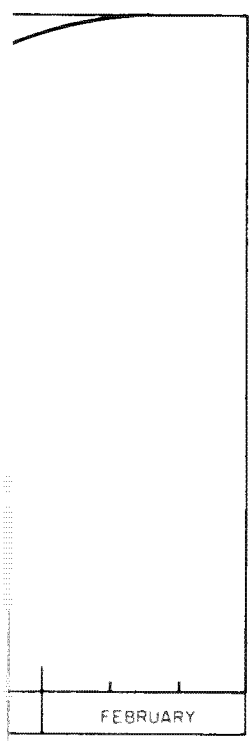
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP PLANTING CURVES

1966





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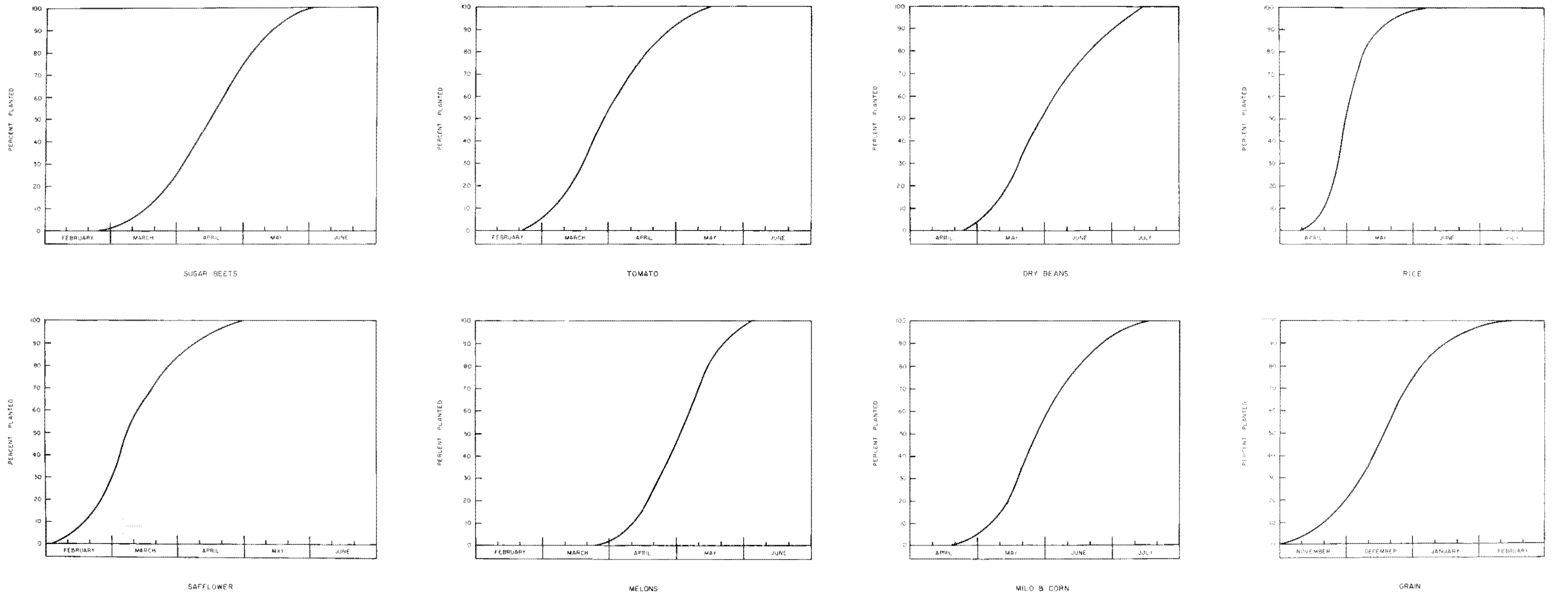
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP PLANTING CURVES

1966



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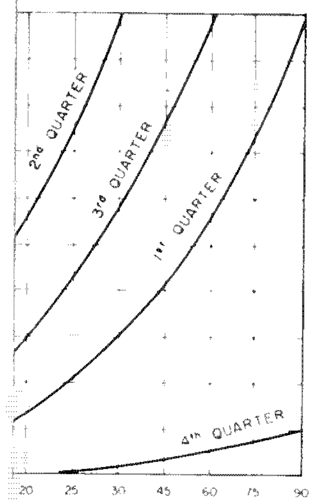
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP PLANTING CURVES

1966

DFCG-6



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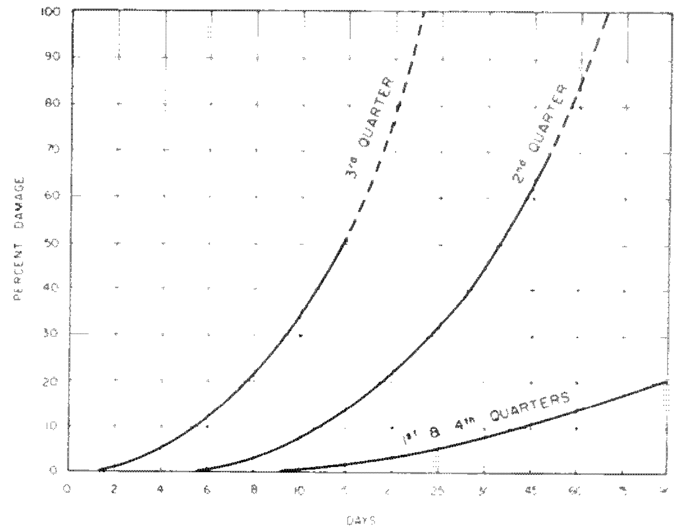
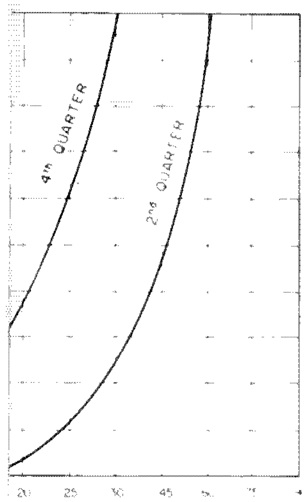
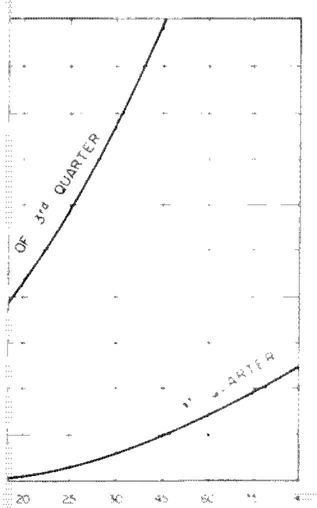


IRRIGATED PASTURE



E



OWER

LEGEND

PERCENT DAMAGE	PERCENT REDUCTION IN YIELD
1st QUARTER	PERIOD FROM DECEMBER 16 THRU MARCH 15
2nd QUARTER	PERIOD FROM MARCH 16 THRU JUNE 15
3rd QUARTER	PERIOD FROM JUNE 16 THRU SEPTEMBER 15
4th QUARTER	PERIOD FROM SEPTEMBER 16 THRU DECEMBER 15
————	PORTION OF CROP REMAINING TO BE HARVESTED
- - - - - -	PORTION OF CROP HARVESTED

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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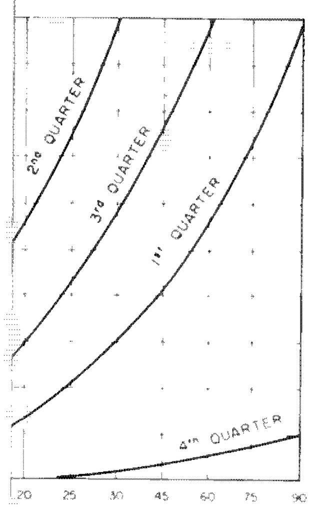
SACRAMENTO DISTRICT
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP DAMAGE CURVES

1966



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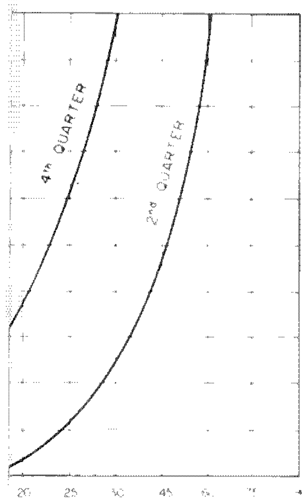
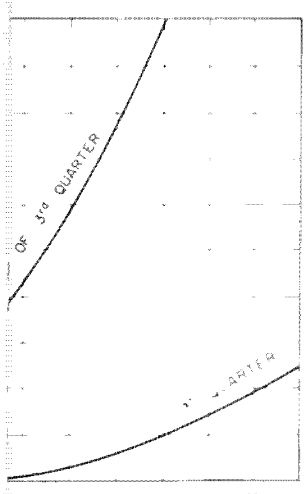
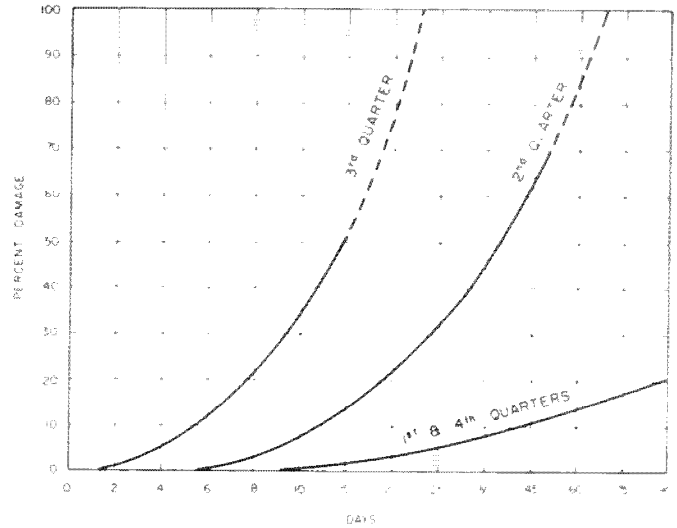


E



P

OWER



IRRIGATED PASTURE

LEGEND

PERCENT DAMAGE	PERCENT REDUCTION IN YIELD
1st QUARTER	PERIOD FROM DECEMBER 16 THRU MARCH 15
2nd QUARTER	PERIOD FROM MARCH 16 THRU JUNE 15
3rd QUARTER	PERIOD FROM JUNE 16 THRU SEPTEMBER 15
4th QUARTER	PERIOD FROM SEPTEMBER 16 THRU DECEMBER 15
————	PORTION OF CROP REMAINING TO BE HARVESTED
- - - - - -	PORTION OF CROP HARVESTED

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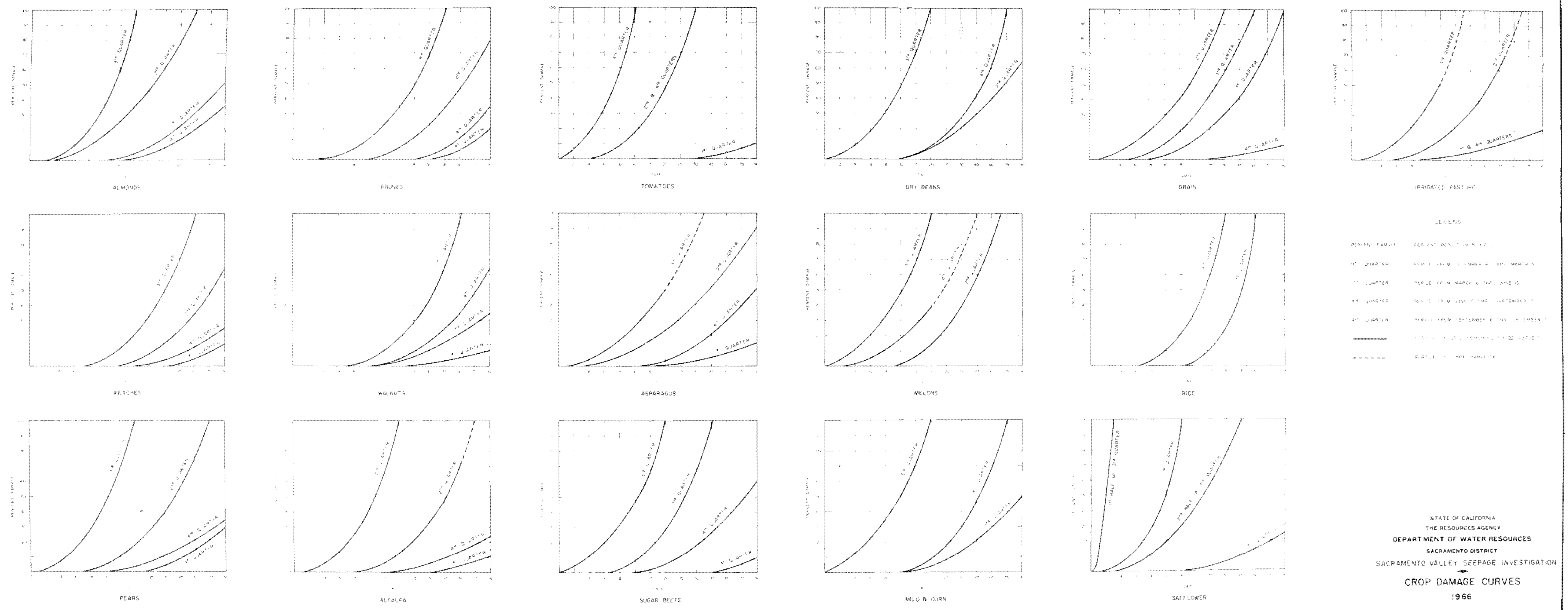
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT

SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP DAMAGE CURVES

1966



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DEPARTMENT OF WATER RESOURCES
SACRAMENTO DISTRICT
SACRAMENTO VALLEY SEEPAGE INVESTIGATION

CROP DAMAGE CURVES

1966