Sacramento River Drainage and Seepage Utilization

WORKING DOCUMENT

February 1977

BUREAU OF RECLAMATION
MID-PACIFIC REGION

SACRAMENTO RIVER DRAINAGE

AND

SEEPAGE UTILIZATION

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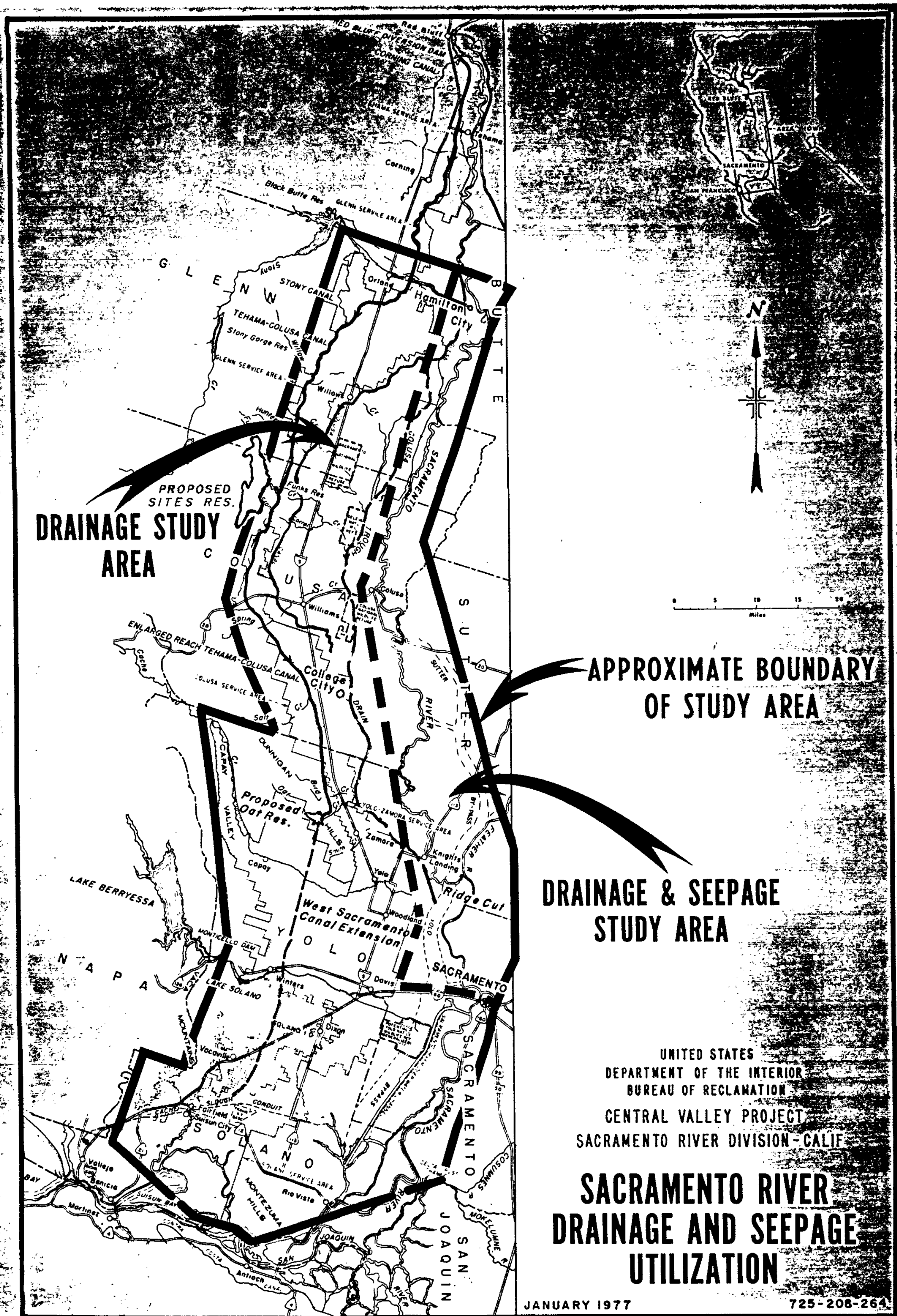
This report was prepared pursuant to Federal Reclamation laws (Act of June 17, 1902, 32 Stat. 388 and acts amendatory thereof or supplementary thereto). Publication of the findings and recommendations herein should not be construed as representing either the approval or disapproval of the Secretary of the Interior. The purpose of this report is to provide information and alternatives for further consideration by the Bureau of Reclamation, the Secretary of the Interior, and other Federal agencies.

February 1977

Bureau of Reclamation

Mid-Pacific Region



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INTRODUCTION

The purpose of this study is to seek alternative solutions to seepage problems along the Sacramento River, drainage problems associated with irrigated lands in the Tehama-Colusa Canal service area, and flooding problems within the Colusa Basin, in a comprehensive manner which considers the utilization of any recaptured water. This is an appraisal study with the objective of determining if further feasibility level studies are justified. Consequently, only data from existing reports and other readily available data are utilized. No field investigations were initiated to obtain new data.

The study area, which is delineated on the frontispiece, includes portions of Glenn, Colusa, Yolo, Solano, Butte, Sutter, and Sacramento Counties. The seepage portion of the study is confined to lands adjacent to the Sacramento River between Hamilton City and Sacramento.

This report identifies the problems and needs of the study area and presents alternative solutions for dealing with them. Conclusions and recommendations are also presented. In addition, background information regarding the study area and a synopsis of factors determining the occurrence of river seepage are provided. The purpose of the document is to provide information and alternatives for further consideration by the Bureau of Reclamation.

Introduction

AUTHORITY

This document is authorized by virtue of the Federal Reclamation Laws (Act of June 17, 1902, 32 Stat. 388 and Acts amendatory thereof or supplementary thereto) and Public Law 94-180 (Act of December 26, 1975, 89 Stat. 1035)

PUBLIC INVOLVEMENT

A Notice of Initiation of Investigation that was given broad circulation in June 1976 brought forth many telephone responses and letter replies which expressed concern regarding seepage and drainage problems in the study area and emphasized the need for an investigation. Two general public meetings were held in July, one at Willows, California, and another at Woodland, California. A citizens advisory committee that was formed, comprised of local citizens, members of private, local, State and Federal entities, has met four times to assist in determining the needs and alternatives pertaining to this study.

The Bureau of Reclamation and the State Department of Water Resources, through meetings and discussions both prior to and since this study began, jointly prepared a document entitled "Prospectus for a Program to Resolve Seepage Problems in the Sacramento Valley," which synopsizes the seepage problems and possible solutions. It proposes a program, which of necessity, would require involvement of landowners along with Federal, State and local entities operating projects which affect the general public interests.

A list of committee members is included in the appendix of this report.

NEED FOR STUDY

Seepage

Over the last several years, there have been an increasing number of complaints regarding the operation of Shasta Dam as it affects streamflow regulation in the Sacramento River and the use of the Sacramento River as a canal which is claimed aggravates the seepage problems of riparian lands. During the winter and spring of 1973-74, in which record rainfall and runoff were experienced in the Sacramento River Basin, the magnitude of seepage and drainage problems led to large damage claims against the Bureau of Reclamation. Subsequently, in March 1976, several landowners filed a lawsuit, which claims in excess of $30 million for seepage damage, against the Bureau of Reclamation and the State of California.

The Yolo County Water Resources Control Board, in a letter dated August 20, 1974, asked the Bureau's opinion on what could be done to solve the seepage problem. Landowners along the river have indicated that they would prefer a solution to the seepage problem rather than have long, drawn out costly litigation over damages.

Introduction

Drainage and Flooding

Drainage and flooding problems, which have plagued the Colusa Basin and other areas for a number of years, have become more significant with increased agricultural development in the Sacramento Valley. With the advent of the Tehama-Colusa Canal coming on line, importing additional water into the Colusa Basin, there is a potential for more return flow passing into the overly taxed Colusa Drain. The Colusa Drain is the primary drainage conveyance facility in the trough of the Basin.

Utilization of Water

Besides seepage, drainage, and flooding problems within the study area, there is also a need for additional water supplies during certain times of the year. Through a broad scope study it should be possible to identify alternatives which utilize some of the water recaptured while solving the problem outlined earlier. A prime example would be the potential reuse of approximately 52,000 acre-feet of return flow which will be available from irrigated lands in the Tehama-Colusa Canal service area under conditions of full development.

PREVIOUS STUDIES

This study relied heavily on data and information from past investigations. The more important ones are discussed below. Other sources are included in the reference list on page 8.

Introduction

The earliest survey of seepage along the Sacramento River was that initiated by the U.S. Bureau of Reclamation in 1941. Data on seepage and high ground-water conditions were collected for a 7-year period until 1948 after which more limited data were collected. The results of this survey were summarized in 1952 in a report titled "Survey of Seepage Along the Sacramento River," which concluded that Shasta Reservoir operations greatly reduce seepage along the Sacramento River, but cannot eliminate it. The most extensive investigations are those conducted by the State Department of Water Resources and documented in "Seepage Conditions in Sacramento Valley," dated June 1955 and Bulletin 125, "Sacramento Valley Seepage Investigation," dated August 1967. The earlier of these two reports covers surveys and studies of the effects of seepage on lands adjacent to the major river and bypass channels in the Sacramento Valley, and suggests possible alternatives for solving the seepage problems. Bulletin 125 extends the work of the former study by collecting data on seepage conditions during the period 1959 through 1965, compiling data on the economic effects of seepage, and developing methodology for estimating seepage conditions under various river stages.

The State Department of Water Resources considered flooding problems in the Colusa Basin in Bulletin No. 109 titled, "Colusa Basin Investigation," published in May 1964. This report concluded, after an extensive investigation, that there were no economically viable solutions to winter flooding in the basin but that one alternative for spring flooding did have economic justification. A 1968 Corps of Engineers reconnaissance study titled, "Colusa Basin Drainage Problem, Colusa and Yolo Counties, California," further considered spring flooding in the lower Colusa Basin and Yolo Bypass.

Addressing the present and future needs of the Colusa Basin, the Bureau of Reclamation, with public participation, recently reviewed and evaluated the water-related problems of the area and developed alternative solutions. In conducting the study, four plan formulation work teams were formed, composed of representatives of interested public and private entities.

Separate reports prepared by these teams were:

1. Water Supply and Water Rights, December 1973
2. Water Quality, September 1973
3. Environmental Appraisal, June 1974
4. Flood Prevention and Drainage, October 1974

Portions of the following two chapters are excerpted or paraphrased from State Department of Water Resources Bulletins 109 and 125. Since these bulletins are no longer available, it was felt that the added background they provide should be utilized in the present report. Of the recent Bureau of Reclamation Colusa Basin work team studies, only the "Flood Prevention and Drainage" report is heavily utilized. The alternative solutions outlined therein are detailed and extended in Chapter 4.

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CHAPTER 2

SETTING

GEOGRAPHY AND TOPOGRAPHY

The Sacramento Valley is bounded on the north and east by the Cascades and Sierra Nevada and on the west by the Coast Ranges, and extends from Shasta Dam on the north to the Sacramento-San Joaquin Delta on the south. The Sacramento River traverses the middle of the valley with numerous tributaries entering it on its course to the Delta.

Land in the upper end of the valley is higher and slopes toward the river from the foothills. Near Butte City, the valley floor starts to level out, resulting in a gradual ridge buildup over the years from silt-laden floodwaters overflowing the natural channel. Consequently, the river now flows on an elevated ridge with lower basins or shallow troughs on either side. The heavier and larger sediments carried by floodflows were deposited on the banks and near the main channel while the finer, smaller particles were carried considerably farther from the main channel. The slope of the ground away from the main channel is relatively steep and gradually flattens toward the center portions of the basins, which are generally 6 to 20 feet lower than the riverbanks.

During seasons of heavy rainfall, and before the present system of levees in the Sacramento Valley was constructed, the flood basins or troughs were filled by runoff from the adjacent plains and hills, and by water from the main river flowing over the banks. The basins usually discharged through sloughs, either back into the main channel, or into the next lower flood basin. In times of great prolonged floods, these basins performed a dual function, acting both as large shallow floodwater channels and as temporary storage or equalizing reservoirs that reduced the peak of the floods. The basins would remain full of water until the river receded to a stage that would allow them to drain.

The basins are identified as the Colusa Basin on the west side of the Sacramento River between Hamilton City and Knights Landing and the Yolo Basin, located south of the Colusa Basin. On the east side, Butte Basin and Sutter Basin are the principal low areas. The Colusa and Yolo Basins are separated by the Knights Landing Ridge. This ridge was formed by sediments from Cache Creek deposited in a manner similar to those deposited by the Sacramento River. The southernmost portion of the study area includes the Suisun Marsh, an area of about 70,000 acres, which is the last remaining marsh of such size in California.

CLIMATE

The climate of the study area is characterized by dry summers with high daytime temperatures and warm nights, and wet winters with moderate temperatures. More than 80 percent of the precipitation occurs during the 5-month period from November through March. The growing season between killing frosts is long; the average for Colusa, located centrally in the area, is about 288 days. The average for Willows is 224 days. Temperatures at Colusa have ranged from 14°F to 114°F; the monthly average ranges from 45°F in January to 78°F in July. Temperatures at Willows have ranged from 15°F to 116°F, and the monthly average ranges from 45°F in January to 80°F in July.

ECONOMY

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 include barley, sugar beets, beans, milo, tomatoes, rice, alfalfa, pasture, and safflower. The orchards are mostly walnuts, pears, and prunes. Within the Colusa Basin, large acreages are devoted to rice.

FISH AND WILDLIFE

Recreation, measured in terms of money spent, is an important activity in the Colusa Basin and the Suisun Marsh. Hunting, particularly for pheasant and waterfowl, constitutes the principal form of recreation in these areas. The many sloughs, channels, and drains in the Colusa Basin also sustain warm-water game fish. Catfish and largemouth black bass are the principal game fish. Lesser numbers of bluegill and green sunfish are also taken. Most of these game fish appear in the Colusa Drain and in channels or ponds on permanently flooded gun club lands along Willow Creek. The numerous irrigation ditches and drainageways in the area are also heavily fished. Fishing for striped bass and salmon occurs primarily in the Sacramento River.

The Pacific Flyway, one of the four major waterfowl migration flyways within the North American Continent, covers California, Oregon, Washington, Idaho, Montana, Nevada, Utah, and Arizona. Ducks and geese using the Pacific Flyway nest and breed, for the most part, in Alberta and Saskatchewan, and move southward to winter in California, Arizona, and Mexico. The breeding areas have been affected only slightly by man's activities, although wintering areas to the south, particularly in the Central Valley in California, are continually reduced as a result of increases in population and accompanying increases in land use. Consequently, the areas are seriously out of balance. Waterfowl populations are limited by insufficient wintering areas, even though their northern breeding areas are sufficient to support a larger waterfowl population.

Setting

Throughout recorded history, California has been the principal wintering ground for migratory waterfowl of the Pacific Flyway. An estimated 60 percent of Pacific Flyway waterfowl winter in California. Extensive marsh areas in the great valleys of the State were used, prior to reclamation, by hordes of ducks and geese. Today these same valleys have a much reduced marsh and water acreage, and are crowded with waterfowl during the winter season.

At least seven migration waterfowl routes converge at the Tule Lake-Lower Klamath concentration area, one of the largest in the nation. From there the birds move in great flocks down into the Central Valley of California.

The Colusa Basin is an important wildlife area in the Sacramento Valley. The basin contains three federally owned national wildlife refuges, the Sacramento National Wildlife Refuge near Willows, the Delevan National Wildlife Refuge near Maxwell, and the Colusa National Wildlife Refuge near Colusa. These three refuges, together with the State-owned Grey Lodge Waterfowl Management Area in Butte County, the Sutter National Wildlife Refuge in Sutter County, and adjoining areas provide the bulk of the waterfowl wintering grounds in the Sacramento Valley.

The Federal and State-owned areas serve primarily to supply needed habitat for feeding and resting as well as refuge areas for waterfowl and other species of wildlife. These areas also function to alleviate crop depredation. During the period from

August to October, before rice is harvested, ricefields are subject to serious monetary losses due to depredation by ducks. Much of this economic loss has been alleviated in recent years by the growing of crops on the State and Federal waterfowl areas, and the attraction of birds to these areas during the critical rice harvest period.

The Colusa Basin provides one of the best pheasant-producing areas in the State. Each year, Colusa County sustains the heaviest kill of pheasants of any county in the State. Other game birds in the basin include the widely distributed mourning dove and the far less numerous California quail.

Naturally, the wetland habitat associated with waterfowl supports a great variety of wildlife other than game birds. Widely distributed species include large numbers of shore birds, egrets, herons, swans, and grebes. In addition, the riparian habitat existing along ditches, drainage, and wasteways supports large numbers of songbirds.

Skunk, opposum, racoon, fox, otter, mink, and muskrat occur in the basin. Muskrat, damaging as they are to irrigation works and agriculture, provide commerce in the winter months to a few people who trap for furs.

The Suisun Marsh, consisting of about 87,000 acres of marshland and intertidal bays and sloughs at the southern end of the study area, is also considered a very important fish, wildlife, and waterfowl area. It is an important segment of winter habitat for waterfowl in the Pacific Flyway, with an average October and December population of 500,000 and 300,000 waterfowl, respectively. Use increases in dry years when other areas are not so attractive. A population inventory conducted in October 1974 indicated that 28 percent of all waterfowl in California were located within the Suisun Marsh.

The Suisun Marsh is regularly a major wintering area for California's most numerous duck, the pintail. Other puddle ducks wintering in the marsh include the American widgeon, mallard, shoveler, and green-winged teal. Isolated, brackish tidal marsh areas provide habitat for rails, gallinules, marsh hawks, and many small animals.

In 1927, the State established the 1,880-acre Joice Island Game Refuge in the marsh, and in 1948 the 8,560-acre Grizzly Island Waterfowl Management Area. In addition to these refuge areas, some 200 private duck clubs (ranging in size from 30 to 1,000 acres) own or lease a total of about 36,000 acres of the marsh.

GEOLOGY AND SOILS

The hills and mountains of the Coast Range are composed mainly of sedimentary sandstones, shales, and conglomerates. These hills, in the western portion of the Colusa Basin drainage area, resemble a giant deck of cards stacked nearly on edge.

The more resistant strata stand out as ridges, while the intervening, less resistant strata have been worn down by erosion. The sedimentary strata dip beneath the valley, lie thousands of feet beneath the central part of the valley, and emerge on the other side in the foothills of the Sierra Nevada. The valley floor was formed primarily by the deposition of material carried by floodwaters of streams. Geologically, the principal formations of the valley are the alluvial fan deposits, the flood basin deposits, and the river deposits. The alluvial fan deposits, which were laid down by streams draining the Coast Ranges, vary in composition from clay to gravel. The flood basin and river deposits are categorized as:

1. Stream deposits--a gray, loose, gravelly sand of high permeability;

2. Flood plain 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.

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.

Setting

The stream deposits extend vertically to a maximum depth of approximately 100 feet and laterally about 1 mile. These soils are normally hydraulically connected with the river and, due to their high permeability, are a significant factor in the seepage problem.

The flood plain 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 flood plain deposits ranges up to 30 feet, but averages about 15 feet. The quantity of seepage which flows through flood plain 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 flood plain 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.

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 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 irrigation water applied to 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.

LAND RECLAMATION AND IRRIGATION DEVELOPMENT

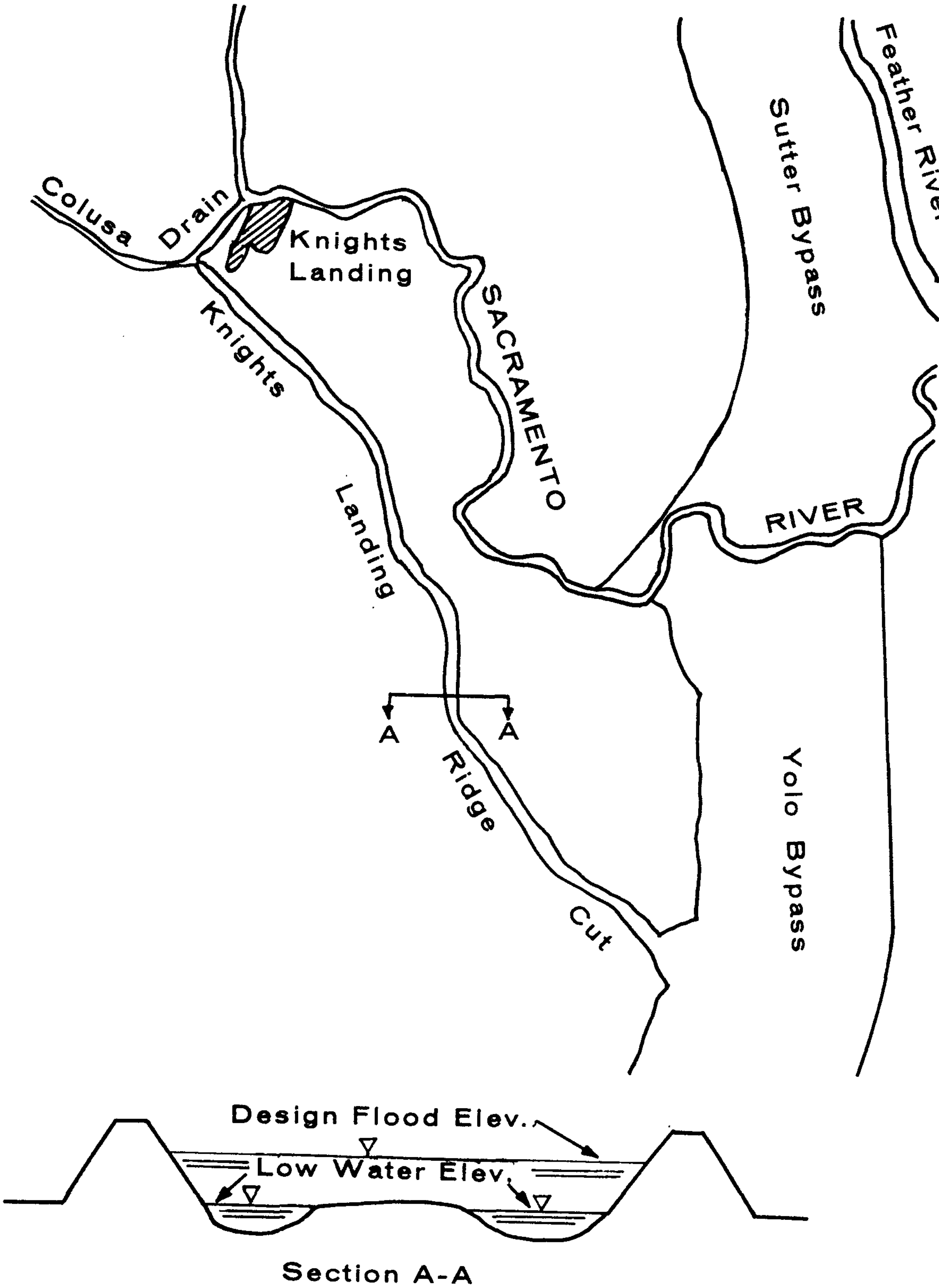
The development of the study area into a productive agricultural region has been dependent upon the progressive reclamation of the area to prevent flooding, improve drainage, and provide irrigation. Through the years, individuals, local districts, and State and Federal agencies have constructed various works necessary for the successful development of the Sacramento Valley.

Early reclamation was accomplished by reclamation districts, many of which are still in existence today. The Sacramento River Flood Control Project, which received Federal sanction in 1917, modified some of the initial reclamation works to conform with its plans. The Project, now substantially completed, consists of a comprehensive system of levees, overflow weirs, drainage pumping plants, and flood bypass channels. The bulk of the floodflows passing through the Sacramento Valley is conveyed by weirs from the Sacramento River in the Sutter and Yolo Bypasses. Floodwaters then continue downstream and return to the Sacramento River in the vicinity of Rio Vista.

Reclamation District No. 108's "back levee" in the Colusa Basin is one of the reclamation works improved as part of the Sacramento River Flood Control Project. The back levee, extending from Knights Landing to high ground near Colusa west of the Sacramento River levee, protects lands to the east (between the two levees) from foothill flood runoff. The back levee was brought to full standards of the Sacramento River Flood Control Project in 1958.

In 1913, the Knights Landing Ridge Drainage District was formed to develop an outlet for water which tended to pond between the back levee and high ground on the west and south during high stages in the Sacramento River. A channel known as the Knights Landing Ridge Cut (see figure 1) was dredged for a distance of about 7 miles from Knights Landing to low lying land in the Yolo Basin at the western edge of the Yolo Bypass. The Cut is about 400 feet wide on the bottom, 20 feet deep at its maximum, and has a design capacity of about 20,000 ft^3/s.

As irrigated agriculture increased in the Colusa Basin, return flows from irrigation during certain periods of the year created flooding problems downstream from the areas irrigated. Because of the inadequacy of drainage facilities, Reclamation District No. 2047 was formed in 1919 to construct a master drain known as the Colusa Basin Drainage Canal or the Colusa Drain. The Colusa Drain starts east of Willows and proceeds in a generally southerly direction to the vicinity of Colusa where it follows the alinement of the back levee. The drain terminates at the Knights Landing outfall gates on the Sacramento River. The design capacity of the drain is 1,450 ft^3/s with the elevation of the water surface at a minimum of 1 foot below the adjoining land so as to provide drainage to these lands. The Colusa Drain also serves as a water supply for adjoining lands. In addition to the Colusa Drain, open ditch drains and improved natural drains have been extensively developed in the Colusa Basin. Such drains vary from 4 to 8 feet in depth with spacings of 1,320 to 5,000 feet. These drains serve lands principally devoted to the raising of rice.



KNIGHTS LANDING RIDGE CUT

FIGURE 1

Setting

Initial irrigation in the study area was developed using water from the adjacent Sacramento River. After construction of the Colusa Drain, irrigation return flows were used by irrigators along this channel. In addition to these water sources, today's irrigators in the Colusa Basin are served by the Glenn-Colusa Canal, the recently completed portions of the Tehama-Colusa Canal, and ground-water pumping. The Tehama-Colusa Canal, which is still under construction, will serve those irrigable lands lying above the existing Glenn-Colusa Canal.

CHAPTER 3

PROBLEMS AND NEEDS

SEEPAGE

General

The Sacramento River system has been extensively leveed in the valley to contain floodwaters which primarily result from snowmelt in the Cascades and Sierra Nevada and from intense rainfall on tributary watersheds. 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 operation and maintenance of these facilities. It also has many lesser effects such as increasing the construction costs of buildings, roads, and airports, and sometimes delays or precludes urban development.

In its broadest meaning, and as most commonly applied, the term seepage is used to describe the high ground-water table and any surface water which results in part from percolation from the river channels and in part from local rainfall and runoff. The term 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 landward side of leveed watercourses which is attributable to percolation from the confined channels.

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 top of 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 manmade 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 no seepage has been documented prior to 1937. Following that year the Department of Water Resources reports 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 possible effects of Shasta Reservoir, which was under construction, 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 most extensive surveys, however, are those conducted by the State Department of Water Resources and documented in "Seepage Conditions in Sacramento Valley," dated June 1955 and Bulletion 125, "Sacramento Valley Seepage Investigation," dated August 1967.

Problems and Needs

Area Affected

For the purpose of defining the study area, the zone directly affected by seepage from the Sacramento River is considered to extend as far out as 1 mile on each side of the river and consists of continuous strips of land on the landward side of the river levees. 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.

Very little seepage occurs north of Hamilton City because the land generally lies above river level. Seepage south of the city of Sacramento is considered as part of the Delta area subject to tidal fluctuations and complex hydraulic conditions. The majority of the seepage occurs south of Colusa.

The area affected varies from year to year depending upon the stage and duration characteristics of the particular year in question. The related seepage damage also varies depending not only on stage and duration, but also the time of year and antecedent conditions.

Seepage Damage

The principal seepage damage of concern in this study is that experienced by agriculture. 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.

Problems and Needs

Seepage can have both beneficial and detrimental effects. Such water 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.

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.

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.

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.

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.

Seepage also limits the use of land in some agricultural areas. 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 would normally be expected to appreciate. Thus, the restriction on land use imposed by seepage reduces the market value of agricultural land and, therefore, the tax revenue.

FLOODING

General

Flooding is a major concern at a number of locations within the study area. Problems of flooding exist along Willow Creek, along the Colusa Drain and its tributary drainage channels, and in portions of the Yolo Bypass below the Knights Landing Ridge Cut. These problems are caused by improper and insufficient individual farm drainage, inadequate facilities to remove drainage from low lying areas into the Colusa Drain and other major drainage canals, insufficient channel capacities of flood and drainage canals tributary to the Colusa Drain and particularly in the drain itself, and inadequate discharge capacity of the Colusa Drain into either the Sacramento River or the Yolo Bypass.

This study focuses on flooding along the Colusa Drain and the inadequate discharge capacity of the drain. Flood and drainage problems along channels tributary to the Colusa Drain are considered only in connection with their relationship to problems of the drain. Because of the impact of the Colusa Drain flows below the Ridge Cut, Yolo Bypass flooding from this source is also addressed.

Existing Drainage Facilities

The Colusa Drain is the primary outlet drain for the Colusa Basin. In the summer, or at any time that flows in the Sacramento River are at elevations less than the discharge level of the outfall gates, collected surface drainage effluent is discharged into the Sacramento River at Knights Landing. When high stages exist in the Sacramento River, Colusa Basin drainage is precluded from discharging at the outfall gates causing a backwater condition. Colusa Drain water levels then rise until the drainage water flows into the Knights Landing Ridge Cut which in turn empties into the Yolo Bypass. The Knights Landing Ridge Cut, constructed across the Cache Creek fan south of Knights Landing, is an original feature of the Colusa Drain.

Problems and Needs

During flood stages of the Sacramento River, water flows from the river into the Yolo Bypass which is a flood protective feature for the city of Sacramento and adjoining areas. At these times flows in the Colusa Basin Drain are blocked at the Knights Landing outfall gates and also partially blocked from entering the Yolo Bypass by the floodwaters already there. Flooding of agricultural land within the Colusa Basin then occurs until the river and bypass floodflows are materially reduced.

Within the Colusa Basin, principally within the area bounded by the Glenn-Colusa Canal on the west and the Sacramento River on the east, open ditch drains and improved natural drains have been extensively developed. Such drains vary from 4 to 8 feet in depth. Drain spacings range from 1,320 to 5,000 feet and serve to drain lands principally devoted to growing rice.

Winter Flooding

During the winter flood period, roughly October through March, floods are caused by precipitation within the Colusa Basin and runoff from the foothill region to the west. The magnitude of the discharge in these winter storms is very large when compared with the channel capacity of the Colusa Drain. The channel capacity in the upper reaches, for example, is exceeded when the discharge at Highway 20 near Colusa is greater than 2,100 ft^3/s. The maximum mean daily discharge of record at this point occurred on February 21, 1958, and was 23,900 ft^3/s. Because the channel is inadequate to handle the discharge, the excess flows flood an extensive area along the channel. In 1958, the flooded area extended continuously from Knights Landing to Orland, a distance of 70 miles. The flooded areas are frequently large at this time of year, but the damages are relatively light since the lands inundated are principally agricultural and idle during the winter. Highways, roads, and public utilities, as well as the limited urban or domestic development within the flood plain, are also subject to damage.

Spring Flooding

In the spring months, April through June, flooding is caused principally by irrigation return flows rather than by precipitation. The channel capacity of the Colusa Drain is usually adequate to handle the irrigation return flows, except in the reach between College City and Knights Landing where flooding of a small area occurs regularly. The resulting damages are large since this flooding occurs in the normal growing season. This spring flooding results from local agricultural practices associated with the growing of rice.

Virtually all of the rice in the Sacramento Valley is planted between April 15 and May 15. In order to control weeds, the ricefields are flooded to a depth of 10 to 12 inches for a period of 3 to 4 weeks. In this time, both the rice and weeds germinate, and both would be drowned out if this depth of water were retained. The rice has a somewhat longer life under the deep water, however, and after the weeds have died but before the rice is harmed, 4 to 6 inches of water is dumped from the fields. The acreage of rice in the Colusa Basin is very large; in recent years, it has averaged around 100,000 acres, reaching a peak of 131,000 acres in 1954. Since the planting and flooding schedule for all this rice is about the same throughout the basin, the dumping practice creates a considerable flow that generally reaches a peak in May. The resulting flow may be augmented by water that must be released from ricefields during sustained north winds prevalent at this time of year. Most ricefields are large and have a considerable fetch, particularly in a north-south direction. Consequently, the water piles up at the south end of the field. In order to protect his checks, the grower must allow part of the ponded water to escape.

Several conditions contribute to the inability of existing works to handle spring flooding. High water in the Sacramento River prevents the drainage water from escaping through the Knights Landing outfall gates into the river. The outlet of the Knights Landing Ridge Cut is inadequate to release the required flow. Backwater resulting from these conditions causes flooding of lands along the west side of the Colusa Drain. Whatever water does escape into the Yolo Bypass causes additional damage by flooding farmland which has been planted at this time of year.

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Problems and Needs

In the early years of this century, when the Knights Landing Ridge Cut and the Colusa Drain were constructed, there was no agricultural development along the west bank of the drainage canal. Overflow onto these low lying lands was expected to occur whenever the outfall gates at Knights Landing were closed. Now conditions have changed, and lands right up to the bank have been brought into crop production. To protect their operations, some landowners along the drainage canal have built low levees at the water's edge. These levees cause a further rise in the water surface. As a result, both the flows through the ridge cut and the springtime damages in the Yolo Bypass are increased.

Although the large fall peak discharges often equal or exceed those of the spring, they have never flooded areas in the Colusa Basin. The absence of fall flooding is due to two facts: (1) The Knights Landing outfall gates at the lower end of the Colusa Drain always have been free to discharge large quantities of water without serious backwater effects during the late summer and fall when the Sacramento River is normally low; (2) in neither the spring nor the fall have irrigation return flows exceeded the channel capacity of the canal unless they were accompanied by the serious backwater effects which result only from the closing of the Knights Landing outflow gates on account of high river stages.

Since the Colusa Drain has virtually no capacity for channel storage, flows that occur in the drain will pond a large quantity of water when even a brief damming of the flow occurs. In the spring, the Sacramento River often rises high enough to close, at least partially, the outfall gates. Between April 1 and June 1 in 15 of the past 40 years, the water has overflowed the banks of the drain between College City and Knights Landing.

Flooding in the Yolo Bypass is coincident with this flooding in the lower Colusa Basin. High stages at the lower end of the Colusa Basin Drainage Canal cause flow through the Knights Landing Ridge Cut into the Yolo Bypass. From the mouth of the Ridge Cut to the Tule Canal on the opposite side of the Bypass, the capacity of two channels that meander through the Yolo Bypass is about 100 ft^3/s. Any excess flow crosses the bypass from west to east as a sheet.

The Tule Canal, located on the east side of the bypass, conveys the water southward as far as the toe drain of the Sacramento Deep Water Ship Channel. The discharge capacity of the Tule Canal is seriously restricted in the reach from the Sacramento Bypass to I-80, causing additional flooding within the Yolo Bypass.

IRRIGATION RETURN FLOW (TEHAMA-COLUSA CANAL)

Lands above the Glenn-Colusa Canal and within the Tehama-Colusa Canal service area are generally without drainage improvements. In a few localities, such as the area northwest of Willows, some open ditch (4 to 6 feet in depth) drainage facilities have been

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developed by individual farmers. These facilities serve as tail water drains and empty into the natural drains of the Willow-Walker Creeks complex. Much of the Tehama-Colusa service area will require drainage facilities for tail water control and shallow ground-water control near and adjacent to the west side of the Glenn-Colusa Canal. It is envisioned that these facilities will consist of a combination of shallow and deep open ditch drains and minor amounts of tile facilities for high water table control.

Most of the small natural drainageways (normally dry during the summer period) that traverse the valley from west to east within the Tehama-Colusa service area continue across the present Glenn-Colusa Irrigation District (GCID) area and have been preempted by them. In most cases these natural drainageways have been improved, rerouted, straightened, etc., by GCID and are used as part of their water distribution system. A number of these natural drainageways are blocked or partially blocked in the summer by GCID's Glenn-Colusa Canal. This operational requirement of GCID has the net effect of reducing the full use of the natural drainageways by landowners within the Tehama-Colusa service area.

During the winter season the sides of the Glenn-Colusa are opened at the larger natural drain crossings and winter runoff waters from the area above the canal are allowed to continue through the system uninterrupted. At locations where such facilities are not available, small culverts under the canal have been provided.

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These latter facilities are of insufficient capacity for future conditions of irrigation in the Tehama-Colusa service area and may, therefore, restrict summer drainage from the upslope areas. Therefore, a potentially serious drainage problem within the Tehama-Colusa Canal service area is expected to develop. Some drainage outlet provisions between water users within the Tehama-Colusa service area and the lower lying Glenn-Colusa Irrigation District will need to be made. The irrigation return flows from the Tehama-Colusa Canal service area will build up to an average of 52,000 acre-feet per year by the year 2000. The return flow would range between 20 ft^3/s and 180 ft^3/s between March and October but no return flow of applied irrigation water would be expected from November through February.

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CHAPTER 4

ALTERNATIVE SOLUTIONS

GENERAL

The alternative solutions presented in this chapter are based to a considerable extent on past studies, augmented with more current information where readily available. New solutions are introduced, however, and appraised to the extent possible with existing data. The nonuniformity of available information is reflected in the varying depth of description and analysis presented on the alternatives. Where possible, quantitative economic information is provided to assess benefits and costs associated with each alternative. This economic data should be considered as very preliminary and in no case better than appraisal grade in quality. Benefits and costs from past studies have been updated to 1976 dollars. A 100-year period of analysis at 6-3/8 percent interest was assumed.

The alternative solutions are organized around the major problems and needs as:

1. Seepage
2. Colusa Drain Flooding
3. Tehama-Colusa Canal Return Flow

Economics, in terms of costs and benefits, is emphasized in this chapter, as the greatest challenge in meeting many of the needs of the study area centers on finding economically viable solutions, i.e., solutions with a benefit to cost ratio better than 1.0:1. Other criteria for evaluating alternatives, such as those incorporating political and environmental considerations, can be more effectively employed at the feasibility phase of the investigation after preliminary economic screening. Table 4, starting on page 79, summarizes the contents of this chapter by tabulating each alternative along with pertinent comments including those of advisory team members, and conclusions.

SEEPAGE

General

The seepage alternatives are not mutually exclusive. A final plan could incorporate several or all of these alternatives. However, any final plan will have to recognize the irregularity and individuality of the problem. It is likely that any final solution will probably need to be implemented on a farm-by-farm basis, taking advantage of existing drainage facilities and individual farm and institutional relationships. Depending on the alternatives selected, new subregional districts may be required in some areas to facilitate the collection and conveyance of seepage water. Figures 2 through 6 show schematics of several hypothetical drainage systems for intercepting seepage.

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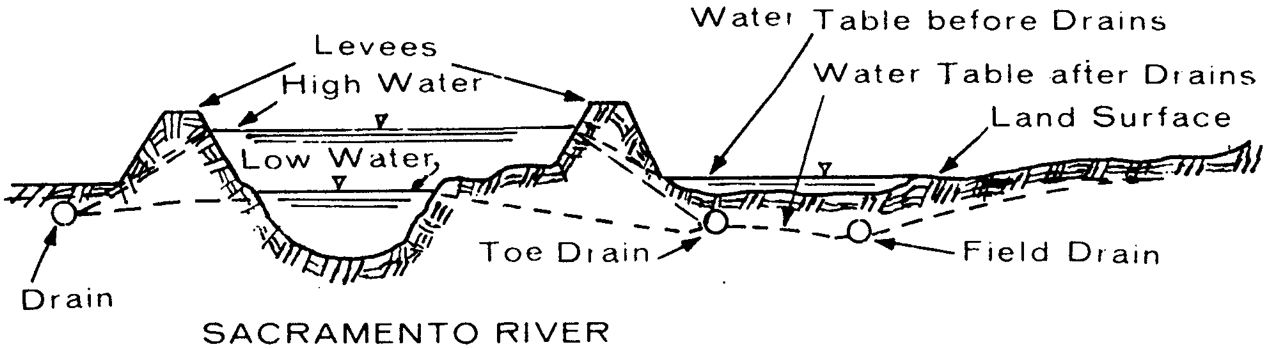
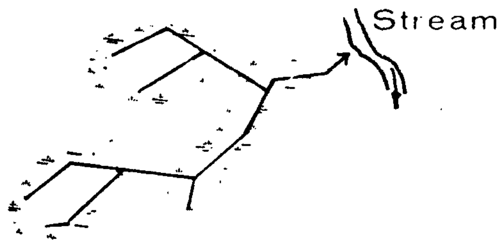
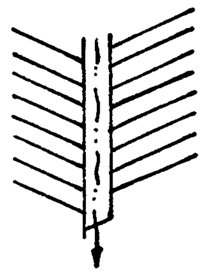


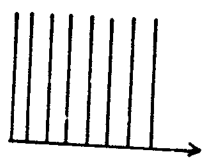
a) LEVEE INTERCEPTOR DRAINS



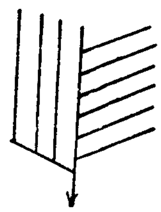
b) RANDOM TILE DRAINS



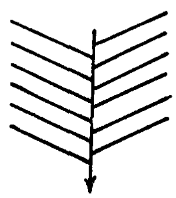
c) DOUBLE MAIN



d) PARALLEL



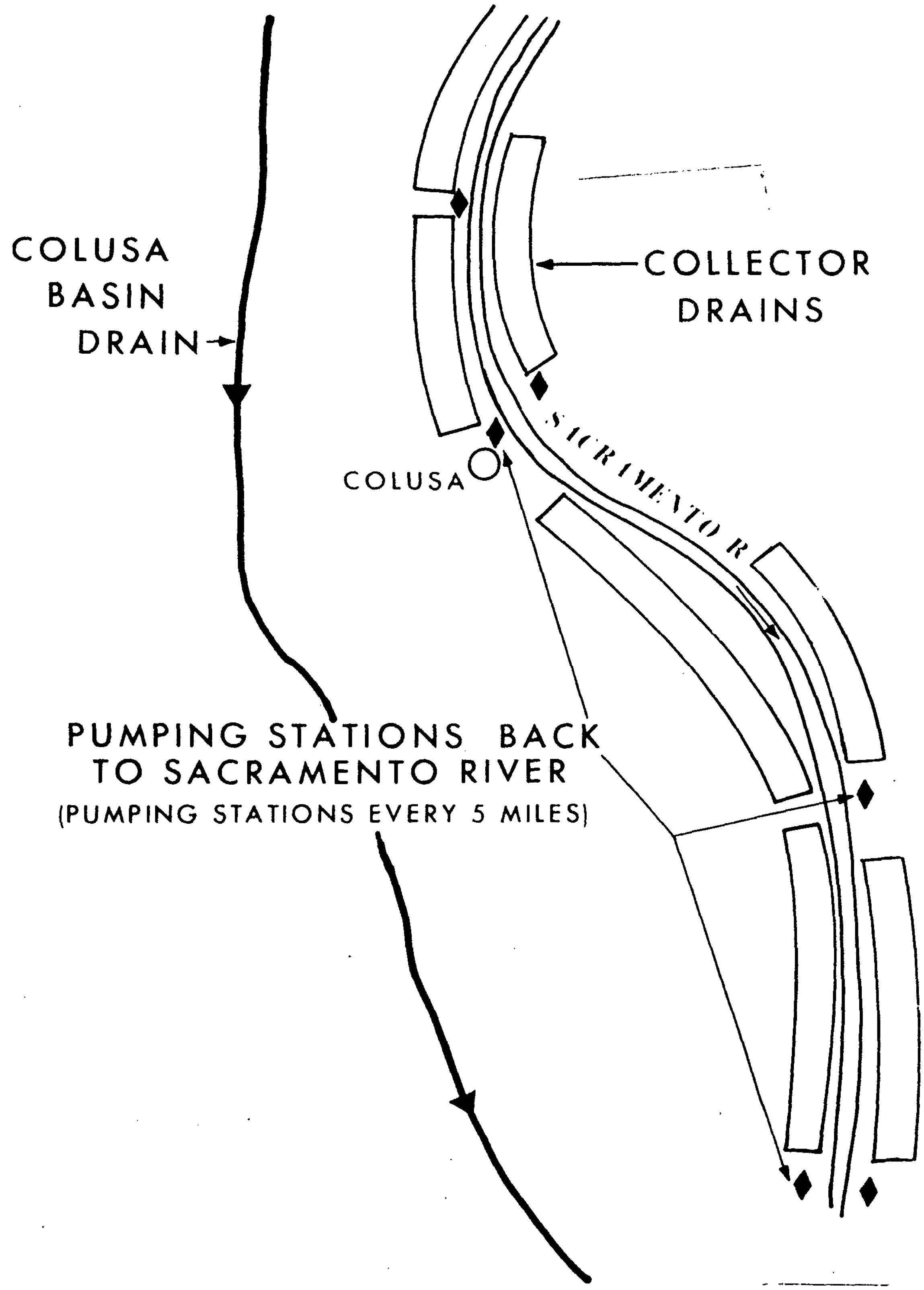
e) GRIDIRON



f) HERRING BONE

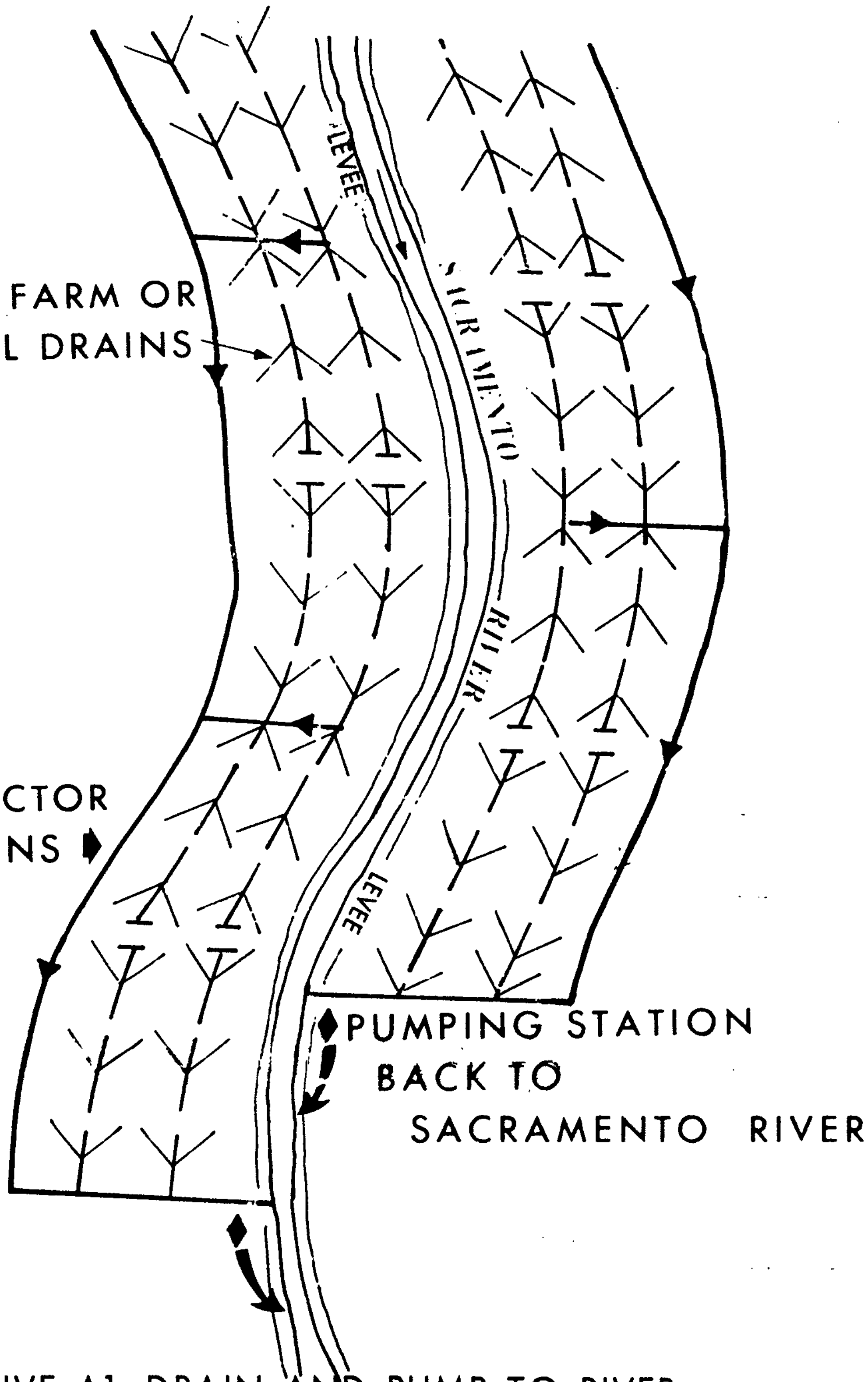
TYPICAL LEVEE AND FARM DRAINS

FIGURE 2



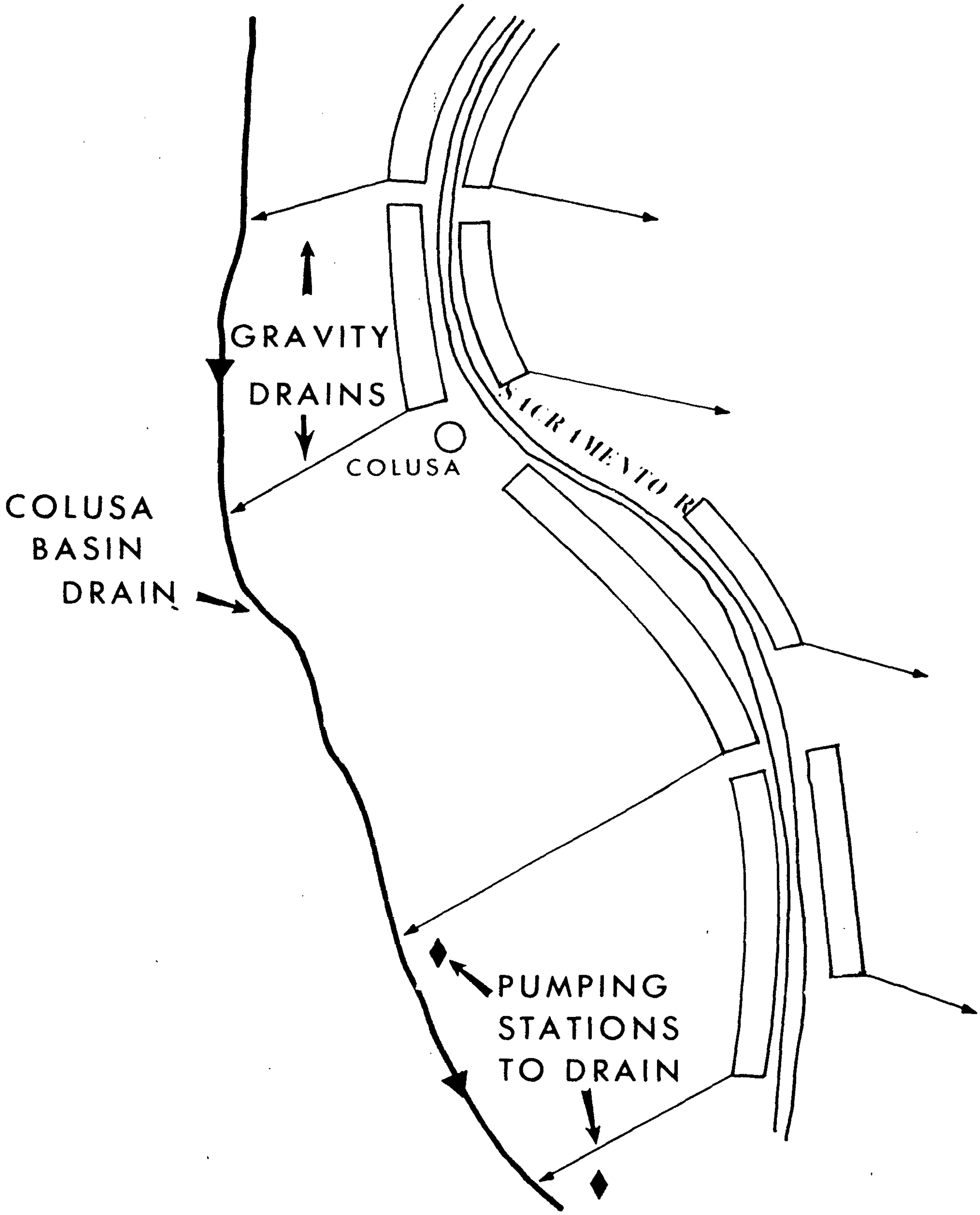
ALTERNATIVE A1, DRAIN AND PUMP TO RIVER

FIGURE 3



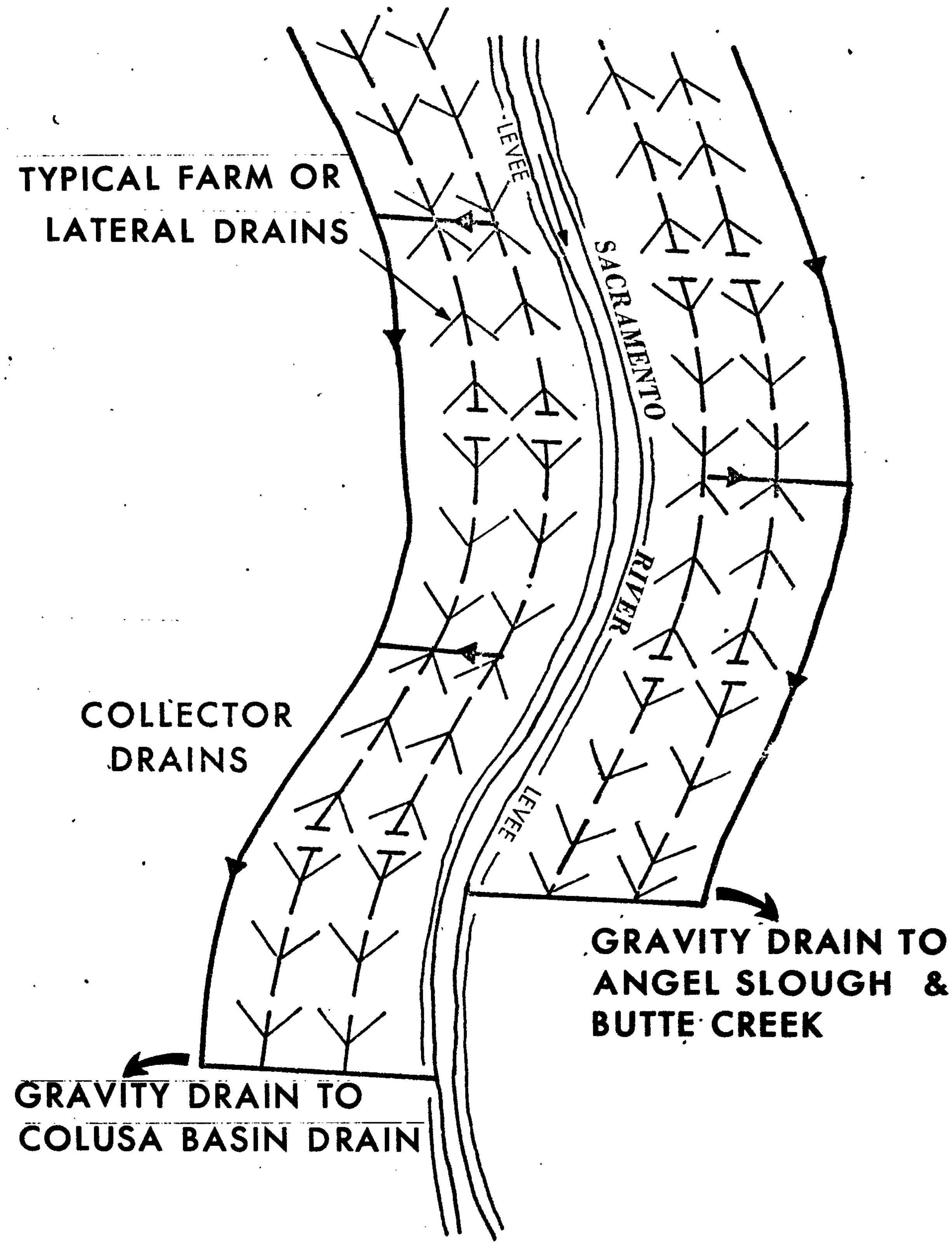
ALTERNATIVE A1, DRAIN AND PUMP TO RIVER

FIGURE 4



ALTERNATIVE A2, DRAIN TO MAJOR COLLECTOR DRAIN

FIGURE 5



ALTERNATIVE A2, DRAIN TO MAJOR COLLECTOR DRAIN

FIGURE 6

Alternative Solutions

Alternative A1, Drain and Pump to River

In this alternative, seepage water would be collected in flexible or tile drains installed parallel to the river. One to three drains would be required at depths of 6 to 12 feet. A collector drain, consisting of drainage pipe, open ditch, or a combination, would be used to direct the water to a sump and pump at the river. While estimates vary as to the quantity of seepage water which would be picked up by the drains, it is reasonable to assume an average of 2 ft^3/s per river mile. Using this figure and assuming pumping plants are located every 5 miles along the river, then each plant would have a capacity of 10 ft^3/s and a lift of about 20 feet.

Open ditches could be used in lieu of tile drains. However, they are much more disruptive to farming operations and present a greater maintenance problem. For this reason, it is likely that minimum use of open ditches would be made not only for initial interception but also for conveyance to the river. Figures 3 and 4 show schematics of hypothetical drainage systems.

The principal advantage of this alternative lies in its simplicity and high degree of flexibility to conform to existing property and institutional configurations. Pumping the water to the Sacramento River prevents any aggravation of the Colusa Drain flood problem but does add water to the Sacramento River. However, this is water that originated in the river and the hydraulic effect of removing seepage water would be a tendency for replacement water to seep from the river. Any possible water right problems are, of course, avoided by returning the water to the river. However, electrical energy is required for pumping, which is an economic detriment.

Alternative A2, Drain to Major Collector Drain

Seepage water would be collected on the farm as described in Alternative A1 but instead of pumping to the river at frequent intervals, the water would be directed in open ditches by gravity flow to the Colusa Basin Drain on the west side of the river, and to a master collector drain along the eastern side of the river. The conveyance ditches would use existing drainage channels as much as possible. In doing so, enlargement of existing ditches and agreements among various entities may be necessary. Seepage waters on the west side of the river between Colusa and Knights Landing will require pumps to lift the water over the Colusa Drain "back levee." Total lift is estimated at about 15 feet. Figures 5 and 6 provide a schematic of this alternative.

Those seepage waters collected on the east side of the Sacramento River starting approximately 10 miles north of Butte City would be directed to an improved Angel Slough extending to Butte Creek. Starting at the confluence of Butte Creek and the Sacramento River and going southward to Tisdale Weir, seepage water would be conveyed southward and disposed by pumping into the Tisdale Weir. In a similar fashion seepage water south of Tisdale Weir would be conveyed in a drain parallel to the river and disposed of by pumping into the river near Knights Landing or into Sutter Bypass.

While Alternative A2 returns less seepage water to the river, its implementation is more complex than Alternative A1 and it aggravates flooding in the Colusa Drain. The latter problem might be mitigated to some extent for the reach below College City by pumping out the added water at the terminal end of the Drain and returning it to the Sacramento River.

Alternative A3, Change Cropping Pattern

Some crops are more susceptible to seepage damage than others. The susceptibility of annual crops varies because of differences in rooting depths and planting times. Orchards are particularly vulnerable because they are deep rooted and represent long-term planting commitments. Walnuts are among the most sensitive of all Sacramento Valley crops. One obvious method of reducing seepage damage is to limit the types of crops grown in seepage-prone areas. This is basically a default alternative if nothing is done to reduce the seepage problem. Indeed, it is presently practiced in many areas along the river.

Alternative A3 is entirely within the control of the individual farmer and easily applied, except where perennial crops are well established. However, farm income is significantly lower than would be the case with higher priced crops and more intensive farming. As a consequence of reduced farm income, tax revenues are also lower.

Among farmers and County taxing agencies there is much opposition to this alternative. In addition to the above disadvantages, it is pointed out that much of the seepage-prone acreage is composed of very high quality soil and that it is one of the few places where certain types of crops will grow. From the environmental standpoint, however, this is seen as a desirable alternative, at least for some of the seepage area.

Alternative A4, Purchase Seepage Land

Another method of accommodating seepage would be direct purchase of the affected lands. Once the land was purchased, several possible uses might be made of it. The purchased land could be converted to a wildlife or recreation area; this would have the disadvantage of removing the land from agricultural production and the local tax resources. Alternatively, the land could be leased back for agricultural use which would maintain agricultural and tax income. Land converted to recreational use could present problems for adjacent land because of public trespassing and the resultant cleanup and policing problems.

If seepage land is purchased, the option of moving the levee back so as to allow the river to meander in a natural manner is then open. While this may be desirable environmentally, the capital costs and local opposition would be enormous and, therefore, its viability is questionable. Also seepage problems would tend to move further inland.

Alternative A5, Purchase Seepage Easement

Under this concept, the landowner would be reimbursed for granting a seepage easement in a manner similar to flood control easements. The main advantage to such an accommodation is that it would not necessarily remove any land from production. The principal disadvantage would be that damages would probably continue. Another obstacle would be establishing a fair and equitable method of applying such a program and determining the amount of reimbursement. It is unlikely that such a program would be viable in the absence of a determination that the seepage conditions were caused by the construction or operation of a water project and there was clear liability upon the owner or operator of the project for such damage.

Alternative A6, Project Reoperation and Development

It is inherent in the operation of multipurpose reservoirs that compromises among often conflicting goals of water supply, flood control, power production, fisheries preservation, recreation, and water quality control must often be made. During the flood season little operational flexibility is available to reduce the seepage problem. The flood control criteria for Shasta Reservoir have recently been revised, however, increasing spring flood control capability. This may help reduce seepage such as that which occurred in 1974.

It is noteworthy, however, that there is considerable uncontrolled runoff to the Sacramento River below Shasta Dam. New reservoirs constructed on these tributaries, such as the proposed Cottonwood Project of the Corps of Engineers, would help reduce river stages during critical seepage periods. These reservoirs could provide the usual multipurpose benefits but a large number of new reservoirs would be required in order to effect a substantial reduction in seepage. Such a program would involve major capital expenditures of questionable economic feasibility, and would encounter considerable environmental opposition. Consequently, upstream control reservoirs, in addition to the few being planned by various agencies, are an unlikely possibility.

Alternative A7, River Conveyance Improvements

Under this alternative are included such items as dredging the Sacramento River, rerouting of high flows, and weir improvement.

Widening or deepening river or bypass channels by dredging would lower river stages at high flows and thus reduce seepage. A considerable length of river would have to be excavated to have any substantial effect on levels. While dredging may reduce seepage, it would involve very high construction and maintenance costs and serious detrimental effects on fish and wildlife would be unavoidable. Upsetting natural sediment deposits usually introduces unexpected erosion and redeposition changes, and increases the water's turbidity.

River stages which cause seepage could be reduced by increasing the amounts diverted into the bypass channels. One version of this idea would be to enlarge the bypasses; another would be to construct gated weirs on the river so that more flow could be diverted to the bypasses after the flood peak had passed. Bypass enlargement would be quite costly and would take considerable land out of production. Changes in bypass operation would reduce seepage along the main river at the expense of increasing the duration of flow in the bypass and could also be detrimental to agricultural operations within the bypass.

Better maintenance of existing weirs such as the Tisdale and Fremont may also be helpful. It has been suggested that sediment buildup at the above weirs tends to increase the upstream backwater elevation. No investigation of this matter was made, however.

Benefits and Costs

Although there have been several studies of seepage conditions in the Sacramento Valley, it is still difficult to estimate the total seepage damage along the Sacramento River and the cost of alternative solutions to the problem. This reflects the complexity and variability of the seepage and the corresponding need for a highly detailed investigation. A key item of information is the areal extent of the seepage problem and the degree of damage both of which vary widely from year to year.

Various estimates of the total seepage area have been made in past studies. This data is summarized in table 1 but can only be considered as providing an indication of the extent of the seepage problem. The seepage area delineations obtained from Bulletin 125, which were based on aerial photographs taken between 1962 and 1965, are far more accurate than those obtained in prior studies. Nonetheless, problems exist in differentiating between seepage water and antecedent rainwater that saturates the soil due to poor internal drainage.

Referring to table 1, the average annual seepage reported between 1945 and 1954, the post-Shasta period, is 3,900 acres with a high of 16,000 acres. The Bulletin 125 aerial photography data acquired in 1962, 1963, and 1965 averages 27,000 acres with a high of 39,000 acres. For comparison, if one assumes that a strip along the river 100 miles long and a half-mile wide on both sides of the river is impacted by seepage, the area would be 64,000 acres. Recognizing that seepage damage is low in some years, 40,000 acres may be a reasonable upper limit for the average annual damage area.

The total seepage damage is of course dependent on much more than the amount of acreage affected. The timing and duration of the seepage event are equally important. Differentiation between

Table 1. Historical seepage acreage estimates

The following data gives an indication of the extent of seepage along the Sacramento River as obtained from past investigations

ORD FERRY TO FREEMONT WEIR[a]

Year	Seepage area (Acres)
1937-38	42,970
1938-39	0
1939-40	0
1940-41	41,453
1941-42	38,100
1942-43	9,750
1943-44	0
1944-45	0
1945-46	3,830
1946-47	0
1947-48	4,948
1948-49	0
1949-50	0
1950-51	3,272
1951-52	16,185
1952-53	5,829
1953-54	4,956

ORD FERRY TO SACRAMENTO WEIR[b]

Date	Seepage area (Acres)
2/21/62	24.000
2/26/62	23,920
10/18/62	14,080
2/22/63	30,240
4/24/63	31,350
2/10/65	39,270

a "Seepage Conditions in Sacramento Valley," State Division of Water Resources, June 1955.
b "Sacramento Valley Seepage Investigation," State Department of Water Resources Bulletin 125, August 1967.

seepage damage and nonrelated anticedent facors must also be made. For example, spring rainfall can delay planting and affect yields of crops already planted. In the event of subsequent seepage, problems can arise in differentiating between the two economic damages.

Without a highly detailed investigation to determine the frequency and magnitude of seepage events for each tract of land along the river, such as would be possible in a feasibility level study, it is difficult to define the benefits associated with seepage reduction. Nevertheless, an attempt at estimating seepage reduction benefits and costs is presented below.

There are two primary types of seepage damage - direct damage to crops and indirect damage due to limitations on land use. Bulletin 125 considered direct damage to a subarea of the river in considerable detail. Updating these figures to 1976 prices gives a damage of about $30 per acre. Damages due to limitation in land use are additive to the $30 per acre and could double the benefits of seepage reduction.

Using Bulletin 125 data, updated to 1976, capital costs for Alternative A1 (drain and pump to river) are estimated to be $27 per acre per year when amortized at 6-3/8 percent interest. Considering only direct damages and capital costs, a pseudo-benefit to cost ratio can be computed as:

Average annual capital costs (amortized at 6-3/8 % interest)	Average annual benefits (direct damage only)	Benefit to cost ratio (B/C)
$27 per acre	$30 per acre	1.1 to 1

It should be noted that the foregoing computation does not account for interest during construction, operation and maintenance costs, and indirect land benefits. While the limited data available suggests that Alternative A1 has a favorable benefit to cost ratio, final determination of economic feasibility will require a feasibility level investigation.

Because of its similarities to the above alternative, Alternative A2 is also assumed to have a favorable benefit to cost ratio, at least for lands which can tie into existing local drainage facilities.

There is insufficient data for estimating the benefit to cost ratio for the remaining alternatives. It can be inferred, however, from Bulletin 125 data that purchase of land or seepage easements would be more expensive than a physical solution. While it is unlikely that recreation and wildlife benefits would be sufficient to balance purchase costs alone, when combined with lease back for agricultural use, the benefits might be more favorable. The economics of these and the remaining alternatives should be delineated in any future feasibility studies.

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COLUSA DRAIN FLOODING

General

There have been several past studies of the Colusa Drain flooding problems. The most recent of these, the Bureau of Reclamation "Colusa Basin Study" is heavily relied upon for delineation of alternative solutions. This latter study was merged into the current investigation. Its findings are documented in "Colusa Basin Study - Flood Prevention and Drainage Work Team Report" dated October 1974. This study, as well as a 1968 Corps of Engineers' study, relied heavily on State Bulletin 109, "Colusa Basin Investigation," completed in 1964. None of these studies were able to find economically viable solutions of major substance. The only economically justified project reported, that of improving the outlet capacity of Knights Landing Ridge Cut and mitigating spring flooding in the Yolo Bypass, was subsequently determined by an internal Corps of Engineers' analysis to have a benefit to cost ratio less than one.

Alternative B1, Foothill Reservoirs

This alternative would provide a combined total of 50,000 acre-feet of flood storage on at least six of the larger foothill streams leading to the Colusa Drain. These reservoirs would protect the stream against flooding in a 50-year storm. Much greater storage capacity would be required to protect the entire Colusa Basin against a similar storm. Foothill reservoirs would not protect the Colusa Basin against spring flooding resulting from ricefield drainage.

The sites related would depend upon size of drainage basin controlled, storage capability of the site, and comparison of unit construction costs. Candidate streams include: South Fork Willow Creek, Logan Creek, Freshwater Creek, French Creek, Stone Corral Creek, and Funks Creek. Downstream channels might have to be enlarged to carry discharge releases from the reservoir after large storms. The reservoir could provide for irrigation water supply and recreational use depending on sizing and operation.

Alternative B2, Restore Flow Capacity of Ridge Cut

By improving the flow capacity of Knights Landing Ridge Cut, water could be quickly evacuated from the Colusa Drain when Yolo Bypass flows decrease. This would reduce the flooding below College City and could increase spring flooding in the Yolo Bypass. To mitigate the latter problem, a new channel across the Yolo Bypass and enlargement of the Tule Canal and toe drain might be required.

The plan would require widening the ridge cut from 400 feet to 1,000 feet by removal and reconstruction of the east levee (left bank) of the ridge cut. The left bank levee was chosen so that the more highly developed agricultural lands adjacent to the right bank levee would not be lost. An alternative course of action would be to clear the brush and tree choked center of the ridge cut channel, retaining the levees in their current location. To provide maximum protection to the lower Colusa Basin area, a control structure would be required to prevent floodflows in the Yolo Bypass from flowing up the cut. This would provide more time in the lower basin during which upstream flows could collect without topping drain levees when the Yolo Bypass remains filled for prolonged periods of time.

Alternative B3, Divert North Basin Streams

North basin streams would be diverted to Stony Creek or directed to the Sacramento River. This would lessen the floodflows in the lower basin and could provide some relief in the upper Colusa Basin. A channel to Stony Creek or the Sacramento River would be expensive and take farmland out of production. As the increased Sacramento River flows upstream of Moulton and Colusa weirs would increase floodflows passing into Butte Basin, possible legal entanglements could result. The increased riverflows would also aggravate the seepage problem.

Alternative B4, Increase Flow Capacity of Colusa Drain

The flow capacity of the Colusa Drain would be increased by constructing a levee along its west bank. Backwater levees along major tributaries would be required to prevent ponding against the drain levee. As an alternative to these backwater levees, pumps could be provided to lift the tributary flow into the drain. While the west side of the drain would be protected against flooding by this alternative, approximately 6,000 acres of land would fall within the leveed area. In addition to adding a west side levee, rehabilitation of the east side levee and some channel cleaning would be required. Provisions to drain ricelands would also have to be included. Total levee length under this alternative would be approximately 142 miles.

Alternative B5, Pump from Colusa Drain to the River

Under this alternative, channels would be constructed to convey floodwaters from the Colusa Drain to pumping plants at various locations along the Sacramento River. Reversible pumps could be installed to provide a supplemental irrigation supply.

This alternative would have high construction and operating costs. The increased flow to the Sacramento River would compound flood and seepage problems along the river and in Butte Basin. For this plan to be highly effective, a gate structure on the Knights Landing Ridge Cut would be required.

Alternative B6, New Drain at Higher Elevation

Construction of a new drain upslope from the Colusa Drain with a 25,000 ft^3/s capacity would provide "50-year" flood protection to the Colusa Basin. The drain would discharge into the Yolo Bypass via Knights Landing Ridge Cut which would probably have to be enlarged. A distinct disadvantage of such a large canal would be the large amount of farmland taken out of production. Also this plan would not relieve the spring flooding in the Colusa Drain due to rice water drainage.

Alternative B7, Divert Streams to Tehama-Colusa Canal and Cache Creek

This alternative would divert foothill streams into the Tehama-Colusa Canal which would be used to convey the floodflows to Cache Creek. The Tehama-Colusa Canal terminates at Oat Creek which has limited conveyance capacity. Hence, the canal would have to be extended southward an additional 9 miles to Cache Creek which has a larger capacity. However, its capacity to handle the additional floodflows may not be sufficient. Cache Creek flood channel capacity is 30,000 ft^3/s and floodflows as high as 40,000 ft^3/s have been gaged in the channel. Thus enlargement of the Cache Creek channel capacity would probably be necessary.

If under ultimate conditions of development the West Sacramento Canals Unit of the CVP is authorized, the portion of the Tehama-Colusa Canal from Funks Creek north will be used to convey surplus Sacramento River water to the future Sites Reservoir during winter months. In this event, capacity might not be available when needed to remove tributary flows. Or, alternatively, the tributary flows could be substituted for the Sacramento flow and pumped to Sites Reservoir; the trade-off being Sacramento River flow reduction versus Colusa Drain flow reduction. An additional problem is that the canal would tend to collect silt from each winter's floodflows, causing high operation and maintenance costs each spring before the irrigation season begins. Finally, and perhaps most significantly, the canal capacity is only 10 percent of tributary floodflows. Thus, only a portion of the flow peaks could be skimmed off.

Alternative B8, Extend Colusa Drain to Suisun Marsh

A drainage and water supply problem exists in the entire area from Stony Creek on the north, southward to Suisun Bay and is not restricted solely to the Colusa Basin area. Solutions to problems in the Colusa Basin can also impact the area to the south - positively and negatively. For instance, increased flow releases to the Sacramento River or Yolo Bypass will affect flood and water quality problems within the Delta and adjoining areas. On the other hand, Yolo and Solano Counties could use a supplemental water supply. Such considerations led to the current alternative - extend the Colusa Drain to the Suisun Marsh.

In this alternative, which can be viewed singularly or integrated with alternatives previously discussed, the Colusa Drain would be extended from a point near the terminal end of the Knights Landing Ridge Cut southward through Yolo and Solano Counties for final disposal in the Suisun Marsh. Besides providing an improved drainage outlet for the Colusa Basin, such a scheme would have the following benefits:

1. Water quality of the Sacramento River would be enhanced by diverting drainage effluent directly to the Delta.

2. The extended portion of the drain could serve as an outlet for treated municipal waste discharges from cities such as Sacramento, Davis, Woodland, Dixon, Vacaville, and Fairfield.

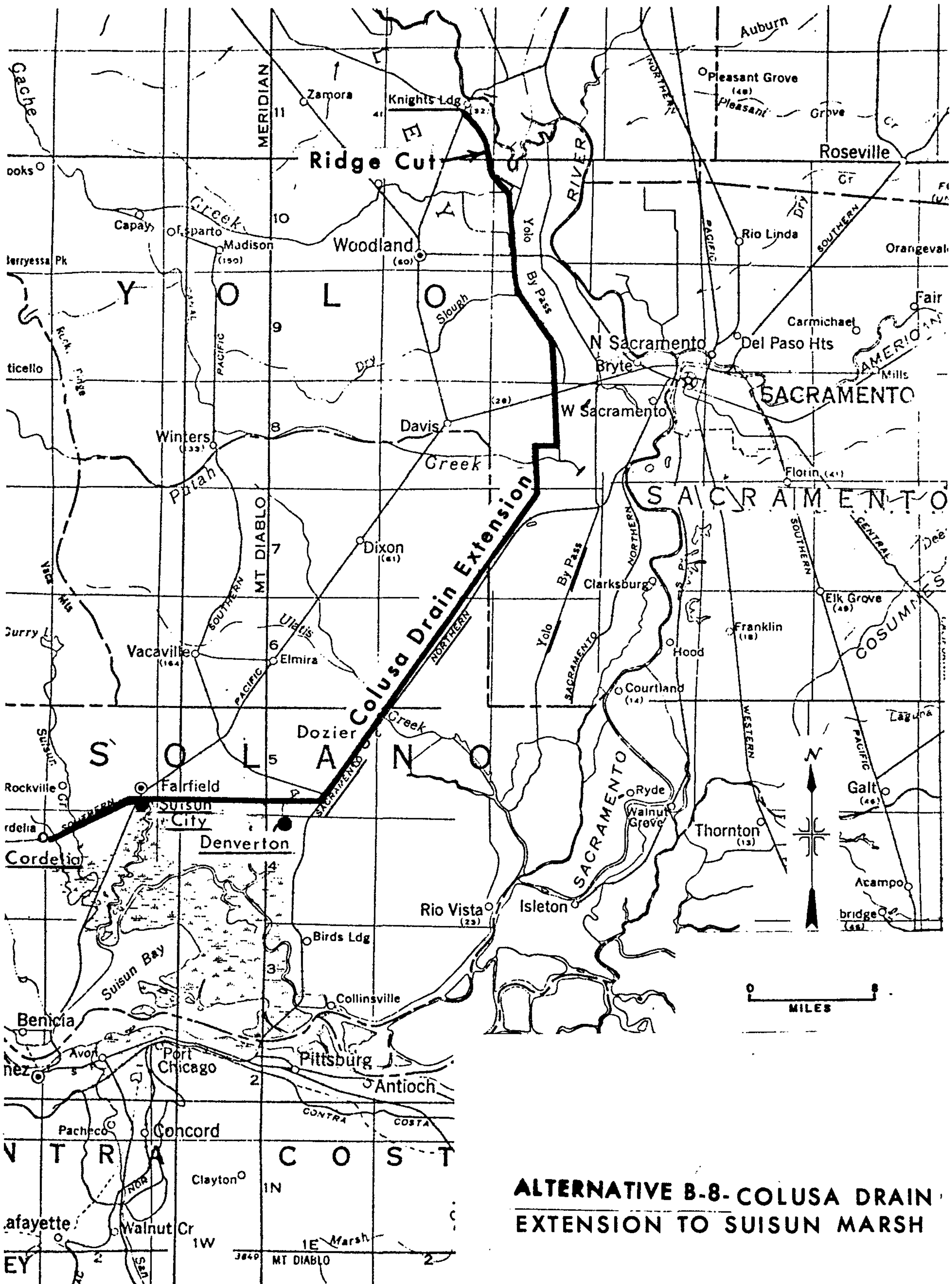
3. The extended portion of the drain could be used by Yolo and Solano Counties for a drainage outlet facility for agricultural return flows.

4. The extended drain could serve as a water supply canal for any area along its route. Water within the canal would in all probability be of sufficient quality for agricultural purposes.

5. The facility could be used to provide water for wildlife enhancement purposes in the Suisun Marsh.

The Suisun Marsh is considered to be brackish; therefore, farm return flows containing salts leached from the soil could be suitable for marsh vegetation. The Suisun Marsh is a major waterfowl resting area along the Pacific Coast Flyway. Studies are now underway to determine if the marsh can be managed so as to maintain or enhance its waterfowl carrying capability. Preliminary estimates indicate the possible beneficial use of a supplemental marsh management water supply of from 50,000 to 450,000 acre-feet annually. A combination of farm return flows containing salts plus treated sewage effluent containing nitrates and phosphates when properly managed for marsh enhancement should greatly benefit waterfowl.

The physical features of this alternative, which are shown on Figure 7, would consist of a 64-mile canal extending south from



ALTERNATIVE B-8- COLUSA DRAIN EXTENSION TO SUISUN MARSH

FIGURE 7

Knights Landing Ridge Cut, along the west side of the Yolo Bypass to the South Fork of Putah Creek, thence west 2 miles to cross Putah Creek, thence south to the Sacramento Northern Railroad tracks. The channel would parallel the west side of the tracks to the Montezuma Hills which it would cross, coming down Denverton Creek. It would then parallel Highway 12 toward Fairfield, passing between that community and Suisun City, circling the Suisun Marsh and ending at Cordelia Slough.

As a portion of this alternative is currently under serious consideration for development by the Solano Irrigation District, (Solano Water Reclamation Project) further analysis is not included in this report. Rather, an additional alternative, B9, considers interfacing the Colusa Drain extension with the District's proposed Solano Water Reclamation Project. If that project does not come to fruition, then further consideration should be given to the present alternative (B8).

<u>Alternative B9, Extend Colusa Drain to Solano Water Reclamation Project</u>

The Solano Irrigation District is intensively studying the feasibility of a Solano Water Reclamation Project. The proposed project would use treated waste water from the Sacramento County Regional Waste Water Treatment Plant, and possibly from the West Sacramento Sanitary District outfall, for the irrigation of farm-lands in south-central Solano County and the enhancement of the

Suisun Marsh habitat. The conveyance facilities will extend from the Sacramento Treatment Plant outfall on the Sacramento River near Freeport westerly across the Sacramento River, the Deep Water Ship Channel, and the Yolo Bypass to the Sacramento Northern Railroad where it proceeds southwesterly along the railroad right-of-way to the irrigation service area.

The irrigation service area could include from 20,000 to 55,000 acres of land generally between Travis Air Force Base on the northwest, Dozier Station on the northeast, the city of Rio Vista on the southwest, and the Suisun Marsh on the southeast. The treated waste water and agricultural return flow would enter a Suisun Marsh delivery system near Denverton to provide water to a marsh enhancement area between Suisun Bay and the Montezuma Slough south of Portero Hills. The proposed project would initially provide 60,000 to 80,000 acre-feet of water for the marsh and as the flow from the treatment plant increases, an additional 50,000 to 70,000 acre-feet is forecast to be available by the year 2020. This water will be of better quality than water presently used for leaching salt from the marshlands.

Preliminary plans have been developed assuming an annual water supply of 157,000 acre-feet allocated to 35,000 of irrigated agriculture and to Suisun Marsh enhancement in the amounts of 100,000 acre-feet and 57,000 acre-feet, respectively. The target date for initial project operation is April 1980.

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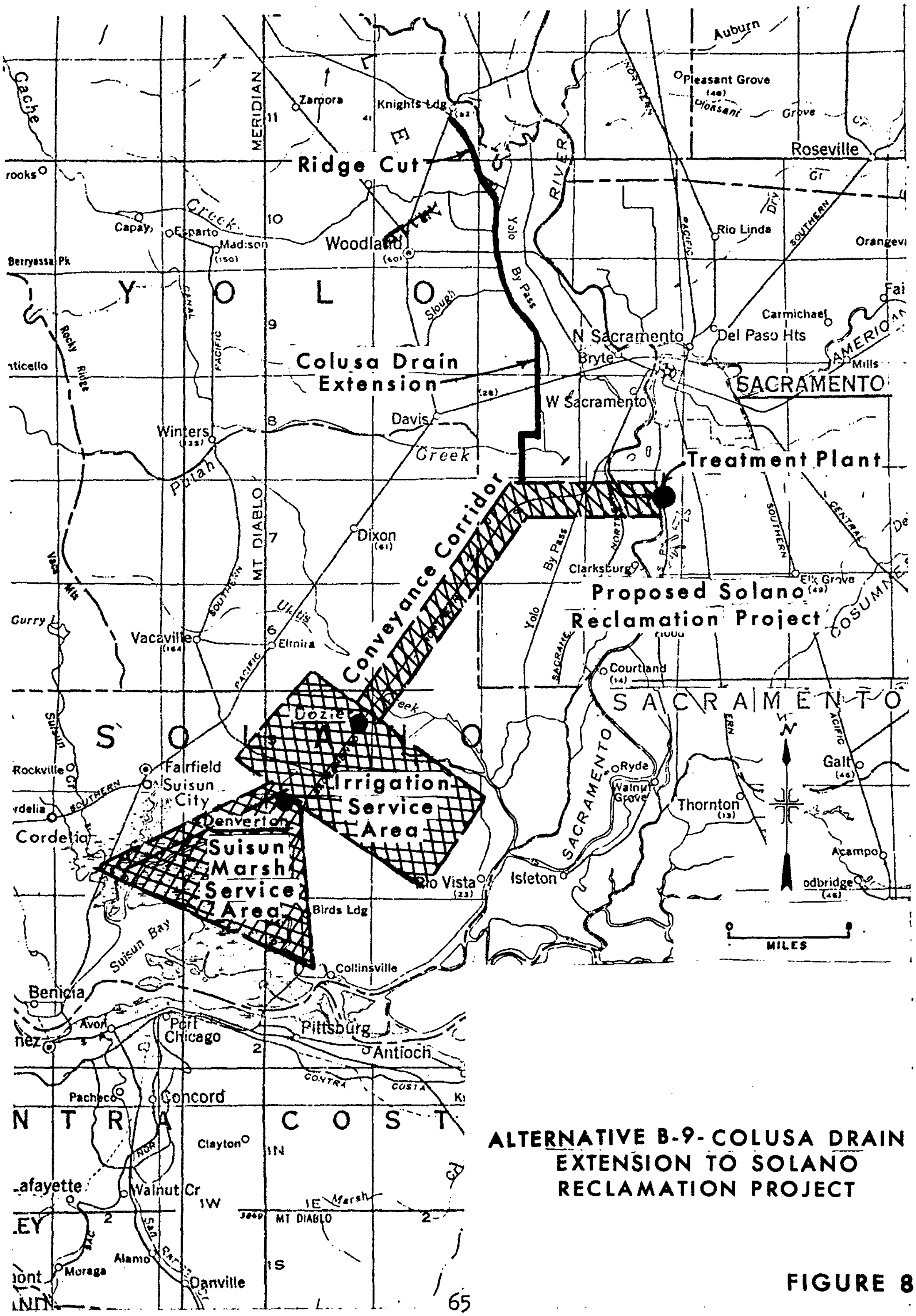
Alternative Solutions

Alternative B9 proposes to interface the Colusa Drain extension with the Solano Water Reclamation Project by extending the drain from the Knights Landing Ridge Cut to the Sacramento Northern Railroad along the alinement described under Alternative B8 (see Figure 8). By improving the ridge cut outlet and bypass conveyance, as described in State Bulletin 109 and the Corps of Engineers 1968 Reconnaissance Report, spring flood benefits would accrue to the lower portion of the Colusa Drain[1/] and the Yolo Bypass to provide adequate flood protection in the bypass, a 2,000 ft^3/s channel would be required. The proposed alinement in the Yolo Bypass should minimize siltation problems which significantly reduced the cost effectiveness of earlier plans.

Future irrigation return flows from the Colusa Drain are estimated to be in the range of 195,000 to 225,000 acre-feet in an average year under conditions of full development. Winter flood-flows would be additive to these quantities. This water supply would be used for irrigated agriculture in Solano County and Suisun Marsh enhancement. Details concerning the intertie with the Solano Water Reclamation Project have yet to be developed. An important consideration is the conveyance capacity of the Reclamation Project facilities. Except during the canning season in late August and September, excess capacity is anticipated to be available however.

1/ To achieve these flood benefits, the center channel of the ridge cut may need to be cleared. This matter requires further analysis.



ALTERNATIVE B-9- COLUSA DRAIN EXTENSION TO SOLANO RECLAMATION PROJECT

FIGURE 8

Both this alternative and the preceding one, B8, have water rights questions associated with them which are complex and without substantial precedent. At issue is the tradeoff between a reduction in the natural flow in the lower Sacramento River during critical summer months and what may amount to a more efficient utilization of water resources for the region as a whole for both agriculture and environmental purposes.

Alternative B10, Flood Retention Reservoirs on National Wildlife Refuges

Under this concept, the peaks of Colusa Drain floodflows would be diverted and stored in shallow retention reservoirs located on public lands. The three national wildlife refuges in the upper Colusa Basin - Sacramento, Delevan, and Colusa - occupy approximately 20,000 acres. Delevan and Colusa border the Colusa Drain and Sacramento lies 4 miles to the west. A portion of the land on these three refuges is left fallow and could be converted to marshland with flood retention capabilities by the addition of dikes and diversion facilities. Although a depth of 1 to 2 feet would be preferred for waterfowl enhancement, a brief flooded depth of 4 feet could be tolerated by marsh plants without great difficulty. As the land is already public and off the tax rolls, no land costs or additional tax losses would be incurred. The major expense would be the construction of dikes to enclose the fallow portions of the refuges and facilities to divert the excess Colusa Drain flows and dewater the retention reservoirs at a later date.

While such a scheme would not have a favorable effect on winter flood peaks, it could be highly effective in reducing flood damages associated with ricefield drainage in the late spring. This alternative merits further valuation to determine if it is engineeringly and economically feasible.

Benefits and Costs

As mentioned earlier in the chapter, the greatest challenge in solving the Colusa Basin flooding problem is finding an economically viable solution; that is, a solution in which the economic benefits balance the costs. None of the first seven alternatives appear to be economically justified. These alternatives were considered in the Colusa Basin Study Work Team Report. Costs from this report, updated to 1976, are presented in table 2. Corresponding benefits are not readily available for most of the alternatives; however, updating the flood benefits of two cases considered in past studies gives sufficient information to conclude that all seven alternatives are not economically feasible. The two cases can be summarized as follows:

Table 2. Estimated costs of Colusa Drain flood control alternatives

Alternative		Capital cost (1976 dollars)	Annual cost[a] (1976 dollars)
B1	Foothill Reservoirs	33,000,000	2,100,000
B2	Restore flow capacity of ridge cut		
	Ridge cut enlargement	4,000,000	260,000
	Control structure or bypass conveyance improvement	10,000,000	650,000
B3	Direct North Basin Streams	24,000,000	1,500,000
B4	Increase flow capacity of Colusa Drain	68,000,000	4,300,000
B5	Pump from Colusa Drain to River	2,000 per ft^3/s installed capacity	130 per ft^3/s installed capacity
B6	New Drain at higher elevation	109,000,000	7,000,000
B7	Direct streams to Tehama-Colusa Canal and Cache Creek	29,000,000	1,900,000
B8	Extend Colusa Drain to Suisun Marsh	Not estimated	Not estimated
B9	Extend Colusa Drain to Solano Water Reclamation Project	26,000,000	1,700,000

See footnote at the bottom of page 69.

Table 2. Estimated costs of Colusa Drain flood control alternatives

Alternative		Capital cost (1976 dollars)	Annual cost[a] (1976 dollars)
B10	Flood retention reservoirs on National Wildlife refuges	Not estimated	Not estimated

a Annual costs represent amortized capital costs for 100 years @ 6-3/8 percent interest; no O&M costs are included.

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Alternative Solutions

Case	Source		Average annual benefits
Winter and spring protection from 1 in 10 yr. flood, entire Colusa Drain using levees	Bul. 109		$1,017,000
Spring flood protection to lower Colusa Basin and Yolo Bypass	CE Reconnaissance (1968) and subsequent analysis (1970)	Lower Colusa Basin	$29,000[a]
		Yolo Bypass	6,000
			$35,000

a May require clearing of Ridge Cut Center Channel, further analysis is required.

The remaining three alternatives, B8, B9, and B10, show promise of being economically justified. However, details have only been developed for Alternative B9, Extend Colusa Drain to Solano Water Reclamation Project. Capital costs, as shown on table 2, include improving the Knights Landing Ridge Cut outlet and the construction of a 2,000 ft^3/s canal to the Reclamation project conveyance facility. Average annual benefits, totaling $1,820,000, assume the sale of 255,000 acre-feet of irrigation water per year, with a net benefit of at least $7/acre-foot, and $35,000 per year flood benefits in lower Colusa Basin and Yolo Bypass. Additive to these benefits would be any wildlife enhancement benefits accruing to the Suisun Marsh. Using the foregoing figures and assumptions, a pseudo-benefit to cost ratio can be computed as:

Average annual benefits		Average annual capital costs (amortized at 6-3/8%)	Benefit to cost ratio (B/C)
Water sale . . .	$1,785,000		
Flood reduction in lower Colusa Basin and Yolo Bypass	35,000		
TOTAL	$1,820,000	$1,700,000	1.1 to 1

Interest during construction and operation and maintenance costs were not considered. This analysis should be construed as an illustration of the concept's potential rather than an explicit determination of the benefit-cost ratio. The cost, benefits, and assumptions related thereto need further evaluation.

TEHAMA-COLUSA CANAL RETURN FLOW

Alternatives

The portion of the Colusa Basin above the Glenn-Colusa Canal that will receive water from the Tehama-Colusa Canal is without a defined drainage outlet. Most of the natural channels that traverse through this part of the area are blocked during the irrigation season by the Glenn-Colusa Irrigation District's Glenn-Colusa Canal. Therefore, drainage flows will back up against the Glenn-Colusa Canal, creating problems for upslope districts. The

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problem was recognized early in the planning phase of the Tehama-Colusa Canal. Provisions for drainage outlets from the areas served irrigation water by the Tehama-Colusa Canal will need to be made between upslope districts and the Glenn-Colusa Irrigation District. The total irrigation return flow from the fully developed Tehama-Colusa service area, including the portion south of the Glenn-Colusa Canal, is estimated to average 52,000 acre-feet per year. Table 3 shows the monthly distribution of the ultimate return flow and the buildup to this amount between now and the year 2000.

South of the Glenn-Colusa Canal, the Tehama-Colusa service area will drain unimpeded to the Colusa Drain. This area will also need to develop drainage collection facilities on a district-by-district basis. These drainage facilities will probably be of the open ditch type and should be provided where a natural outlet is not available to each landholder for disposal of drainage effluent. In many cases pump back facilities by individual land-owners can serve to recirculate tail water back to the farm of origin. Such facilities, in cases where water tables are not a problem, may be a cost effective method of drainage disposal. In those areas where water tables are high and troublesome deep internal onfarm and outlet drainage works will be needed to maintain proper salt balance and relieve high water table conditions.

Figures 9 and 10 illustrate the four basic alternatives for handling the irrigation return flow; namely (1) pump back for

Table 3. Total annual agricultural drainage outflow - Tehama-Colusa Canal service areas and Yolo-Zamora Units - cubic feet per second and acre-feet per year

Year	Drainage outflow to Colusa Drain by months - cubic feet per second												Acre-Feet Per Year
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1													9,800
2													10,020
3	0	0	5	15	24	34	40	38	23	4	0	0	10,870
4													11,810
5													13,360
6													15,090
7													16,820
8	0	0	8	26	41	59	69	67	40	7	0	0	18,990
9													20,105
10													24,290
11													26,390
12													28,660
13	0	0	13	44	69	98	114	112	67	12	0	0	31,380
14													33,510
15													35,310
16													37,090
17													38,790
18	0	0	17	56	89	126	148	144	86	16	0	0	40,490
19													42,040
20													43,540
21													44,850
22													45,965
23	0	0	20	66	103	147	172	167	99	18	0	0	47,120
24													47,820
25													48,590
26													49,400
27													50,050
28	0	0	21	67	105	149	175	170	102	19	0	0	50,610
29													51,110

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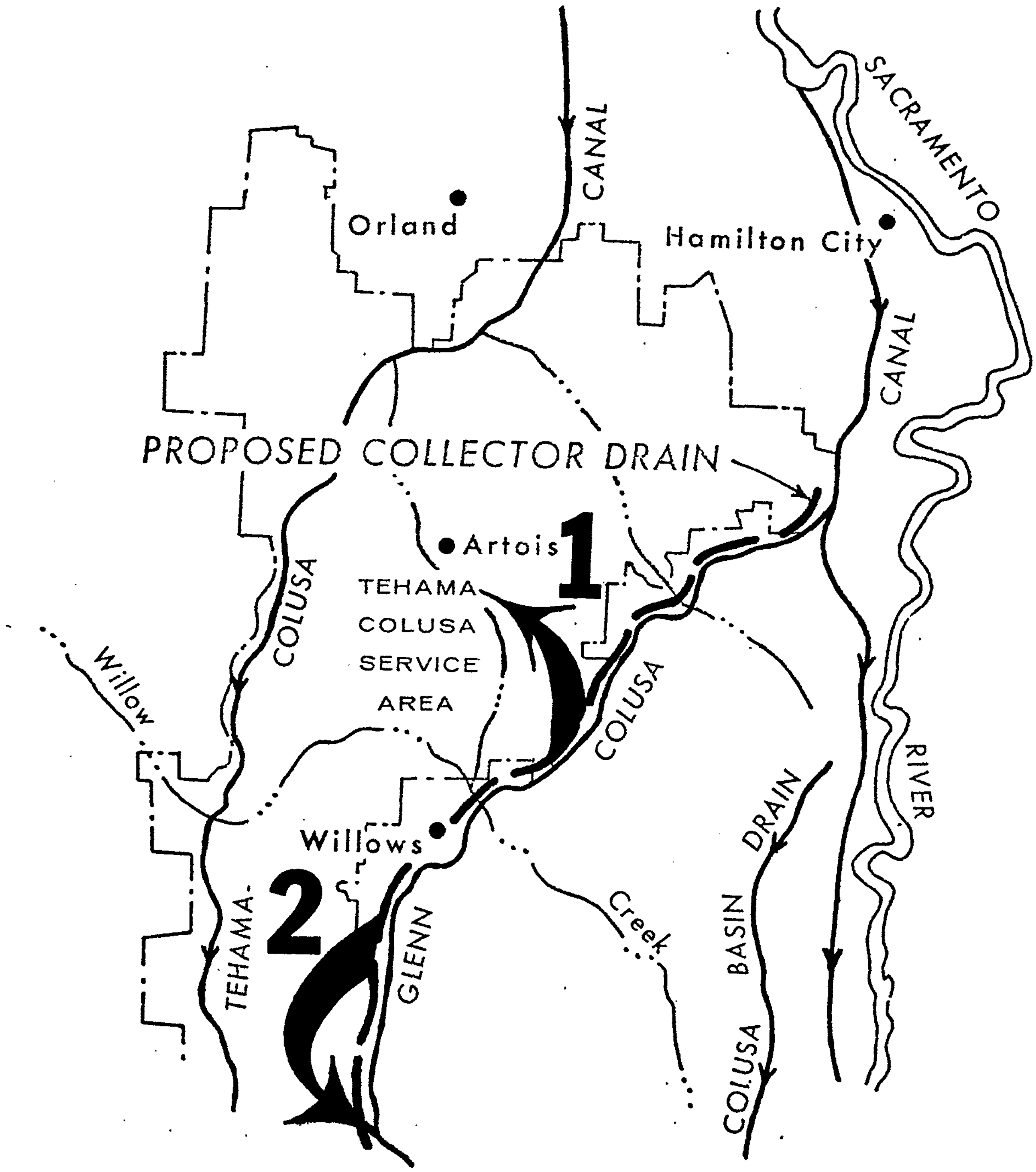
Table 3. Total annual agricultural drainage outflow - Tehama-Colusa Canal service areas and Yolo-Zamora Units - cubic feet per second and acre-feet per year

Year	Drainage outflow to Colusa Drain by months - cubic feet per second												Acre-Feet Per Year
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
30													51,690
31													51,790
32													52,090
33	0	0	22	69	108	154	181	176	105	19	0	0	52,210
34													52,240
35	0	0	23	69	108	154	181	176	105	19	0	0	52,500

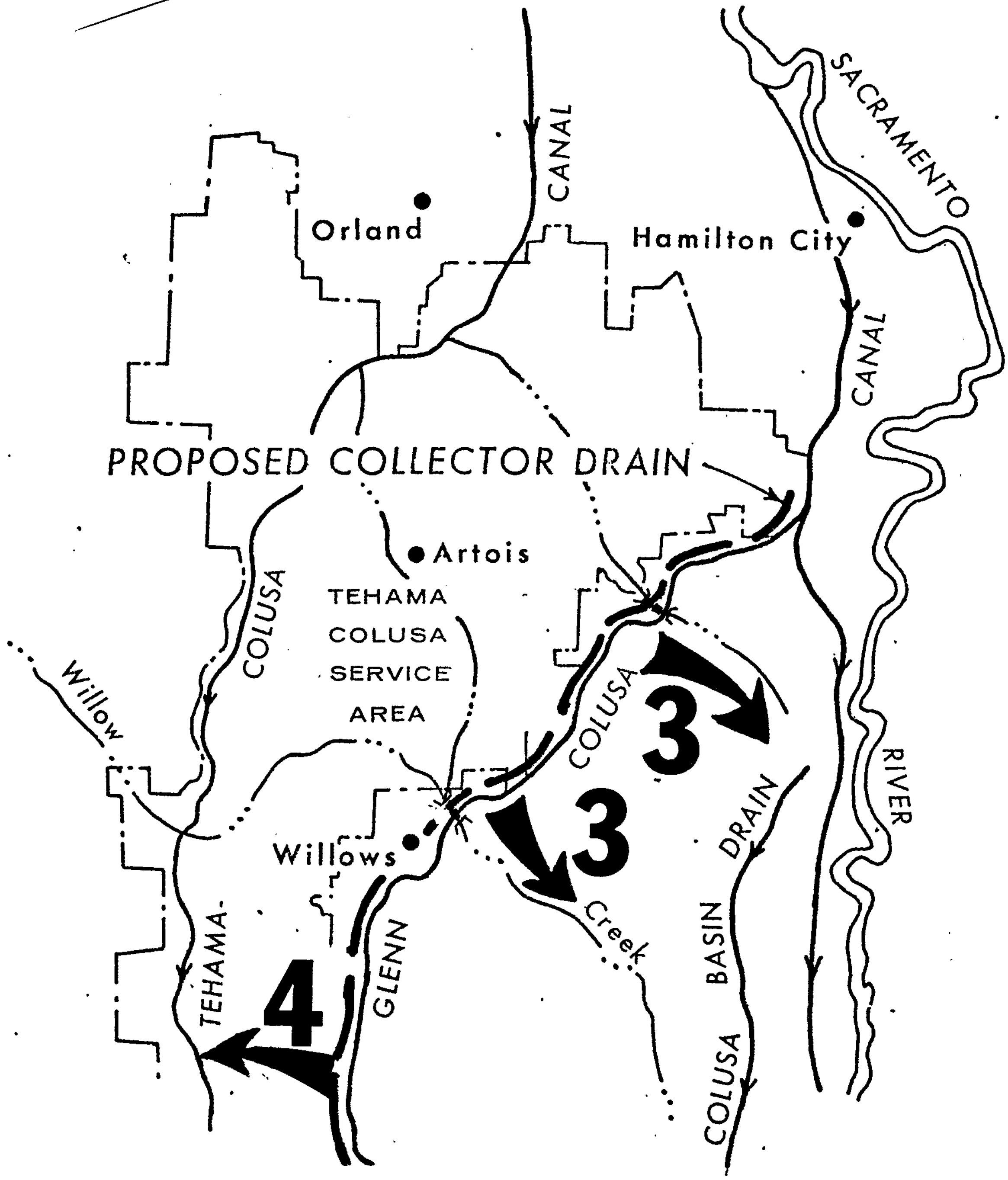


1 Pump back for reuse in Tehama-Colusa Service Area

2 Pump into Glenn- Colusa Canal for reuse

TEHAMA-COLUSA IRRIGATION RETURN FLOW ALTERNATIVES

FIGURE 9



3 Route to Colusa Basin Drain Via Natural Stream

4 Pump back to Tehama-Colusa Canal for reuse

TEHAMA-COLUSA IRRIGATION RETURN FLOW ALTERNATIVES

FIGURE 10

reuse in Tehama-Colusa service area, (2) pump into Glenn-Colusa Canal for reuse, (3) route to Colusa Drain, and (4) pump back to Tehama-Colusa Canal for reuse south of canal terminus and/or within Tehama-Colusa service area.

Benefits and Costs

As indicated previously, the problem of irrigation return flow from the Tehama-Colusa service area was anticipated in feasibility planning for the Tehama-Colusa Canal and determined to be within the capability of future irrigators to resolve. It is expected that the benefits of resolving the problem will outweigh project costs. However, due to the complexities involved in estimating the benefits and costs of alternative solutions, no quantifiable benefits were determined for this study. A feasibility study would further determine the costs and benefits of each alternative.

For planning purposes, costs were estimated in the Tehama-Colusa Canal feasibility studies for the most expensive solution, that of routing all return flow to the Colusa Drain. Such a scheme, similar to Alternative 3 above, was estimated to require 548 miles of surface drains, 60 miles of interceptor drains, and 40 miles of terminal drains, costing a total of $14 million in 1976 dollars.

In addition to the foregoing planning estimate, the Bureau of Reclamation is currently conducting more detailed planning to formulate design and cost estimates to meet drainage requirements in certain subareas within the Tehama-Colusa service area.

Alternative Solutions

The detailed plans upon which a reliable cost estimate can be made will depend on mutually advantageous arrangements between those above and below the Glenn-Colusa Canal as to the best means of routing and utilizing the return flow. Such a solution will undoubtedly reduce the cost below the above figure.

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Table 4

Summary of Alternatives

ALTERNATIVES	COMMENTS	CONCLUSIONS
A. SEEPAGE		
1. Drain and pump to Sacramento River River	Increases flow in Sacramento River but avòids any possible water rights questions.	Economically justified, benefit-cost ratio estimated to be 1.1 to 1.
2. Drain to Colusa Drain on west side of river and to parallel drain on east side of river	Angel Slough on the east side of river has remnant population of rare, endangered California Hibiscus which could be threatened if the slough is used as a collector drain.	Assumed to have favorable benefit-cost ratio (at least for west side of river). Not as simple as 1. above.
3. Change cropping pattern to more seepage tolerant crops	Entirely within the control of the individual farmer and east to apply, except where perennial crops are well established. Farm income and consequently tax revenue are less than with higher-priced crops and more intensive farming.	Default alternative if nothing is done.
4. Purchase seepage land	Could be converted to wildlife or recreation area, or leased back for agricultural use. Would remove some land from agricultural production and local tax rolls.	More expensive than physical solution. Unlikely that wildlife and recreation benefits alone would justify economically. Lease back for agricultural production would improve economics.
5. Purchase seepage easement	No land would be removed from production but seepage damages would continue.	Unlikely option unless liability established for damages caused by water project operations.
6. Project reoperation and development	Little Project operational flexibility exists which would reduce the seepage problem. Additional reservoirs to control Sacramento River tributary inflow would reduce seepage.	Not a likely possibility.
7. River conveyance improvements	Includes options of dredging the Sacramento River, re-routing high flows, and weir improvement.	Further study required.

ALTERNATIVES	COMMENTS	CONCLUSIONS
B. COLUSA DRAIN FLOODING		
1. Construct foothill reservoirs with combined flood storage of 50,000 acre-feet	Could provide irrigation water supply and recreation use depending on sizing and operation of reservoirs. Downstream channels may have to be enlarged to carry reservoir releases after large storm.	Does not appear economically justified.
2. Restore flow capacity of Knights Landing Ridge Cut	Would evacuate water in Colusa Drain quickly when Yolo Bypass flows decrease; but in late spring may be detrimental to bypass agriculture. Thus additional construction may be required in the bypass. Improving Ridge Cut channel would cause adverse wildlife impact requiring mitigation.	Does not appear economically justified.
3. Divert north basin streams to Stony Creek or Sacramento River	Would reduce floodflows in lower portion of basin. Possible legal entagelements resulting from increasing floodflows into Butte Basin via Moulton and Colusa Weirs. Would worsen seepage problem.	Does not appear feasible due to legal and economic considerations.
4. Increase flow capacity of Colusa Drain	Add new levee along west bank to protect west side of drain against flooding. Approximately 6,000 acres of land would fall within the leveed area. Wildlife mitigation measures should be incorporated. Consideration should be given to providing an adequate outlet capacity.	Does not appear economically justified.
5. Pump from Colusa Drain at various locations to the Sacramento River	Reversible pumps could be used for irrigation if necessary. High construction and operating costs. Would increase seepage problem.	Does not appear economically justified for either spring or winter flooding.
6. New drain at higher elevation than Colusa Drain	To provide "50-year" flood protection to the Colusa Basin. A 25,000 ft^3/s canal would be required. Could possibly be used also as an irrigation canal.	Does not appear economically justified.

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ALTERNATIVES	COMMENTS	CONCLUSIONS
B. COLUSA DRAIN FLOODING (Cont'd)		
7. Divert streams to Tehama-Colusa Canal and thence to Cache Creek.	Would help to reduce flood peaks. Would increase floodflows in Cache Creek and sedimentation in Tehama-Colusa Canal. Canal capacity only 10 percent of floodflow.	Does not appear economically justified.
8. Extend Colusa Drain to Suisun Marsh	Would reduce spring flooding in Yolo Bypass, enhance Sacramento River water quality, serve as treated waste effluent outlet and agricultural return flow conveyance, provide irrigation water, and provide wildlife enhancement to Suisun Marsh.	Consider further if Solano Water Reclamation Project planning is terminated.
9. Extend Colusa Drain to proposed Solano Water Reclamation Project conveyance facility	Would provide benefits similar to those in the preceding alternative. Short time frame in which to complete interface planning/design and obtain funding if changes in the Reclamation Project are required.	Appears economically justified but further analysis is necessary.
10. Flood retention reservoirs on National Wildlife Refuges	Low dikes would be formed around fallow land to make a combination flood retention reservoir and marshland. Flood waters would be diverted from nearby drainage channels.	Merits further evaluation to determine engineering and economic feasibility.
C. TEHAMA-COLUSA CANAL RETURN FLOW		
1. Pump back for reuse in Tehama-Colusa service area	Tailwater drains and pumps on individual farms would recirculate water. A final collector drain parallel to Glenn-Colusa Canal may also be required.	May be desirable for area south of Glenn-Colusa Canal.
2. Pump into Glenn-Colusa Canal for reuse	Not practical for area south of Glenn-Colusa Canal. Plan would require construction of collector drain parallel to Glenn-Colusa Canal and installation of pumps at various points along collector drain.	May be best overall alternative. Probably most cost-effective solution for portion of area.

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ALTERNATIVES	COMMENTS	CONCLUSIONS
C. TEHAMA-COLUSA CANAL RETURN FLOW (Cont'd)		
3. Route to Colusa Basin Drain	Possible supplemental water supply for downstream irrigators. Possible increase in late spring flood problems in lower Colusa Drain.	If extend drain to Yolo and Solano Counties, may be desirable alternative. May be a necessary option south of Glenn-Colusa Canal.
4. Pump back to Tehama-Colusa Canal for reuse	Water could be reused in Tehama-Colusa service area or conveyed to Oat Reservoir for use south of the canal terminus.	Desirability will depend on comparative economics and water supply needs.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Based on a review of previous studies, the seepage problem appears economically and engineeringly feasible to solve. While the areal extent of seepage damage varies from year to year, the average annual damage area does not appear to exceed 40,000 acres. A highly detailed investigation will be necessary, however, in order to adequately quantify the benefits and costs associated with seepage reduction and to formulate a specific project plan. This plan should be developed on an individual farm basis and integrated into the total drainage needs of the study area.

2. The most favorable seepage alternative appears to be tile drains with a collector system which discharges either to the river or to existing drains (Alternatives A1 and A2). Other alternatives considered include A3, Change cropping pattern to more seepage tolerant crops; A4, Purchase seepage land; A5, Purchase seepage easement; A6, Project reoperation and development; and A7, River conveyance improvements. Some of these other alternatives merit further analysis, particularly A5 which includes options such as dredging the Sacramento River, rerouting high flows, and weir improvements.

3. Two categories of flooding occur in the Colusa Basin, winter flooding from tributary runoff and precipitation, and spring flooding; principally resulting from irrigation return flows. Although winter flooding is greater in magnitude than spring flooding, only moderate amounts of damage per acre occur as the mostly agrarian area impacted is seldom planted during the winter period. Consequently, there are insufficient benefits to justify the construction of winter flood control works. While spring flooding, primarily along the lower portion of the Colusa Drain and the Yolo Bypass, causes significant agricultural damage, the potential benefits still tend to fall short of meeting costs in most cases.

4. Only two flood control alternatives appear worthy of further consideration: B8/B9, Extend the Colusa Drain to the proposed Solano Waste Water Facility or to the Suisun Marsh; and B10, Construct flood retention reservoirs on the national wildlife refuges. Only small flood benefits are anticipated from either of these alternatives, accruing mainly to the lower Colusa Basin and Yolo Bypass in the late spring. The remaining flood control alternatives, while engineeringly possible, do not appear economically justified. These are: B1, Construct foothill flood reservoirs; B2, Restore flow capacity of Knights Landing Ridge Cut; B3, Divert north basin streams to Stony Creek or Sacramento River; B4, Increase flow capacity of Colusa Drain; B5, Pump from Colusa Drain at various

locations to the Sacramento River; B6, New drain at higher elevation than Colusa Drain; and B7, Divert streams to Tehama-Colusa Canal and thence to Cache Creek.

5. The formation of a master drainage district in the Colusa Basin, possibly including the Yolo Basin, is desirable in order to develop, implement, and administer a regional drainage plan.

6. Irrigation return flow from the Tehama-Colusa Canal service area, amounting to about 52,000 acre-feet per year under conditions of full development, can be successfully handled by a variety of options. Candidate alternatives are C1, Pump back for reuse in Tehama-Colusa service area; C2, Pump into Glenn-Colusa Canal for reuse; C3, Route to Colusa Basin Drain; and C4, Pump back to Tehama-Colusa Canal for reuse. Additional study is necessary to detail the costs of these alternatives and determine water reuse preferences before the most desirable option(s) can be selected.

RECOMMENDATIONS

1. A feasibility level study of the seepage problem should be undertaken with emphasis on use of tile farm drains, utilizing existing drains for the effluent when appropriate, otherwise pumping to the river. Further analysis of other alternatives may also be warranted however.

2. A feasibility plan for reducing seepage should develop detailed information concerning:

a. Present and potential land classification and land use.

b. Existing farm boundaries and location and capacity of local drain systems.

c. Effectiveness and depth and size requirements for tile drains.

d. Quantity of seepage water to be collected.

e. Costs and benefits of each alternative.

f. Repayment capability.

g. Methods of financing and cost sharing.

3. A regional drainage entity, composed of at least Glenn, Colusa, and Yolo Counties and possibly Solano County as well, should be formed which would be capable of coordinating drainage actions and resolving existing and future drainage problems.

4. Further appraisal should be made of the concept of constructing flood retention reservoirs on the three national wildlife refuges located in the Colusa Basin.

5. Since the Colusa Drain extension is predominately a water supply alternative for Solano County rather than a flood control measure for the Colusa Basin, any further investigation should be conducted by the ongoing Solano County Water Project Feasibility Study.

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6. A feasibility level plan should be developed for using and disposing of the irrigation return flow from lands which will be served by the Tehama-Colusa Canal.

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APPENDIX A

CITIZENS' ADVISORY COMMITTEE

Local people, representing private organizations as well as local, State, and Federal governmental entities responsible for resource conservation, have participated in this study. Messrs. Al Dolcini and Linton Brown of the Northern Division, State Department of Water Resources, participated in the committee meetings as technical advisors. The following list gives the committee members name and the organizational group represented:

COMMITTEE

George Basye	Chairman
James Munson	Vice Chairman

MEMBER	AGENCY
Charles Harris	State Water Resources Control Board
Earle Cummings Frederick Meyer (Alternate)	California Department of Fish and Game
Romeo Rivera Dennis Knudson (Alternate)	U.S. Soil Conservation Service
Arthur Champ Mark Capik (Alternate)	U.S. Army Corps of Engineers
David Sill Merle Hehnke (Alternate)	U.S. Fish and Wildlife Service
Robert Clark Richard Haapala (Alternate)	Glenn-Colusa Irrigation District
Eugene Massa Arnold Andriotti (Alternate)	2047 Reclamation District

Committee (Continued)

MEMBER	AGENCY
Ken Lerch	Knights Landing Drainage District and Knights Landing Water Association
Gleason Renoud George Basye (Alternate)	California Central Valley Flood Control Association
Anne Sands Greg Howe (Alternate)	Davis Audubon Society
William Erdman Lee Richter (Alternate)	Sacramento Valley Landowners Association
Leslie Sanborn, Jr. James Munson	Landowner Landowner
Mary Knapp	Sutter County Board of Supervisors
Keith Hansen	Glenn County Board of Supervisors
Ed Ross	Colusa County Board of Supervisors
David Barton	Yolo County Board of Supervisors
Jack Madigan	Butte County Board of Supervisors
Dick Brann	Solano County Board of Supervisors
Henry Kloss	Sacramento County Board of Supervisors

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APPENDIX B

SEEPAGE FACTORS

GENERAL

The purpose of this appendix is to provide supplemental background to those readers unaquainted with the many interrelated and sometimes complex factors which affect seepage and seepage damage. A major portion of the following discussion is extracted from State Department of Water Resources Bulletin 125, "Sacramento Valley Seepage Investigation," published in August 1967.

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.

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 immediately adjacent to the channel. 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 may reach the ground surface.

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.

The above concept of the formation and dissipation of seepage is influenced by a number of factors. The factors which have the greatest influence are:

1. Stage and duration of the river or contributory watercourse above a base level below which seepage does not occur;
2. Antecedent soil moisture conditions;
3. Topography of the land adjacent to the watercourse;
4. Geology and soils in the area;
5. Location and change in the ground-water table; and
6. Drainage works in the area.

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. These factors usually have only a minor influence on seepage, and therefore are not discussed in this report.

STAGE-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 becomes noticeable. 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 by the Department of Water Resources indicate that at the onset of seepage, the seepage area depends primarily

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upon the height of the river surface above critical stage and the antecedent soil moisture and ground-water conditions. The influence of these latter 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.

SOIL MOISTURE

Antecedent soil moisture conditions have a bearing on the rate at which seepage develops 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 antecedent soil moisture content primarily depends on the amount of rainfall and the ground-water level shortly before the river rises. The wide variability in these factors accounts for the considerable difference in the rapidity with which seepage may occur and in the magnitude of the seepage area. 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 TABLE

The timing and ultimate area of seepage is highly dependent on 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 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. In most of the irrigated agricultural lands adjacent to the Sacramento River, 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.

TOPOGRAPHY

The topography of an area also has a 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. This is well illustrated by the greater seepage experienced by low spots and depressions in a field. Local runoff also tends to collect in these depressions further contributing to waterlogging.

SOIL CHARACTERISTICS

Soil 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. Flood plain and natural levee deposits--brown, clayey silts and fine silty sands of high-to-low permeability; and

3. Flood basin deposits--gray, stiff clay of low permeability.

Seepage flows through the permeable stream deposits and flood plain and natural levee deposits. The flood basin deposits formed fine-textured clayey soils which, because of low permeability, generally restrict the flow of seepage and act as impermeable boundaries.

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 flood plain and stream deposits.

Vertical permeability of the flood plain 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 flood plain deposits is due not only to the irregular deposition of soils, but also to structural features such as small holes and cracks which affect permeability more than does the grain-size distribution. These holes and cracks are 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.

Anisotrophy, the ratio of vertical permeability to horizontal permeability, also affects the rate of seepage flow. The State Department of Water Resources in their investigation found that the anisotropic ratios of the stream deposits were generally close to unity.

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 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.

DRAINAGE FACILITIES

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, as previously mentioned. 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 facilities have been installed in the study area to relieve waterlogging problems caused by precipitation and seepage from rivers and bypasses. Drainage ditches and tile drains are the most common types of facilities. Relief wells have been used in several locations.

Seepage Factors

The type of drainage facility which is most effective depends primarily upon local soil and drainage conditions. Open drainage ditches are used extensively throughout the problem area. They consist of 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 manmade 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 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 can 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.

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.

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.

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OTHER CONSIDERATIONS

A basic knowledge of soil moisture conditions and the ecological factors affecting plant growth is important in understanding the effects of seepage on agricultural production. 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.

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.

It is important to distinguish between moisture from seepage and moisture from other sources. Seepage differs from applied irrigation water and rainwater 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 undesirable salts upward into the crop root zone. In contrast, irrigation and rain-water percolate downward without saturating the soil, and bring in oxygen and carry away excess salts.